Sequential Pricing: Theory and Experiments

Cary Deck

John Aloysius

Amy Farmer

FTC Microeconomics Conference
November 2008

Support by the Center for Retailing Excellence and the Information Technology Research Institute is gratefully acknowledged.

University of Arkansas
Sam M. Walton College of Business

Tracking Customers in the Store

Firms are currently using item level RFID technology to track items in a shopping cart.

-Theft Detection

-Restocking

Technology could also be used for

-Dynamic Pricing

A seller can know you have peanut butter in your cart as you approach the jelly.

Setting Sequential Prices

-straightforward in online markets cookies, “shopping carts”, etc.

-more difficult in stores?

From HGTV.com

What's New: Intelligent Shopping Cart…

…the store’s directory is right on the screen. When you find your item, scan the barcode under the LED light indicator then add it to your cart. The computer keeps a running tally of your purchases...

What are the Market Implications?

Sellers have information on preferences

scanner data

frequent buyer cards

correlated values

complements/substitutes

Traditionally, sellers have set prices in advance.

Now sellers can adjust prices in real time and tailor them to specific shopper.

What would a monopolist do in this setting?

What would happen in competitive markets?

Simultaneous Pricing (Pure Components)

Sellers know distribution of buyer types and set optimal prices given this information.

1. Sellers post single price for each product.
2. Buyers observe prices and make decisions.

Sellers can attempt to increase profits by engaging in price discrimination: Quantity Discounts, Coupons (potentially based upon previous behavior), etc.

(Mixed) Bundling

Adams and Yellen (1976) show that bundling can improve profitability on two unrelated items by raising prices on single items and offer a bundle at a discount.

Venkatesh and Kamakura (2003) consider the case where the bundle has an additive value: $V_{AB} = (1+\theta)(V_A+V_B)$

$\theta > 0 \Rightarrow$ A and B are complements

$\theta < 0 \Rightarrow$ A and B are substitutes

Again, prices are set before customers make purchases.

Sequential Pricing

Seller can set prices incrementally during the shopping trip.

Example: Suppose we have two types of people, *X* and *Y*, with $V_A^X = V_B^X = 100$ and $V_A^Y = V_B^Y = 20$.

If each type is equally likely then the expected profit is

$100 under pure components ($P_A = 100$ & $P_B = 100$)

$100 with mixed bundling ($P_{AB} = 200$) &

$110 under sequential pricing

($P_A = 100$, $P_{B|A} = 100$, & $P_{B|\neg A} = 20$)

Sequential Pricing – No Discrimination

1. Seller posts a price for Good A
2. Buyer makes purchase decision for Good A
3. Seller sets unconditional price of Good B
4. Buyer makes purchase decision for Good B

The monopolist will first maximize

$$\max_{P_B}(P_B - C_B)\int_{P_B}^{\infty}\int_{0}^{P_A} f_A(V_A)\,f_B(V_B)\,dV_A dV_B + (P_B - C_B)\int_{P_A}^{\infty}\int_{\frac{P_B-\theta V_A}{1+\theta}}^{\infty} f_A(V_A)\,f_B(V_B)\,dV_A dV_B$$

Given the optimal P_B^* the monopolist will maximize

$$\max_{P_A}(P_A - C_A)\int_{P_A}^{\infty}\int_{0}^{\frac{P^*_B-\theta V_A}{1+\theta}} f_A(V_A)\,f_B(V_B)\,dV_A dV_B + (P^*_B - C_B)\int_{P^*_B}^{\infty}\int_{0}^{P_A} f_A(V_A)\,f_B(V_B)\,dV_A dV_B +$$

$$(P_A - C_A + P^*_B - C_B)\int_{P_A}^{\infty}\int_{\frac{P^*_B-\theta V_A}{1+\theta}}^{\infty} f_A(V_A)\,f_B(V_B)\,dV_A dV_B$$

Sequential Pricing – No Discrimination

Under the assumption that f(V_A)~U[0,100] & f(V_B)~U[0,100]

$$P_B^* = \frac{C_B(P_A\theta - 100) - \frac{100^2}{2}(2+3\theta) + \frac{\theta P_A^{\,2}}{2}}{-2(P_A\theta + 100)}$$

and the first stage problem becomes

$$\max_{P_A} \frac{(P_A - C_A)}{100^2}\left[100^2 - P_A P_B^* + \frac{P_A P_B^* - 100P_B^*}{1+\theta} + \frac{\theta(100^2 - P_A^{\,2})}{2(1+\theta)}\right]$$

which can be solved using Mathematica.

