Food Loss in Agricultural Value Chains

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What is food loss? And why does food loss matter?

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Food loss is the phenomenon of crops perishing before reaching retailers or consumers.

Why should we care?

1. Food loss decreases welfare of...
   - farmers by decreasing profits and increasing risk
   - consumers by decreasing food access and increasing prices
2. Food loss is large in scale.
   - Food loss is a global problem, but is endemic in developing countries World Map
   - Average food loss is 20-30%, and as high as 50-60% for fruits and vegetables
   - Over 50% of all food loss in developing countries occurs on the farm

Why does food loss occur?

This paper investigates two features of agricultural wholesale markets:

- Crops are perishable
- Finding a buyer takes time

Mitigation strategies:

- Invest in better storage technologies
- Improve the process of farmers finding buyers

This Project

Two questions:

1. What are the welfare costs of food loss?
2. How much do we stand to gain by
   a) Decreasing the perishability of food through improvements in storage technology?
   b) Improving the process through which farmers find buyers (e.g. a commodity exchange)?

The Challenge

1. Lack of data on farmer crop disposition practices
   - Aggregate statistics don't speak to market features
   - Farmer surveys focus on pre-harvest productivity
2. Lack of a theoretical framework
   - Neoclassical trade models assume durable goods and instantaneous trade

Approach

1. Collect primary data on food loss in Ghana's fruit & vegetable supply chains
2. Develop an equilibrium model of agricultural wholesale markets with food loss, storage, and search frictions
3. Quantify the model and explore implications for policy

Results

1. Survey results:
   - Food loss is correlated with how easy it is for a farmer to find a buyer
   - Farmers adjust both investment in storage and search intensity when it is difficult to find a buyer

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   - The economy is inefficient due to farmer risk-aversion: food loss is too low, not too high.
   - Social planner can improve welfare through state contingent transfers (insurance)
   - Storage subsidies, financed by taxes on consumption, are state contingent transfers - so they increase welfare *and* food loss.

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3. Quantitative results:
   - Improvement in search frictions can lead 40% welfare gain (e.g. a commodity exchange)
   - To reduce food loss in Ghana to US levels, storage technology needs to be 80% more effective but only increase welfare by 15%

Overview

Survey Design

- Farmer selection:
  - Small scale (<50 acres)
  - Sold fruits or vegetables in the last season
  - 1500 farmers
- Trader selection:
  - Bought fruits/vegetables last season
  - Buy direct from farmers
  - 500 traders
- Random selection of villages across Ghana
- Non-random sampling of farmers and traders within each village
- Focus on pepper farmers in today's talk

Farmer Survey Instrument

1) Demographics
   - Age, martial status, education
2) Marketing practices
   - Where sales are made, how often, quantity, prices, distance from farm
3) Storage and Loss
   - Storage practices, losses
4) Interactions with traders
   - How farmers contact traders, bargaining, search intensity
5) Cooperation with other farmers
   - Farmer associations, pooling, coordination costs

Trader Survey Instrument

1) Demographics
   - Age, martial status, education
2) Sourcing practices
   - Location, quantity, prices, search intensity, farmer information, coordination challenges
3) Marketing practices
   - Location, quantity, prices, customer information
4) Costs
   - Transportation, fixed costs
5) Cooperation with other traders
   - Information on other traders, coordination challenges

What do we learn about agricultural wholesale markets in Ghana?

1. Food loss occurs in discrete unpredictable events Cause of Loss
2. Farmers for whom it is hard to find buyers experience more food loss Finding Buyers
3. Farmers for whom it is hard to find buyers invest more in storage technologies on the extensive margin Storage Extensive Marvin
4. Farmers with higher food loss invest in better storage technologies on the intensive margin Storage Intensive Margin
5. Farmers sell primarily to traders by calling them directly Calling Buyers
6. Traders reject bad quality harvest at the point of sale Fraction Bruised

Overview

Model Environment

- Time is continuous and indexed by t
- Unit mass of risk-averse farmers
- Endogenous mass of risk-neutral traders
- Incomplete asset markets and frictional wholesale markets
- Crops depreciate over time, so farmers who are unable to meet with traders can lose their harvest
- Rate of depreciation and rate of matching are endogenous decisions

