Price Discrimination with Experience Goods: Sorting-Induced Biases and Illusive Surplus

Ron Goettler, Karen Clay
Carnegie Mellon University

Federal Reserve Bank of Boston
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What we do

- Estimate a dynamic structural model of consumers'
  - weekly usage of a **nondurable experience good**
  - **tariff choice** from among a menu of three two-part tariffs
- Use household level data from an online grocer operating as a monopolist in a Midwest city.
- Simulate the estimated model under a variety of counterfactual pricing schemes.

Why we do it

Positive Objectives

- How much uncertainty do consumers have regarding the value of this new service?
- Do consumers have biased prior beliefs?
- How quickly is the uncertainty/bias resolved?
- Are preferences and learning rates related to demographics?

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Normative Objectives

- How effective are two-part tariffs?
- What is the optimal menu of two-part tariffs?
- What is the effect of biases and switching costs on optimal tariffs and consumer surplus?

Results

- Consumers have **sorting-induced biases**:
  - Those who choose tariffs with high (fixed, ex-ante) fees and low per-delivery prices tend to be overly optimistic.
  - Beliefs can be biased conditional on tariff choice, even if consumers are correct on average.
  - Consumers expect CS of \$118 but realize CS of $-$\$45.

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  - The optimal two-part tariff has a high fee and low per-delivery price, if switching costs *always* high.
  - If switching costs are *occasionally* low, the optimal two-part tariff has a low fee and high per-delivery price.

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  - The optimal two-part tariff has a high fee and low per-delivery price, if switching costs *always* high.
  - If switching costs are *occasionally* low, the optimal two-part tariff has a low fee and high per-delivery price.
- The gain in profits from offering a menu of tariffs is minimal.

Literature Review

Estimating Learning Models

- Miller (1984)
- Eckstein, Horsky, and Raban (1988)
- Erdem and Keane (1996)
- Ackerberg (2003)
- Crawford and Shum (2005)

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- Courty and Hao (2000)
- DellaVigna and Malmendier (2005)

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- DellaVigna and Malmendier (2005)

Experience Goods

- Nelson (1970)
- Bergemann and Välimäki (forthcoming)

Ordering Details

Ordering Online

- Initially connect direct via modem, then HTML
- Must know product names—no visual cues
- Delivery next day during a two-hour window
  Customer must be present
- Prices are the same as in partner chain
- Learn about service via print/radio advertising, mass mailings, news media, in-store advertising by partner chain, delivery truck displays, and word-of-mouth

Tariff Choice

Data

- 5310 households (HH) enrolled 9/16/97 to 1/23/99
- Each HH chooses one of three tariffs (menu is fixed)
- 3 puzzles:
  - HH could change at any time, but only change when quit
  - 79% of HH on high fee plan have usage rates below the level needed to justify this plan
  - Many HH on plans with fees never use the service

Plan #	F	p	plan shares	usage for min cost	mean usage	never order
Plan 1	$5.76	$0	.12	.67–1	.56	.12
Plan 2	$1.14	$6.95	.32	.23–.67	.36	.18
Plan 3	$0	$11.95	.56	0–.23	.20	.57

Demographic Characteristics, by Plan

characteristic	Plan 1	Plan 2	Plan 3
share all demographics missing	27.3	33.5	66.5
share no demographics missing	8.9	5.6	2.4
share income missing	60.3	61.3	80.4
share income $>$ 90k	38.2	30.7	23.2
share income 50–90k	45.2	42.4	49.2
share income $<$ 50k	16.6	26.9	27.5
mean # adults	2.1	2.0	2.0
mean # children	1.9	1.4	1.3
mean week enrolled	24.0	23.2	21.3
share female	75.4	70.8	68.5
share married	89.5	79.4	76.1
share co-habit	3.1	5.9	5.5
share single	7.4	14.7	18.3