If C_A=C_B= θ = 0 then P_A*=P_B*=50.

Sequential Pricing - Discrimination

Step 3 becomes 3′. Seller sets <u>conditional</u> price of Good B

The monopolist maximizes

$$\max_{P_B|q_A=0}(P_B - C_B)\int_{P_B}^{\infty} f_B(V_B)dV_B \quad \text{and} \quad \max_{P_B|q_A=1}(P_B - C_B)\int_{P_A}^{\infty}\int_{\frac{P_B-\theta V_A}{1+\theta}}^{\infty} f(V_B)\,f(V_A \mid V_A \geq P_A)dV_A dV_B$$

Using the optimal Good B prices from above, the monopolist then chooses P_A to maximize expected profit

Sequential Pricing - Discrimination

Under the assumption of a uniform distribution of values

$$P_B^* \mid (q_A = 0) = \frac{100 + C_B}{2}$$

$$P_B^* \mid (q_A = 1) = \frac{100(1+\theta) + \frac{\theta(100 - P_A)}{2} + C_B}{2}$$

and therefore

$$P_A^* = \frac{50 - C_B - \frac{C_B{}^2}{200} + 100 + C_A - \frac{1}{100}\left[100(1+\theta) + \frac{\theta(100 - P_A)}{2} - C_B\right]\left[50 + \frac{\theta(100 - P_A)/2 - C_B}{2(1+\theta)}\right]}{2}$$

Again, if $C_A = C_B = \theta = 0$ then $P_A^* = P^*_{B|A} = P^*_{B|\neg A} = 50$.

Numerical Comparison

θ	Pure Components	Sequential Pricing w/o Discrimination	Mixed Bundling	Sequential Pricing w/ Discrimination
-0.5	38.87	39.45	38.87	39.66
-0.4	38.87	39.45	39.96	40.69
-0.3	38.87	40.32	42.68	42.47
-0.2	39.02	43.81	46.26	44.72
-0.1	44.06	47.17	50.51	47.39
0.0	50.50	50.50	55.27	50.50
0.1	56.40	53.46	60.05	53.63
0.2	62.54	56.45	65.51	57.11
0.3	68.43	59.32	70.85	60.72
0.4	74.39	62.23	76.43	64.60
0.5	80.50	65.13	81.97	68.64
0.6	86.16	67.89	87.30	72.62
0.7	92.03	70.80	92.82	76.86

Numerical Comparison

ρ	Pure Components	Sequential Pricing w/o Discrimination	Mixed Bundling	Sequential Pricing w/ Discrimination
-1.00	50.50	50.50	100.00	57.71
-0.75	50.91	50.91	67.64	53.63
-0.50	51.36	51.36	59.87	51.89
-0.25	50.67	50.67	56.83	50.75
0.00	50.50	50.50	55.27	50.50
0.25	50.67	50.67	54.22	50.76
0.50	51.36	51.36	52.70	52.08
0.75	50.91	50.91	50.91	53.61
1.00	50.50	50.50	50.50	57.71

Distributions generated by removing corners of [0,100]x[0,100]

Competitive Markets

Many retailers are not monopolists!

Buyers have the ability to comparison shop.

Following Varian (1980), a fraction α of shoppers are uninformed and visit one of the *n* sellers selected randomly and 1-α are informed.

Informed shoppers know P_{Ai} $\forall i$ =1,…,n and only visit the lowest price seller if $V_A \geq \min \{P_{A1},\ldots P_{AN}\}$

Only buyers who actually visit seller *i* observe P_{Bi}.