Timeline

- Farmers are born with x units of harvest
- Each period farmers choose:
  - How much to invest in storage
  - Which market to search in
- Each period, farmers either
  - Match with traders. Traders then draw an iid match-quality shock and decide whether to buy the harvest
  - Lose their harvest to pests, mold, etc.
  - Nothing happens and the process repeats next period
- Farmers who successfully make a sale or lose their harvest die and get replaced by an identical farmer

Search and Matching Technology

- Traders pay fixed cost κ to enter the market
- Let $\mathcal{U}(p)$ be the measure of unmatched farmers in sub-market p; $\mathcal{V}(p)$ be the measure of unmatched traders in sub-market p
- Define market tightness $\theta(p) := \mathcal{V}(p)/\mathcal{U}(p)$.
- Matching technology: flow $s(p) = \mathcal{U}(p)^{\alpha}\mathcal{V}(p)^{1-\alpha}$ of matches
- Rate of farmer match: $f(\theta(p)) = s(p)/\mathcal{U}(p) = \theta(p)^{1-\alpha}$
- Rate of a trader match: $q(\theta(p)) = s(p)/\mathcal{V}(p) = \theta(p)^{-\alpha}$
- Traders accept a harvest with probability $\Omega(p)$

Farmer Problem

Hamilton-Jacobi-Bellman equation of a farmer searching for a trader:

$$\rho V^s = \max_{c,i} \left\{ u(c) + \delta(i)[V^l - V^s] + \max_p \{ f(\theta(p))\Omega(p)[V^m(p) - V^s] \} \right\} \tag{1}$$

$$\text{s.t} \quad c + p_i i \leq M \tag{2}$$

where

- $u(c)$ is the utility of consuming c
- p_i is the cost of investing in storage; i is the units invested
- M is the farmer endowment
- $V^l = u(M)$ is the continuation value from losing the harvest
- $V^m(p) = u(px)$ is the continuation value from matching
- $\Omega(p)$ is the probability a trader accepts the harvest

Trader Problem

Hamilton-Jacobi-Bellman equation:

$$\rho J^s(p) = q(\theta(p)) E_\xi [\max\{J^m(p,\xi) - J^s(p), 0\}] \tag{3}$$

where

$$J^m(p,\xi) = \pi(p,\xi) + J^s(p) \tag{4}$$

$$\pi(p,\xi) = (p_A \xi - p)x \tag{5}$$

and $\xi \overset{iid}{\sim} Beta(\omega, \phi)$. Free entry requires that

$$\min\{\kappa - J^s(p), \theta(p)\} = 0 \tag{6}$$

Simplification

Equilibrium

Definition. A block recursive equilibrium consists of a set of value functions $V^s, J^s, J^m(p)$, a market tightness function $\theta(p)$, and the unmatched farmers' search strategy function p^*, storage investment strategy function i^*, and consumption strategy c^*, such that:

1) Given $V^m(p)$ and $\theta(p)$, V^s solves the farmer problem with optimal storage strategy i^*, optimal search strategy p^*, and optimal consumption strategy c^*.
2) $J^s(p)$ and $J^m(p)$ solve the trader problem
3) Given $J^m(p)$, market tightness $\theta(p)$ satisfies the free entry condition.

Lemma. There exists a unique block recursive equilibrium. Equilibrium Properties

Equilibrium Food Loss

Lemma. Let δ^* be the equilibrium depreciation rate, p^* be the equilibrium price, θ^* be the equilibrium market tightness, $f(\theta)$ be the farmer match rate, and $\Omega(p)$ be the probability of traders accepting the harvest. Then:

$$E[\text{Fraction Food Lost}] = \frac{\delta^*}{\delta^* + f(\theta^*)\Omega(p^*)}$$

$$E[\text{Storage Duration}] = \frac{1}{\delta^* + f(\theta^*)\Omega(p^*)}$$

$$E[\text{Shelf Life}] = \frac{1}{\delta^*}$$

Bilateral Efficiency

Lemma. The decentralized equilibrium is inefficient. Farmer food loss in the decentralized economy is *too low*, not too high relative to the efficient baseline.

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Intuition. Risk-averse farmers want to smooth consumption across states. They therefore search in markets with lower prices and higher probabilities of matching. Food loss is therefore inefficiently low.

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Robustness (preliminary). When farmers are risk-averse, the economy is always inefficient. Trader risk aversion generates the same inefficiency. But farmer and trader risk-aversion have counteracting effects on food loss.