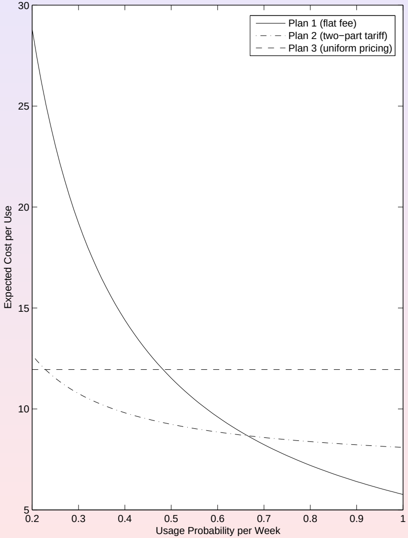
Demographic Characteristics, by Plan

characteristic	Plan 1	Plan 2	Plan 3
share age 18–24	0.3	3.1	2.6
share age 25–44	35.5	38.6	37.0
share age 35–49	58.5	49.3	50.0
share age 50–64	5.7	7.3	8.4
share age 65+	0.0	1.7	2.0
share some HS	0.3	0.3	1.1
share graduate HS	6.6	10.1	10.8
share some College	19.7	25.0	31.2
share graduate College	49.6	43.1	36.7
share some Grad School	23.8	21.4	20.1

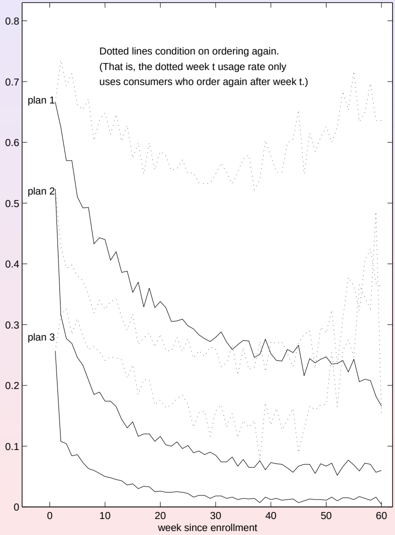
Demographic Characteristics, by Plan

characteristic	Plan 1	Plan 2	Plan 3
share fulltime out	66.8	70.2	72.0
share parttime out	14.5	10.5	11.0
share fulltime in home	14.5	13.5	10.6
share student	0.9	1.8	0.9
share retired/other	3.4	4.0	5.6
share full out spouse	89.0	87.5	86.9
share part out spouse	3.4	4.3	3.6
share full home spouse	3.7	4.1	2.6
share student spouse	0.6	0.8	1.9
share retired/other spouse	3.4	3.3	5.0

Expected Cost per Delivery



Usage Rates


Dotted lines condition on ordering again.
(That is, the dotted week t usage rate only
uses consumers who order again after week t.)
plan 1
plan 2
plan 3
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
week since enrollment

A Bayesian Learning Model

- Each consumer (i.e., HH) is endowed with an unknown match-value, μ_i, for the online grocer
- Each week, consumers decide whether to use online or traditional grocer
- If use online grocer, the realized utility provides unbiased signal of μ_i, which is used to update beliefs
- At end of week consumers decide whether to change tariffs
- Consumers maximize expected discounted utility

Utility

$$\max_{\{s_\tau(I_{i\tau}),c_\tau(I_{i\tau},s_\tau,u_{i\tau})\}_{\tau=t}^{\infty}} \mathrm{E}\left[\sum_{\tau=t}^{\infty}\beta^{\tau-t}\left(\alpha F_{s_\tau}+\delta_{i\tau}\mathcal{I}(s_\tau\neq s_{\tau-1})+U_{ic_\tau\tau}(s_\tau,u_{i\tau})\right)\middle| I_{it}\right]$$

- $c_t \in \{0,1\}$ is the consumer's usage choice in period t.
- $s_t \in \{1,2,3\}$ is the tariff choice.
- u_{i1t} is i.i.d. shock, known by consumer, not econometrician.
- F_{s_t} is the fixed fee of the selected tariff at beginning of t.

$$\begin{aligned}\text{traditional grocer:}\quad U_{i0t} &= u_{i0t}\\ \text{online grocer:}\quad U_{i1t} &= \mu_i+\epsilon_{it}+\alpha p_{s_{it}}+u_{i1t}\end{aligned}$$

- $p_{s_{it}}$ is the per-use component of tariff s_{it}.
- $\mu_{it} \equiv \mu_i + \epsilon_{it}$ is the experience signal.