Experimental Design

3x2 across subjects design

3 underlying relationships between goods

Baseline: $\theta = 0$, $f(V_A) \sim U[0,100]$, & $f(V_B) \sim U[0,100]$

Complements: like baseline except $\theta = 0.3$

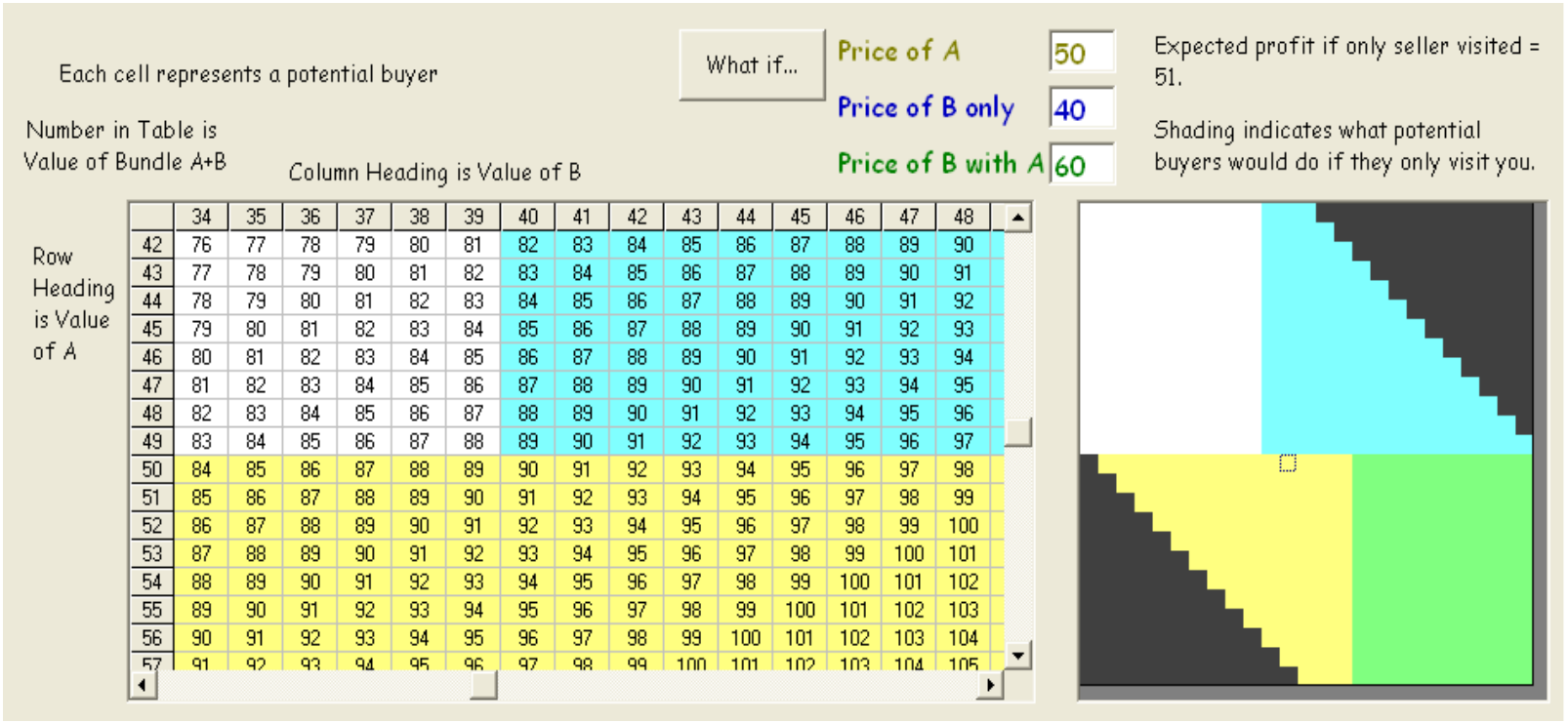
Correlated Goods: $\theta = 0$, $f(V_A, V_B) \sim U\{S\} \Rightarrow \rho = +0.5$
where S = all (a,b) s.t. $0 \leq a,b \leq 100$ and $|a-b| \leq 50$

