Food Waste and the Sharing Economy

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Introduction

Food Loss / Waste

"... Every year six billion pounds of fruits and vegetables go to waste on farms across the U.S. just for looking a little different from other produce..."
- Reilly Brock, Blogger, Imperfect Produce, Aug. 2015

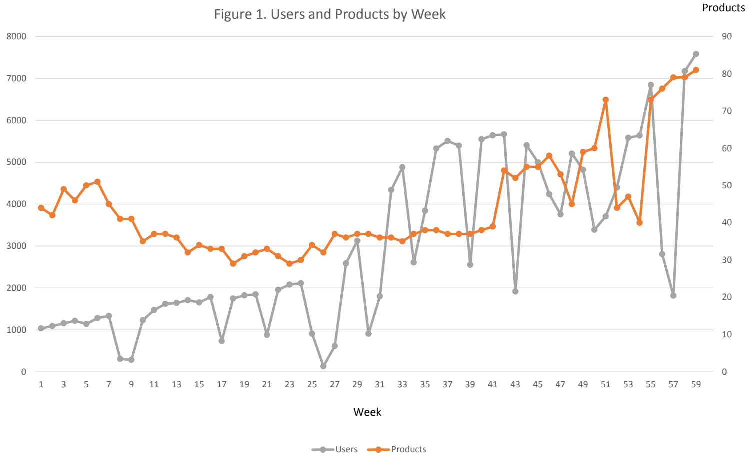
Food Loss / Waste

That doesn't make sense.

Food Loss / Waste

- Scale of food waste problem huge
  - $165 billion in value (Buzby et al. 2014)
  - 25% of fresh water (Hall et al. 2009)
  - 18% of volume in landfills (EPA 2016)
  - 300 million bbls of oil (Hall et al. 2009)
- Source of problem
  - Forecasting errors at each point in supply chain
  - Agents have no incentive to manage waste
- Sharing economy
  - Collaborative peer-to-peer mutualization systems (CPMS)
  - Uber, AirBnB, etc.
  - Create markets for under-utilized assets
  - Asset in this case is farmer's land
  - Botsman and Rogers (2010); Botsman (2013)

Growth of Imperfect Produce



How do CPMSs Work?

- Most CPMSs are two-sided platforms
  - Demand for service from user
  - Eg. The Uber-rider
  - Demand for distribution by asset-owner
  - Eg. The car-owner
  - The CPMS is the platform that connects the two
- All retailers are two-sided markets
  - Demand for goods by customers
  - Demand for shelf-space by suppliers
  - Richards and Hamilton (2013)
- Positive network externalities
  - Demand from customers rises in number of suppliers
  - Demand from suppliers rises in number of customers
  - Viability determined by strength of network effects
- If we can get this to work...

What We Do

- Model of two-sided demand for ugly produce
  - Consumer demand for "boxes"
  - Nested model of platform choice and items
- Model of supplier demand for distribution
  - Supply conditional on demand strength
  - Equilibrium model of pricing and variety on offer
- Estimate with data from CPMS in California
  - Imperfect Produce, Inc.
  - Sources fresh produce below retail grade
  - Sells boxes of produce on subscription
- Simulate changes in item prices
  - Find that 25% rise in price leads to 60% rise in demand
- Market-level impacts
  - CPMS diverts demand from traditional channels
  - Makes more complete use of land commited to produce

Empirical Model

Background

- Theory of network economics well-understood
  - Armstrong (2006)
  - Rochet and Tirole (2003, 2006)
  - Benefit to buyers rises in the number of...
    - Other users
    - Software titles
    - Entries in yellow-pages, etc.
  - Virtuous cycle in which supply creates demand
- Empirical examples from technology
  - Computer hardware / software (Nair, Chintagunta, Dube 2004)
  - Video games (Clements and Ohashi 2005)
  - Intermediation systems (Caillaud and Jullien 2003)
  - Yellow pages (Rysman 2004; Kaiser and Wright 2006)
  - Many others
- We are the first to consider market for surplus food

Surplus Food?