Implications for policy

- Policies, such as state-contingent transfers/insurance, can return the economy to the first best.
- Consider storage subsidies that are financed through a consumption tax. This is, effectively, a state contingent transfer.
  - Storage subsidies only matter to farmers who are searching for a buyer.
  - A tax only affects farmers who have succesfully sold their crops.
- Storage subsidies therefore increase welfare *and* food loss!

Overview

Model Calibration

The equilibrium is a function of 10 parameters:

$$\{\rho, \delta_0, \beta, p_i, M, \kappa, \alpha, p_A, \phi, \omega\}.$$

Three approaches: Values

- Use values from the literature
- Estimate values from survey data
- Simulated method of moments Details

Model Fit

1. Over-identification restriction Details
   - Can test whether the Poisson process for food loss accurately describes the data
   - Find that over-identification restriction holds
2. Internal Validity Details
   - Model moments equal data moments
3. External Validity Details
   - The model is calibrated using averages. How well does it capture heterogeneity?
   - Compare the effect of harvest size (x), baseline depreciation rate (δ_0), and trade fixed cost (κ) on food loss and market tightness
   - Find qualitatively consistent effects in both the model and data for all outcome variables

Potential Welfare Gains From Reducing Search and Matching Frictions

Flow of matches with search frictions:

$$s(p) = \mathcal{U}(p)^{\alpha}\mathcal{V}(p)^{1-\alpha}$$

Flow of matches without search frictions:

$$s(p) = \max\{\mathcal{U}(p), \mathcal{V}(p)\}$$

Table: Welfare Gains in Frictionless Economies

	Welfare (Relative to baseline)	Food Loss (%)
Baseline	1	9.8
No rejection	0.96	9.1
No search	1.42	0.1
No rejection or search	1.29	0

Storage Improvement Needed to Reduce Food Loss to US Levels

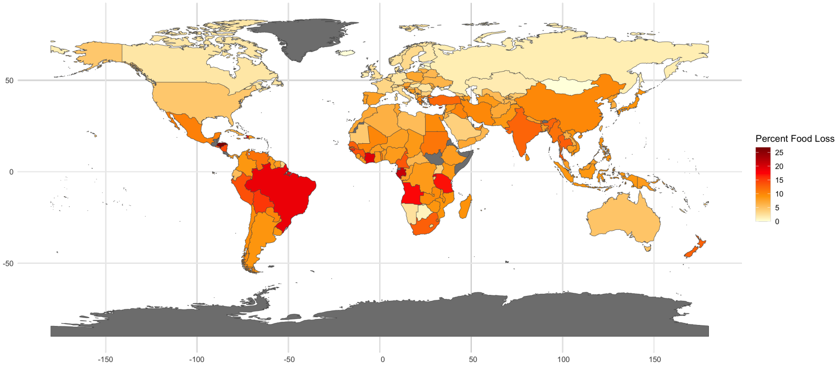
Table: Storage Improvement Needed to Reduce Food Loss to US Levels

	Storage Improvement (%)	Welfare (Relative to baseline)
Partial Equilibrium	55	1.13
General Equilibrium	80	1.15

Conclusion

- Some level of food loss is efficient. Food loss should not be used as a proxy for welfare.
- Storage subsidies can increase both welfare and food loss.
- There are large welfare gains from reducing search and matching frictions, which are difficult to close with improvements in storage.
- Lots of open questions!

Global Food Loss



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Example of Pepper Drying

Figure: Pepper Drying in Ghana's Volta Region

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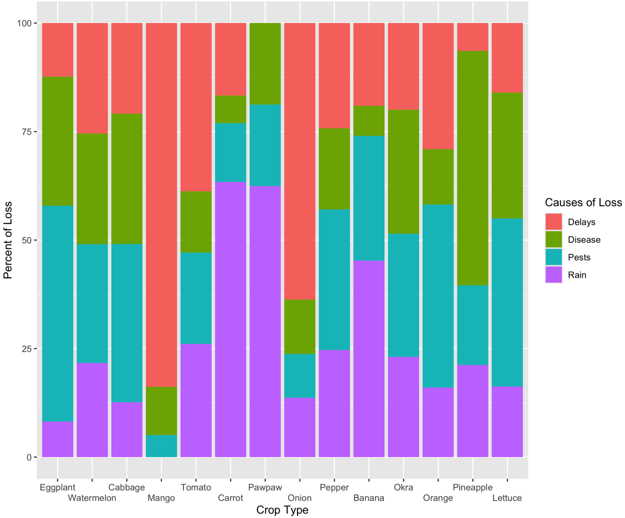
Food Loss is Unpredictable