2 sequential pricing strategies

with and without conditional pricing

On Screen Tool

Positive Correlation Treatment ($\rho = 0.5$ & $\theta = 0$)



	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
42	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
43	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
44	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
45	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
46	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
47	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
48	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
49	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
50	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
51	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
52	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
53	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101
54	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102
55	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
56	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
57	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105

Experimental Design

Other Parameters: $C_A = C_B = 0$, $n = 4$, $\alpha = 0.8$

Markets lasted 750 periods @ 3 seconds each

Automated buyers

Sellers could adjust prices at any point

Sellers could observe prices and profits of rivals

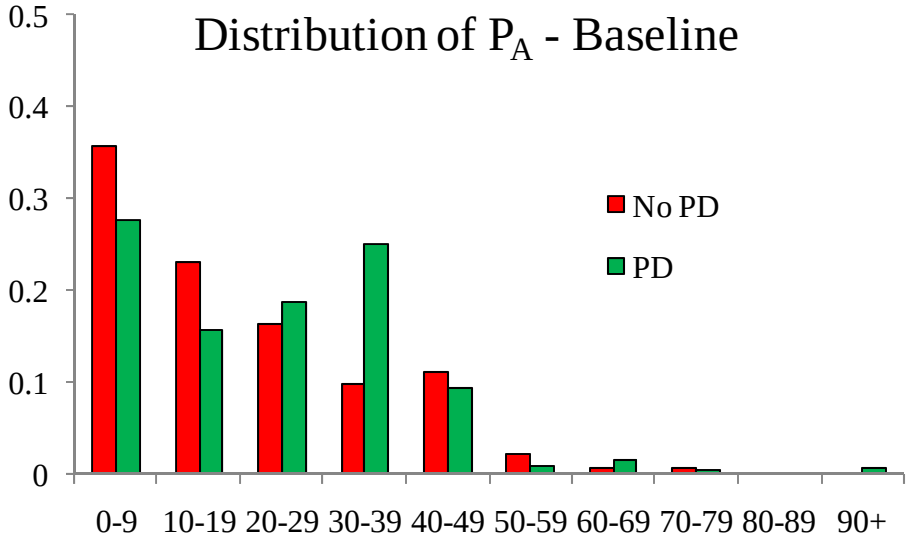
4 replications of each of the 6 experimental conditions

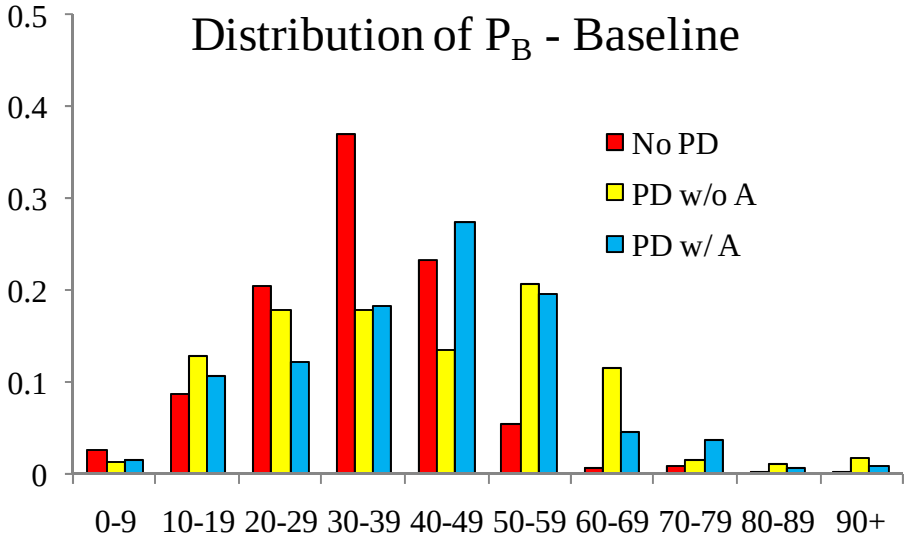
Sessions lasted 90 minutes including directions and handout