Bayesian Learning with Normal priors and signals

$$
\begin{aligned}
\text{Signal Noise:} \quad \epsilon_{it} &\sim \text{i.i.d. } N(0, \sigma_\epsilon^2), \\
\text{Initial Prior:} \quad \mu_i &\sim N(m_{i0}, \sigma_{i0}^2) \\
\text{Posterior:} \quad \mu_i &\sim N(m_{it}, \sigma_{it}^2), \quad \text{where} \\
m_{it} &= \frac{\sigma_\epsilon^2 m_{i0} + \sigma_0^2 \mu_{it}}{\sigma_\epsilon^2 + \sigma_0^2} \\
\sigma_{it}^2 &= \frac{\sigma_\epsilon^2 \sigma_0^2}{\sigma_\epsilon^2 + \sigma_0^2}
\end{aligned}
$$

Bellman Equation

$$V_u(m_{it}, \sigma_{it}, s_{it}, u_{it}) = \max_{c_{it}, s_{it+1}} \mathrm{E}\left[U_{ic_{it}t} + \beta V_u(m_{it+1}, \sigma_{it+1}, s_{it+1}, u_{it+1}) | (m_{it}, \sigma_{it}, s_{it}, u_{it}), c_{it}\right]$$

Following Rust (1987), assume u is type I extreme value and integrate it out.

$$V(m_{it}, \sigma_{it}, s_{it}) = \ln\Bigg[\exp\left(\beta \int \max_{s_{it+1}} \left\{V(m_{it}, \sigma_{it}, s_{it+1}) + \alpha F_{s_{it+1}} + \delta_{it}\mathcal{I}(s_{it+1} \neq s_{it})\right\} G_\delta(d\delta_{it})\right)$$
$$+ \exp\left(m_{it} + \alpha p_{s_{it}} + \beta \int \max_{s_{it+1}} \left\{V(m_{it+1}, \sigma_{it+1}, s_{it+1}) + \alpha F_{s_{it+1}} + \delta_{it}\mathcal{I}(s_{it+1} \neq s_{it})\right\} G_\delta(d\delta_{it}) \Phi(d\mu_{it} | m_{it}, \sigma_{it})\right)\Bigg] + \text{Euler's constant}$$

- G_δ is the iid distribution of switching costs.
- Φ is the perceived distribution of experience signals, which accounts for σ_ϵ and uncertainty about μ_i (via σ_{it}).

Solution and Implications

- Numerically solve using value function iteration, Hermite quadrature.
- Linear interpolation of m_{it}. Fine grid for counterfactuals.
- Incentive to experiment increases in β and σ_{it}, decreases in σ_ϵ.
- Consumers on high F tariffs will tend to have high m_{it}.
  - This sorting is muted by switching costs, δ.
  - Higher consumption by consumers facing low p due to low p and sorting.