- Consumers demand variety
  - Draganska and Jain (2005)
  - Richards and Hamilton (2015)
  - Particularly true online (Brynjolfsson and Simester 2011)
  - Retail long-tail argument
- Suppliers demand distribution
  - Slotting fees paid by food manufacturers
  - Promotional allowances, pay-to-stay fees
  - Scan-based trading another example
  - There is a "price" for shelf-space
- Retail distribution is two-sided
- Optimal price and variety depends on:
  - Consumer preference for variety
  - Firm profit from distribution

Imperfect Produce as CPMS?

- General definition of sharing economy
  - Botsman (2013)
  - What is a "sharing economy" firm?
  - Entity that facilitates the trade of underutilized products or services
- How it works
  - Suppliers enter item / volume on IP app
  - Products that do not make retail grade or over-contract
  - Buyers set up subscription for box
  - Boxes are S,M, or L and fruit or veg
  - Boxes are delivered by IP per schedule
  - IP picks up, assembles, and delivers
- Number of suppliers and items varies by:
  - Season
  - Category

Overview of Model

- Structural model of surplus food
  - Estimate demand from buyers
  - Estimate supply from farmers
  - Equilibrium model of item provision
  - Simulate equilibrium for policy analysis
- Demand model
  - Household-level model of item-purchase
  - Nested model of:
    - Probability of purchase
    - Number of items purchased
  - Product is total number of items purchased
- Supply model
  - Assume Bertrand-Nash rivalry in price and variety
  - Estimate conditional on demand parameters
- Account for endogeneity in each part

Demand: Order Probability

- CES utility:

$$U_i(q_{i1}, q_{i2}, ...q_{iN}, z_i) = \left(\sum_{j=1}^{N} q_{ij}^{\theta}\right)^{\sigma} + z_i,$$

- Where:
  - q_{ij} = quantity of item type j by household i
  - z_i = quantity of numeraire good
- Random indirect utility function:

$$V_i(p, N, y_i) = (1-\sigma\theta)(\sigma\theta)^{\frac{\sigma\theta}{1-\sigma\theta}} N^{\frac{\sigma(1-\theta)}{1-\sigma\theta}} p^{\frac{\sigma\theta}{\sigma\theta-1}} + y_i + \varepsilon_i,$$

- Where:
  - CES price index is $p = N_j^{\frac{\theta-1}{\theta}} p_j$ with symmetry
  - For number of items N_j in box-type j.

Demand: Order Probability

- Assume ε_i are Type I Extreme Value distributed
- Probability i buys in week t is:

$$P_{it} = \Pr(V_{it} > V_{it}^* + \varepsilon_{it}) = \frac{\exp(V_{it})}{(1 + \exp(V_{it}))}.$$

- Empirical model includes:
  - $\mathbf{x}_i$ = vector of household attributes (CR_{it}, ITT_{it}, etc)
  - $\mathbf{z}_j$ = vector of box attributes (SM_j, $PROM_j$, ORG_j, etc)
- Account for unobserved heterogeneity:

$$\begin{aligned} \sigma_i &= \sigma_0 + \sigma_1 v_1,\ v_1 \tilde{} N(0,1) \\ \theta_i &= \theta_0 + \theta_1 v_2,\ v_2 \tilde{} N(0,1), \end{aligned}$$

Demand: Number Purchased

- Number purchased is an integer variable
- Poisson order-quantity model:

$$P(Q_{ijt} = q_{ijt} | Q_{ijt} > 0) = \frac{\exp(-\lambda_i)(\lambda_i)^{q_{ijt}}}{(1 - \exp(-\lambda_i))q_{ijt}!},$$

- Where:
  - q_{ijt} = number of items by i on t in box j,
  - λ_i = Poisson distribution parameter with:

$$\lambda_i = \exp(\phi_{i0} + \phi_p p + \phi_N N + \sum_{k=1}^{K} \phi_k x_k)$$

  - for x_k box-attribute variables above.
- Number purchased expected to:
  - Fall in price index p,
  - Rise in variety index N
  - ϕ_N = key love-of-variety parameter
- Test against Negative Binomial alternative.