Average payment $\approx$ \$18.00 + \$7.50 participation payment

Findings: Baseline

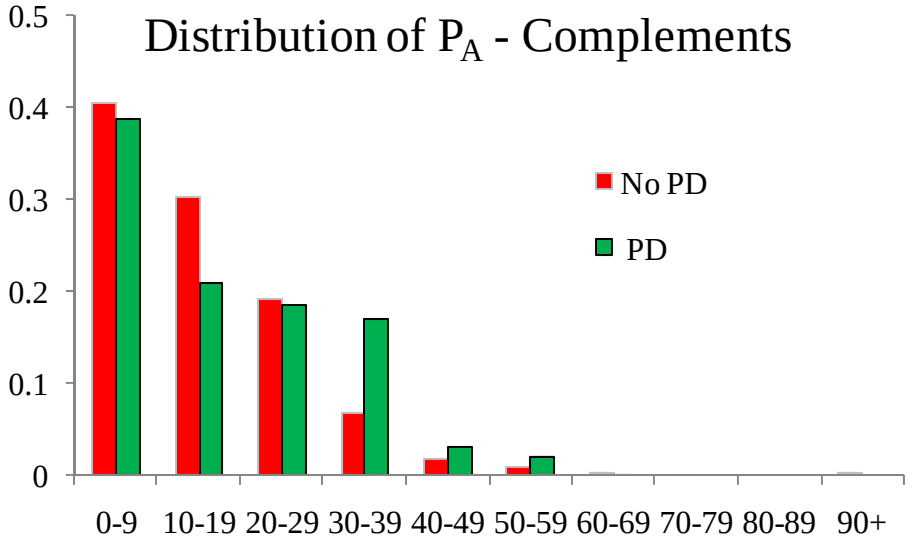
- Ability to price discriminate *nominally* increases P_A and P_B.
- Sellers do not discriminate based upon purchase of A.
- Low price seller of A does not charge more for B.
- Ability to price discriminate does not affect welfare.