Initial Beliefs

- Let $G_\mu(\mu_i)$ denote the distribution of match-values
- Rational Expectations assumes G is known by the consumer
  - Prior mean and variance is mean and variance of G
  - Conditional on tariff choice, beliefs are unbiased.
  - High usage by Plan 3 consumers is ok (information incentive).
  - Persistently low usage by Plan 1 consumers not ok.
- Instead, we assume G is not known by the consumer.
  Let $m_{i0} \sim N(\mu_i, \sigma_0^2)$ denote the consumer's signal of μ_i
  - Prior for μ_i is N(m_{i0}, σ_0^2)
  - On average, consumers have unbiased priors
  - Conditional on tariff choice, however, beliefs are biased

Initial Tariff Choice

- To address Puzzle #3 (many HH choose tariff with fee and never use the service) we allow "ex-ante" mistakes in the initial tariff choice.

$$\max_{s_{i0} \in \{1,2,3\}} \lambda_{s_{i0}} + \Lambda(V(m_{i0}, \sigma_{i0}, s_{i0}) + \alpha F_{s_{i0}}) + \xi_{i,s_{i0}},$$

- The optimal initial tariff maximizes $V(m_{i0}, \sigma_{i0}, s_{i0}) + \alpha F_{s_{i0}}$.

- Alternative: consumers receive another signal after enrollment, before usage.

Likelihood

$$L_i(\theta) = \int \Bigg[\prod_{t=0}^{\tau_i} Pr(s_{it}|m_{it}, \sigma_{it}, s_{it-1};\theta) Pr(c_{it}|m_{it}, \sigma_{it}, s_{it};\theta) \prod_{t=\tau_i+1}^{T_i} \sum_{s_{it}} Pr(s_{it}|m_{it}, \sigma_{it}, s_{it-1};\theta) Pr(c_{it}|m_{it}, \sigma_{it}, s_{it};\theta) \Bigg] \Phi(d\{m_i\}_{t=0}^{T_i}|\mu_i;\theta) G_\mu(d\mu_i)$$

- $\Phi(d\{m_i\}_{t=0}^{T_i}|\mu_i;\theta)$ integrates over the entire sequence of beliefs conditional on the match value
- $G_\mu(d\mu_i)$ integrates over the match value
- After the last usage in week τ_i the tariff choice is censored
- s_{it} is deterministic (i.e., 0 or 1) given beliefs and s_{it-1}
- $\Pr(c_{it})$ is logit (Miller, 1984, Rust, 1987)

Random Coefficients via Importance Sampling

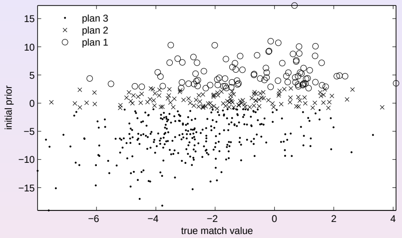
$$L_i(\rho) = \int L_i(\theta_i) g(\theta_i|\rho) d\theta_i = \int L_i(\theta_i) \frac{g(\theta_i|\rho)}{h(\theta_i)} h(\theta_i) d\theta_i$$

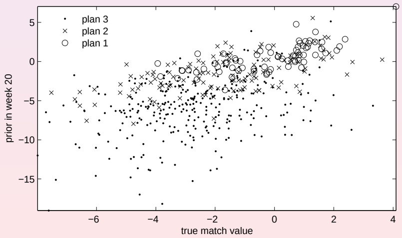
- $g(\theta|\rho)$ is density of random coefficients, parameterized by ρ
- Draw $(\theta_i^1, \ldots, \theta_i^{NS})$ from h (based on no RC estimates)
- Compute $L_i(\theta_i^{ns})$ once and choose ρ to maximize

$$\tilde{L}_i^{NS}(\rho) = \frac{1}{NS} \sum_{ns=1}^{NS} L_i(\theta_i^{ns}) \frac{g(\theta_i^{ns}|\rho)}{h(\theta_i^{ns})}$$