Supply: Pricing

- Platform profit expression:

$$\Pi_t = E[Q_t](p_t - r_t - w_t) - v(N_t),$$

- Where:
  - $E[Q_t]$ = expected number of items sold,
  - p_t = price index,
  - r_t = constant marginal cost of selling,
  - w_t = wholesale price of ugly produce,
  - $v(N_t)$ = cost of variety: $v_N > 0$.
  - Cost of variety first-order TSE: $v(N_t) = \gamma_0 N_t + (1/2)\gamma_1 N_t^2$
- Optimal platform price:

$$\mathbf{p} = \mathbf{r} + \mathbf{w} - \psi E[\mathbf{Q}_p]^{-1} E[\mathbf{Q}],$$

- Where: $\mathbf{Q}_p$ = matrix of demand price-derivatives.

Supply: Variety

- First-order conditions in variety:

$$\nu_N = -E[\mathbf{Q}_N]E[\mathbf{Q}_p]^{-1}E[\mathbf{Q}],$$

- Where:
  - $\mathbf{Q}_N$ = matrix of demand variety-derivatives
  - Marginal cost of variety: $\nu_N = \gamma_0 + \gamma_1 \mathbf{N}$
- Optimal variety expression:

$$\mathbf{N} = -\tau_1 E[\mathbf{Q}]_N E[\mathbf{Q}]_p^{-1} E[\mathbf{Q}] - \tau_0,$$

- Retailing cost:

$$r_{jt} = \delta_0 + \sum_{l=1}^{L} \delta_l v_l$$

- Where:
  - v_l = input-price indices (retail wages, fuel, etc.)
- Estimate pricing, variety, retailing cost together
- Account for endogeneity using control function method.

Data

Data Description

- Imperfect Produce, Inc.
  - Started by Ben Curtis, Ben Chesler, Ron Clark in 2015
  - Now have over 7,500 subscription-customers
  - Ben^2 from The Recovery Network
- Transactional data from Jan 2016 - Feb 2017.
  - ID for purchaser, date of purchase
  - Price paid for box, box contents
  - Promotional activity
  - Wholesale price paid by IP
  - No demographics for households
- Supply data
  - Invoice data for purchases
  - But, no consistent volume measure
  - ID numbers for suppliers allows N calculation

Data Summary

Table 1. Data Summary

Variable	Units	Mean	Std. Dev.	Min.	Max.	N
Number of Items	#	46.3801	14.5647	29	83	201836
Box Size	#	7.5409	3.9272	4	12	201836
Order Dollars	$	20.3375	11.1023	6	450	201836
Order Items	#	13.5346	7.6526	4	381	201836
Promotion Dollars	$	0.2719	2.3352	0	140.12	201836
Item Price	$ / Item	1.5710	0.2727	0.38	11.18	201836
Organic	%	26.4185	44.0899	0	100	201836
Fruit	%	1.9283	13.7518	0	100	201836
Vegetable	%	2.2389	14.7947	0	100	201836
Small	%	24.5338	43.0288	0	100	201836
Medium	%	21.2296	40.8934	0	100	201836
Large	%	4.4452	20.6097	0	100	201836

Note: Data from Imperfect Produce, LLC.

Reduced-Form Regressions

Table 2. Reduced-Form Sales Volume Regression

	Model 1		Model 3	
	Estimate	Std. Err.	Estimate	Std. Err.
Constant	34.3496*	0.1444	32.6954*	0.1605
Price	-7.2329*	0.0684	-7.0529*	0.0691
Number of Items	0.5574*	0.1045	0.4071*	0.1552
Organic	3.8004*	0.0334	3.6016*	0.0330
Fruit	0.2259*	0.0738	0.1797*	0.0709
Veg	0.0445	0.0691	0.0519	0.0664
Small	-15.0453*	0.0870	-14.1456*	0.0843
Promotion			0.3807*	0.0041
Week			0.0185*	0.0043
Week^2			-0.1105*	0.0726
R^2	0.4582		0.5002	
F	11,006.35		9,472.21	