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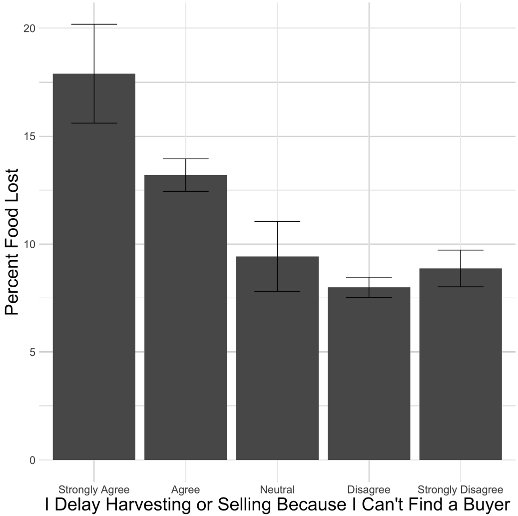
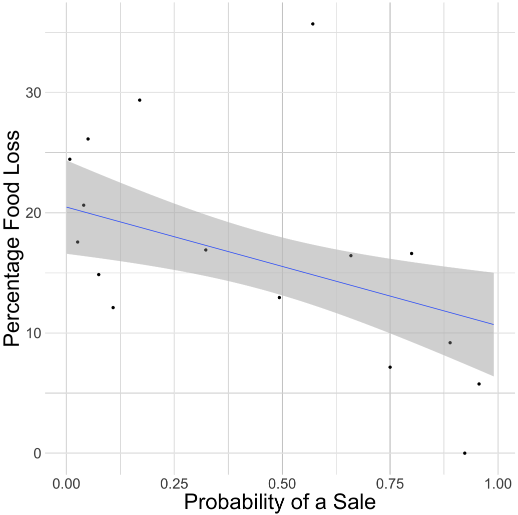
Search Frictions: Food loss increasing in market tightness





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Directed Search Environment

Table: Percent of Farmers by Buyer and Sale Method

Search Method	Primary Buyer				
	Consumer	Exporter	Food Processor	Trader	Total
Bring to Farmgate	0.2	0.1	0.0	9.6	9.9
Bring to Market	1.3	0.0	0.0	25.4	26.6
Buyer Calls	0.2	0.00	0.1	3.0	3.2
Call Aggregator	0.0	0.1	0.2	8.4	8.6
Call Buyer	0.1	0.4	1.6	49.6	51.7
Total	1.7	0.6	1.9	95.9	100

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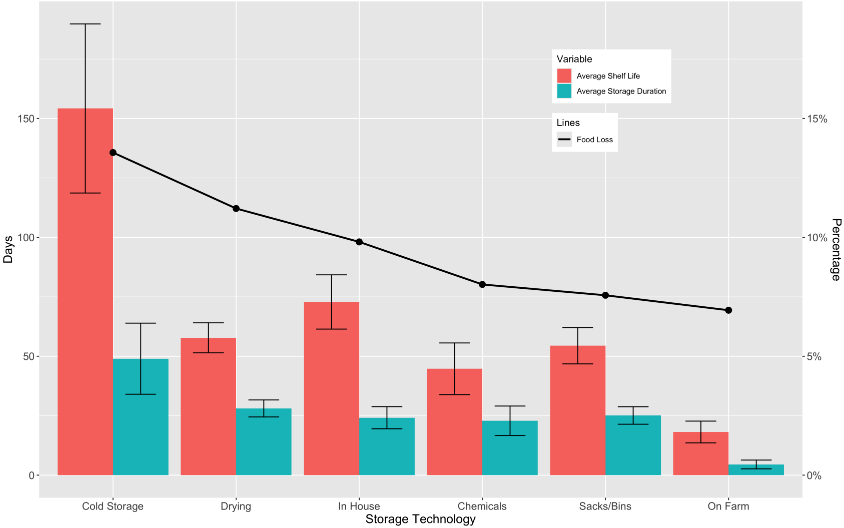
Storage Technology