- See Ackerberg (2002) for details

Sorting of Beliefs and Match Values across Plans

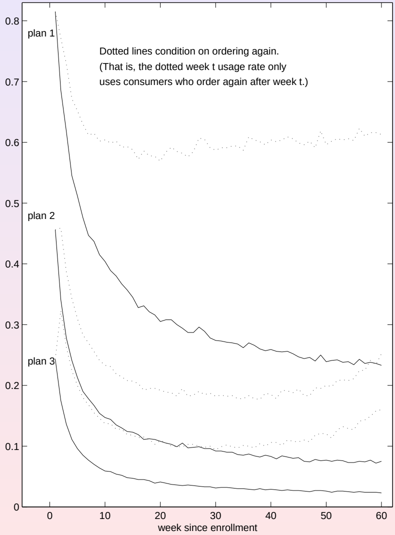




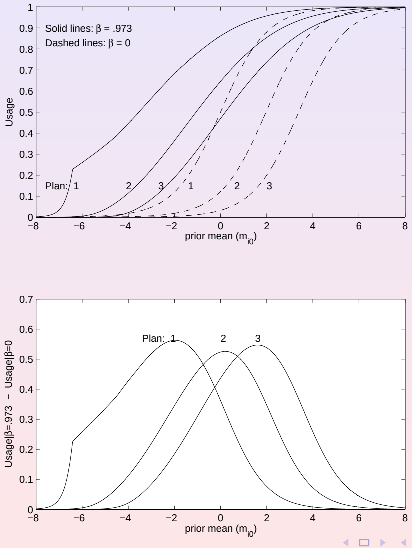
Parameter Estimates

Parameter		Myopic Model	Dynamic Model	Dynamic w/ Random θ_i mean θ_i	Dynamic w/ Random θ_i std.dev. θ_i
μ_{G_μ}	(mean	−0.473	−2.190	−2.180	1.765
	match quality)	(.025)	(0.021)	(0.075)	(0.068)
σ_{G_μ}	(std. dev.	1.146	2.136		
	match quality)	(0.017)	(0.018)		
σ_0	(initial uncertainty)	6.664	4.998	5.253	1.736
		(0.096)	(0.031)	(0.061)	(0.057)
σ_ϵ	(experience	5.200	5.388	5.639	1.938
	signal precision)	(0.054)	(0.035)	(0.075)	(0.055)
β	(weekly	0	0.973	0.965	0.012
	discount factor)		(0.001)	(0.001)	(0.001)
α	(price coefficient)	−0.287	−0.284	−0.292	0.106
		(0.001)	(0.001)	(0.005)	(0.003)
δ	(switching cost)	1.778	50.030	34.897	11.555
		(0.003)	(0.029)	(0.602)	(0.461)
Λ	(initial tariff,	0.546	0.036	0.083	0.050
	$V - \alpha F_{s_i 0}$ coeff.)	(0.035)	(0.002)	(0.008)	(0.011)
λ_1	(initial tariff,	−0.828	0.582	0.313	0.261
	plan 1 intercept)	(0.079)	(0.051)	(0.041)	(0.034)
λ_2	(initial tariff,	−0.516	−0.178	−0.043	0.139
	plan 2 intercept)	(0.036)	(0.032)	(0.025)	(0.027)
	Log likelihood	–55768.4	–54689.1	–54264.4	

Simulated Usage Rates



Incentive to Acquire Information



Posterior Beliefs: Learning Rates

cumulative usage	Posterior standard deviation	Posterior mean w/ $+\sigma_0$ bias
0	4.998	4.998
1	3.664	2.686
2	3.030	1.837
3	2.641	1.396
4	2.371	1.125
5	2.170	0.943
6	2.013	0.811
8	1.780	0.634
10	1.613	0.521
15	1.340	0.360
20	1.171	0.275
30	0.965	0.187
50	0.753	0.114
70	0.639	0.082

Last column uses $\mu_i = 0, m_{i0} = \sigma_0$.
$\sigma_0 = 4.998, \quad \sigma_\epsilon = 5.388$.