Results

Order-Probability Model

Table 3a. Demand Estimates: Logit / NB-P Model

	Model 1		Model 3	
	Estimate	Std. Err.	Estimate	Std. Err.
σ	0.7736*	0.0905	0.7790*	0.0938
σ(s)			0.0100*	0.0023
θ	0.7342*	0.2752	0.7362*	0.1597
θ(s)			0.0094	0.0064
Consumption Rate	30.6115*	0.1214	30.6124*	0.1195
Inter. Time	21.2850*	0.1263	21.2854*	0.1176
Lagged Q	-4.1132*	0.0550	-4.1121*	0.0438
Promotion	-0.2807*	0.0020	-0.2583*	0.0016
Week	-6.9485*	0.0348	-6.9425*	0.0357
Price Control			2.7108*	0.0306
Network Control			7.2893*	0.0745
LLF	-540739		-542233	
AIC	5.6130		5.629	

Purchase-Quantity Model

Table 3b. Demand Estimates: Logit / NB-P Model

	Model 1		Model 3	
	Estimate	Std. Err.	Estimate	Std. Err.
Constant	3.9838*	0.0018	3.9852*	0.0001
Price	-0.7018*	0.0006	-0.6997*	0.0008
Network Size	0.0155*	0.0002	0.0040*	0.0000
Promotion	0.0286*	0.0002	0.0332*	0.0000
λ(s)			0.0351*	0.0000
Price Control			-0.0149*	0.0000
Network Control			0.0099*	0.0001
T	0.0054*	0.0008	0.0455*	0.0000
Q	6.4870*	0.0059	6.4870*	0.0001
LLF	-540739		-542233	
AIC	5.6130		5.629	

Supply-Side Model

Table 4. Pricing and Platform Size Model Estimates

	Model 1		Model 3	
Variable	Estimate	Std. Err.	Estimate	Std. Err.
Network Size Model				
Constant	4.3560*	0.0577	4.0172*	0.0324
Marginal Network Value	0.2627*	0.1180	0.5517*	0.1984
Retail Margin Model				
Constant	3.0186*	0.2279	2.4422*	0.3821
Fruit Price	-1.0351*	0.1513	-0.5052*	0.2282
Veg Price	-0.1452*	0.0738	-0.4967*	0.1206
Retail Wage	0.7122*	0.0751	0.9139*	0.0856
Conduct Parameter	0.0926*	0.0470	0.5519*	0.1769
R^2 / LLF / G	0.261		263.691	
R^2 Eq. 2	0.007			

Simulated Network Effects

Table 5. Counter-Factual Simulation of Indirect Network Effects

ϕ_N	Price	Std. Dev.	t-ratio	Network	Std. Dev.	t-ratio
100%	1.5968*	0.2855	2.4807	51.2097*	12.2843	12.6246
50%	1.5838	0.2790	1.2460	48.6327*	9.7849	6.8530
0	1.5710	0.2727		46.3802	7.7350	
-50%	1.5584	0.2666	-1.2566	44.4179*	6.1383	-7.5409
-100%	1.5459*	0.2607	-2.5234	42.7151*	5.0222	-15.0809

Note: Simulation conducted with estimates in table 4.

Policy Simulations

Table 6. Policy Simulations: Subsidizing Ugly Produce

η	Price	t-ratio	Network	t-ratio	Volume	t-ratio
0%	1.5710		46.3802		17.4204	
10%	1.6487	5.3997	47.3121	3.2322	21.2023	5.4955
25%	1.7701	14.4139	48.5055	7.3581	27.9214	13.6411
50%	1.9207	28.2955	52.8411	15.5564	39.7491	22.4382
90%	2.1109	46.0590	75.3317	91.3504	53.6898	29.0965

Note: t-ratio compares subsidy to 0% (base case).

Conclusions

Conclusions

- Imperfect Produce subject to indirect network effects
  - Equilibrium price rises in network size
  - Network size rises in price
- Simulations show
  - Strength of network effect affects price / network
  - Subsidizing surplus food strengthens price / network
  - Isomorphic to tax on discarded food
- We rock!

Thank You!

Questions?