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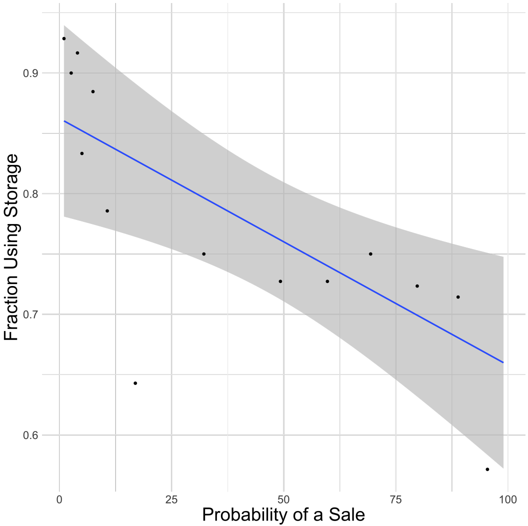
Storage usage decreasing in market tightness



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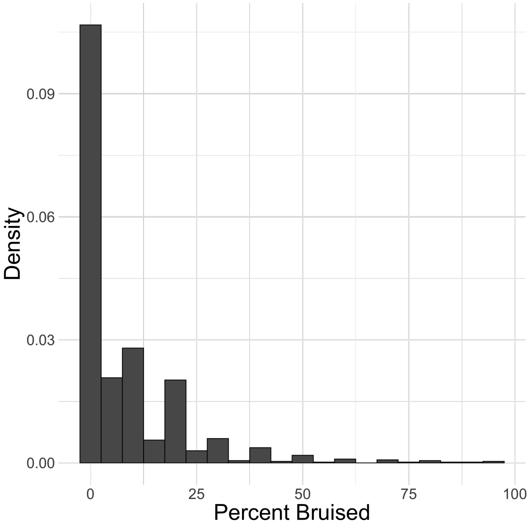
Farmers reject on average 10% of crops



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Equilibrium Properties

1. Define the joint match surplus as:

$$S(p) = \underbrace{(V^m(p) - V^s)}_{\text{Farmer Surplus}} + \underbrace{E[(J^m(p) - J^s)]}_{\text{Trader Surplus}}$$

and let the share of the surplus captured by the farmer be given by

$$\eta(p) = (V^m(p) - V^s)/S(p)$$

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Equilibrium Properties

2. The competitive crop price, $p^* = \arg\max_p f(\theta(p))\Omega(p)(V^m(p) - V^s)$, exists and has a unique solution characterized by the following optimality condition:

$$\underbrace{\eta'(p^*)\left(\frac{\alpha}{\eta(p^*)} - \frac{1-\alpha}{1-\eta(p^*)}\right)}_{\textit{Share Channel}} = -\underbrace{\frac{S'(p^*)}{S(p^*)}}_{\textit{Risk Aversion}} - \underbrace{\alpha\frac{\Omega'(p^*)}{\Omega(p^*)}}_{\textit{Limited Commitment}}$$

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Equilibrium Properties

3. The optimal storage strategy i^* exists and has a unique solution characterized by the following optimality condition:

$$\underbrace{p_i u'(M - p_i i)}_{Marginal\ Cost} = \underbrace{-\delta'(i)\, V^s}_{Marginal\ Benefit}$$

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Model Calibration

Table: Calibrated Parameter Values

Parameter	Description	Value	Source
ρ	Discount rate	0.03	Literature
p_i	Storage price	1	Normalized
δ_0	Storage baseline	20	Data
p_A	Retail price	770	Data
ω	Beta Distribution	1.3	GMM
ϕ	Beta Distribution	0.2	GMM
α	Match elasticity	0.79	SMM
β	Storage elasticity	1.8	SMM
M	Farmer endowment	3.6	SMM
κ	Trader Fixed Cost	47	SMM

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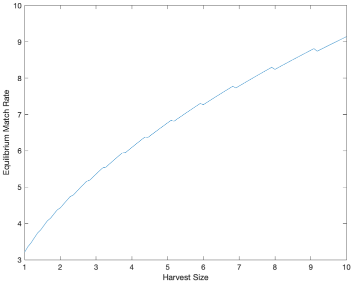
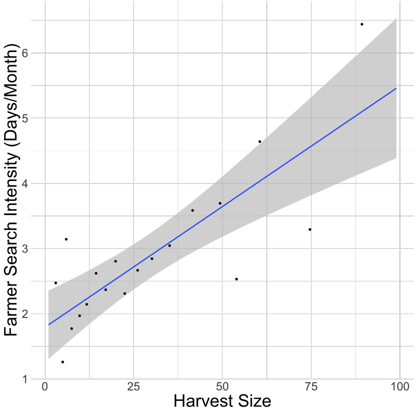
Model Fit: Change in Harvest Size (x)