Pricing Counterfactuals

Two goals:

- Isolate the effects on consumer behavior and revenues of
  - ex-ante tariff choice mistakes
  - switching costs
  - match-value uncertainty
- Investigate optimal monopolist pricing:
  - Ex-ante versus ex-post pricing
  - Price discrimination via menus to screen consumers

Mistakes, Switching Costs, and Uncertainty

Model Description	Usage: initial, final (Plan share: initial, final) Plan 1	Plan 2	Plan 3	Revenue disc. $(\frac{Rev_{final}}{1-\beta_{firm}})$	CS realized (expected)
Using estimates	.812, .622 (.129, .049)	.454, .067 (.321, .321)	.240, .014 (.551, .630)	472.9 (448.4)	-45.9 (118.5)
No mistakes (i.e., optimal s_{i0})	.993, .615 (.184, .090)	.723, .084 (.222, .222)	.056, .008 (.593, .688)	499.7 (476.7)	-45.4 (139.0)
No switching costs ($\delta = 0$, optimal s_{i0})	.945, .930 (.540, .030)	.404, .408 (.057, .012)	.016, .011 (.403, .958)	193.2 (171.0)	-19.5 (159.6)
No uncertainty ($\sigma_0 = 0$, optimal s_{i0})	.915, .915 (.032, .032)	.401, .401 (.012, .012)	.012, .012 (.956, .956)	182.7 (182.7)	6.0 (6.0)

All revenue and surplus values are in dollars per consumer.
Weekly $\beta_{firm} = .998$. Hence, one dollar per week has present value of $500.

Optimal Tariffs: Base Model

Tariff Description	Usage: initial, final (Plan share: initial, final) Plan 1	Plan 2	Plan 3	Revenue disc. $(\frac{Rev_{final}}{1-\beta_{firm}})$	CS realized (expected)
$F_1 = 4.85,\ p_1 = 0$ (flat fee tariff)	.929, .298 (.417, .417)			998.1 (998.1)	-59.5 (138.3)
$F_3 = 0,\ p_3 = 6.12$ (per-use tariff)			.426, .071 (1.0 , 1.0)	232.4 (215.4)	-9.6 (164.5)
$F_2 = 4.85,\ p_2 = .85$ (1 two-part tariff)		.927, .272 (.400, .400)		1005.0 (1003.7)	-60.8 (129.6)
$F_1 = 4.85,\ p_1 = .85$ $F_2 = 4.84,\ p_2 = 5.11$ (2 two-part tariffs)	.930, .273 (.380, .380)	.801, .129 (.020, .020)		1009.7 (1008.0)	-61.4 (127.8)

- Ex-ante pricing better for firms, but worse for consumers

Optimal Tariffs: Base Model with No Mistakes

Tariff Description	Usage: initial, final (Plan share: initial, final) Plan 1	Plan 2	Plan 3	Revenue disc. $(\frac{Rev_{final}}{1-\beta_{firm}})$	CS realized (expected)
$F_1 = 4.85$, $p_1 = 0$ (flat fee tariff)	.932, .297 (.417, .417)			998.1 (998.1)	-59.6 (138.3)
$F_3 = 0$, $p_3 = 6.51$ (per-use tariff)			.420, .066 (1.0 , 1.0)	230.9 (213.1)	-10.6 (160.3)
$F_2 = 4.85$, $p_2 = 1.15$ (1 two-part tariff)		.930, .263 (.395, .395)		1005.9 (1004.0)	-61.2 (126.5)

- Essentially same as base model (with mistakes)

Optimal Tariffs: Random Switching Costs

Tariff Description	Usage: initial, final (Plan share: initial, final) Plan 1	Plan 2	Plan 3	Revenue disc. $(\frac{Rev_{final}}{1-\beta_{firm}})$	CS realized (expected)
$F_1 = 3.09$, $p_1 = 0$ (flat fee tariff)	.829, .794 (.654, .082)			155.8 (125.0)	-21.9 (184.9)
$F_3 = 0$, $p_3 = 6.12$ (per-use tariff)			.426, .071 (1.0 , 1.0)	232.4 (215.4)	-9.6 (164.5)
$F_2 = .03$, $p_2 = 6.11$ (1 two-part tariff)		.558, .139 (.764, .500)		235.4 (217.7)	-10.4 (163.8)
$F_1 = .58$, $p_1 = 4.54$ $F_2 = .05$, $p_2 = 7.03$ (2 two-part tariffs)	.636, .508 (.318, .110)	.543, .056 (.430, .284)		240.8 (219.9)	-13.2 (169.3)
$F_1 = .59$, $p_1 = 4.54$ $F_2 = .05$, $p_2 = 7.03$ $F_3 = 0$, $p_3 = 10.78$	.486, .513 (.416, .108)	.724, .066 (.260, .236)	.086, .002 (.324, .656)	243.0 (221.4)	-13.7 (167.9)

- Ex-post pricing yields higher revenue when $\text{Prob}(\delta_{it} = 0) = .1$

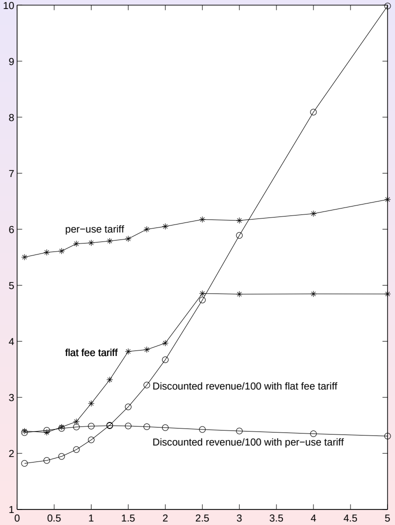
Optimal Tariffs: Random Coefficients Model

Tariff Description	Usage: initial, final (Plan share: initial, final) Plan 1	Plan 2	Plan 3	Revenue disc. $\left(\frac{Rev_{final}}{1-\beta_{firm}}\right)$	CS realized (expected)
$F_1 = 3.28$, $p_1 = 0$ (flat fee tariff)	.877, .293 (.515, .358)			587.2 (579.5)	-44.5 (879.3)
$F_3 = 0$, $p_3 = 6.78$ (per-use tariff)			.401, .056 (1.0 , 1.0)	206.8 (189.1)	-12.0 (784.7)
$F_2 = 3.18$, $p_2 = 1.70$ (1 two-part tariff)		.868, .237 (.485, .333)		601.9 (590.3)	-47.0 (809.5)
$F_1 = 3.66$, $p_1 = 1.21$ $F_2 = 3.14$, $p_2 = 1.74$	.884, .282 (.119, .075)	.864, .230 (.366, .253)		602.7 (590.8)	-47.7 (818.1)

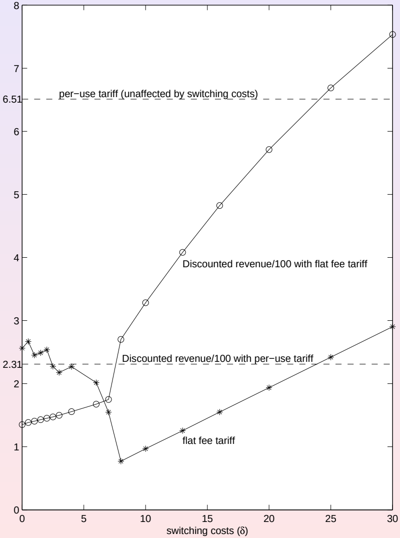
Values generated by simulating 5000 consumers over 100 weeks for each of 100 draws of θ.

- Minimal ability to screen consumers to increase revenues

Tariffs and Revenues as Initial Uncertainty varies



Tariffs and Revenues as Switching Costs vary



Conclusion

- Peapod serves 250,000 customers and offers a per-use price of $6.95.
- A puzzle: what demand systems would yield a substantial gain for using menus to segment consumers?