$$\frac{\partial f(\theta^*)}{\partial x} > 0$$





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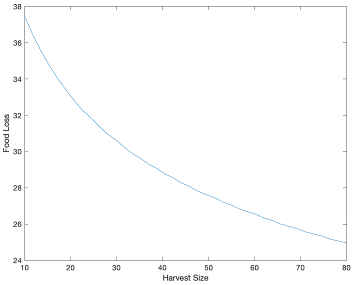
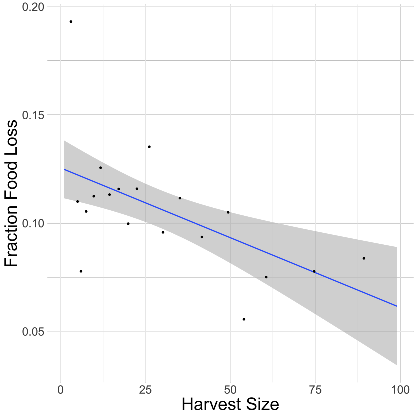
Model Fit: Change in Harvest Size (x)

$$\frac{\partial \text{Food Loss}}{\partial x} < 0$$





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Trader Problem Simplified

Lemma. For each sub-market (p), there exists a unique cut-off value $\bar{\xi}(p)$ such that traders accept harvests when $\xi \geq \bar{\xi}(p)$ and reject harvests when $\xi < \bar{\xi}(p)$. This value is given by

$$\bar{\xi}(p) = p/p_A.$$

Furthermore, the probability of a trader accepting a harvest in sub-market (p) is

$$\Omega(p) = 1 - Beta(p/p_A; \omega, \phi)$$

and the HJB of a trader searching in sub-market (p) can be re-written as

$$\rho J^s(p) = \underbrace{q(\theta(p))}_{\text{Rate of Matches}} \underbrace{\Omega(p)}_{\text{Probability of Accepting}} \underbrace{(p_A E[\xi | \xi \geq p/p_A] - p)}_{\text{Expected Profit per Match}}.$$

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Simulated Method of Moments

Approach:

- Four parameters: α, β, M, κ.
- Four moments: δ^*, $f(\theta^*)$, c, $\Omega(p)$.
- δ^*, $f(\theta^*)$ are unobservable and need to be estimated in the data.

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Estimating equation:

$$\text{E[Fraction Food Loss]} = \delta^* \times E[\text{Storage Duration}]$$
$$\text{Average Food Loss}_i = \delta^* \times \text{Average Storage Duration}_i + \varepsilon_i$$

where i indexes the farmer.

Identification

Two identification challenges:

- Simultaneity
- Measurement Error

Instrumental variable approach:

- Instrument storage duration using distance to market
- Relevance: Distance to the market affects storage duration and shelf life through market tightness
- Exogeneity: Distance to the market does not affect food loss directly

Estimates of δ^*

Table: Effect of Storage Duration on Food Loss - Peppers

	OLS		2SLS	
	(1)	(2)	(3)	(4)
Average Storage Duration	0.3***	0.2***	1.8***	1.8***
	(0.1)	(0.1)	(0.2)	(0.5)
Implied Shelf Life (Months)	40	60	6	6
Observations	569	569	569	569
Controls		✓		✓
R^2	0.1	0.2	−1.1	−1.1
Adjusted R^2	0.1	0.2	−1.1	−1.1
Residual Std. Error	0.2	0.2	0.3	0.3
F Statistic	39.0***	42.1***		

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Calibration Fit

Table: Simulated Method of Moments

Parameter	Target Moment	Data Value	Model Value
β	Depreciation rate $\delta(i)$	2.0	2.1
α	Match rate $f(\theta)$	22.0	22.1
M	Consumption c	1.1	1.2
κ	Acceptance Rate $\Omega(p)$	0.9	0.9

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Model Fit: Poisson Process

Corollary:

$$\text{E[Fraction Food Loss]} = \frac{E[\text{Storage Duration}]}{E[\text{Shelf Life}]} \equiv \text{Relative Storage Duration}$$

Estimating equation:

$$\text{Food Loss}_i = \underbrace{\Gamma}_{0.89^{\star\star\star}} \times \text{Relative Storage Duration}_i + \varepsilon_i$$

where i indexes the farmer.

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