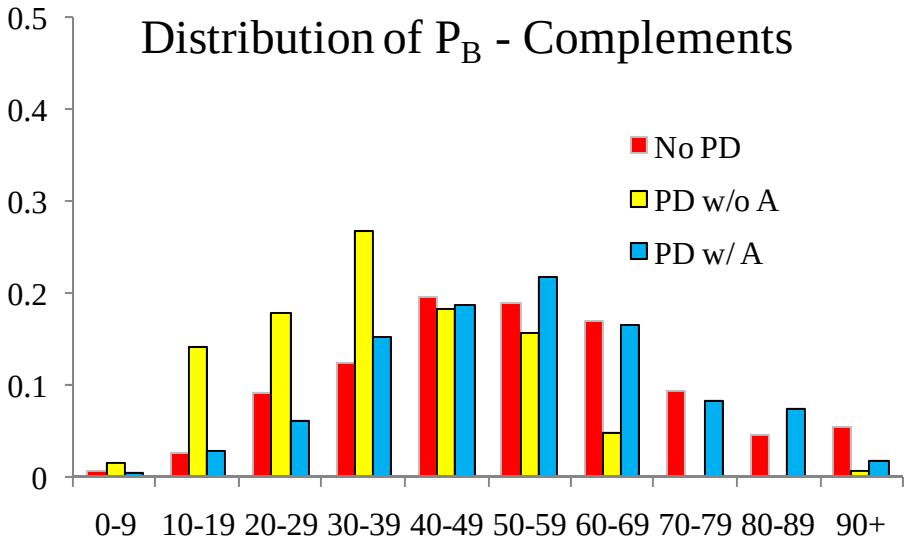




Findings: Complements

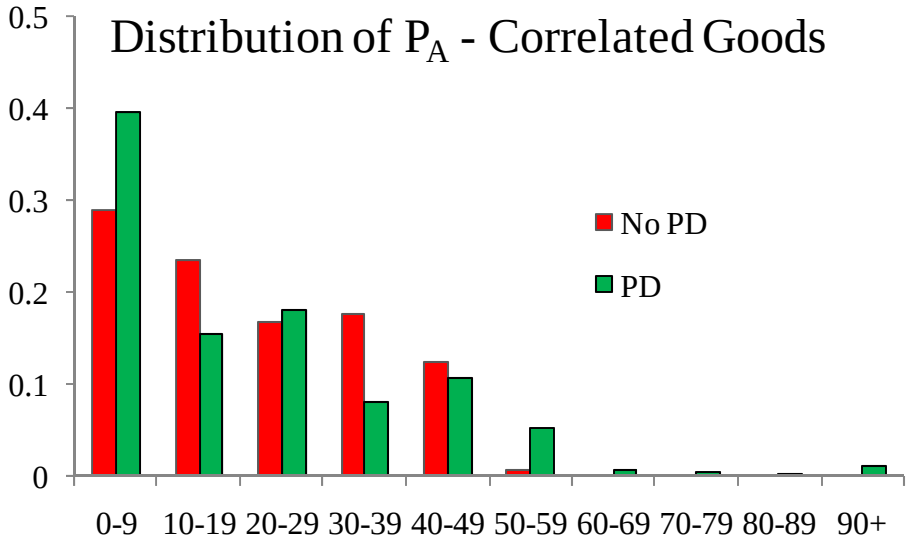
- Ability to price discriminate *nominally* increases P_A.
- Purchasing A leads to a higher P_B when the seller can discriminate. Without discrimination all buyers are charged the same price as those who purchased A.
- Low price seller of A does not charge more for B.
- Ability to price discriminate does not affect welfare.

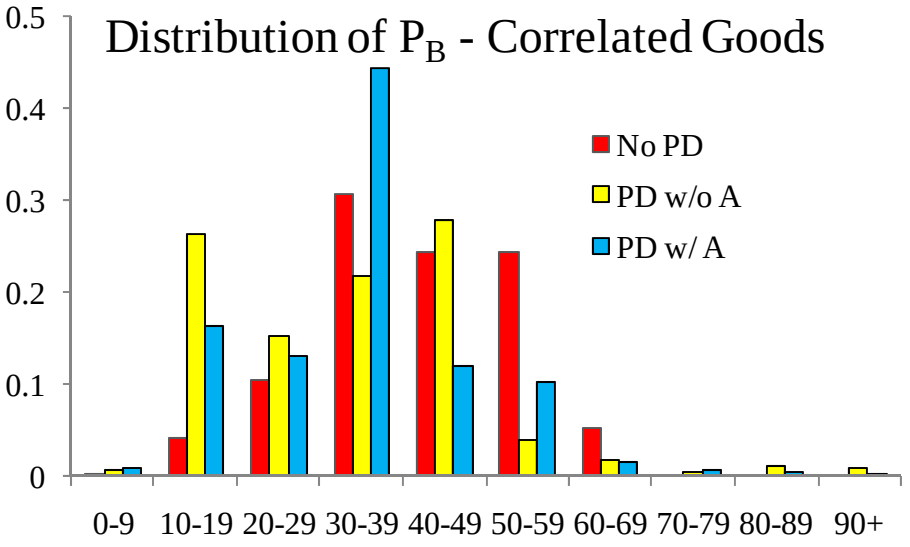




Findings: Correlated Goods

- Ability to price discriminate does not affect P_A.
- Buyers who purchased Good A were quoted the same P_B as buyers could not be tracked. Buyers who could be indentified as not purchasing A were quoted a lower P_B.
- Low price seller of A does not charge more for B.
- Ability to price discriminate does not affect welfare.

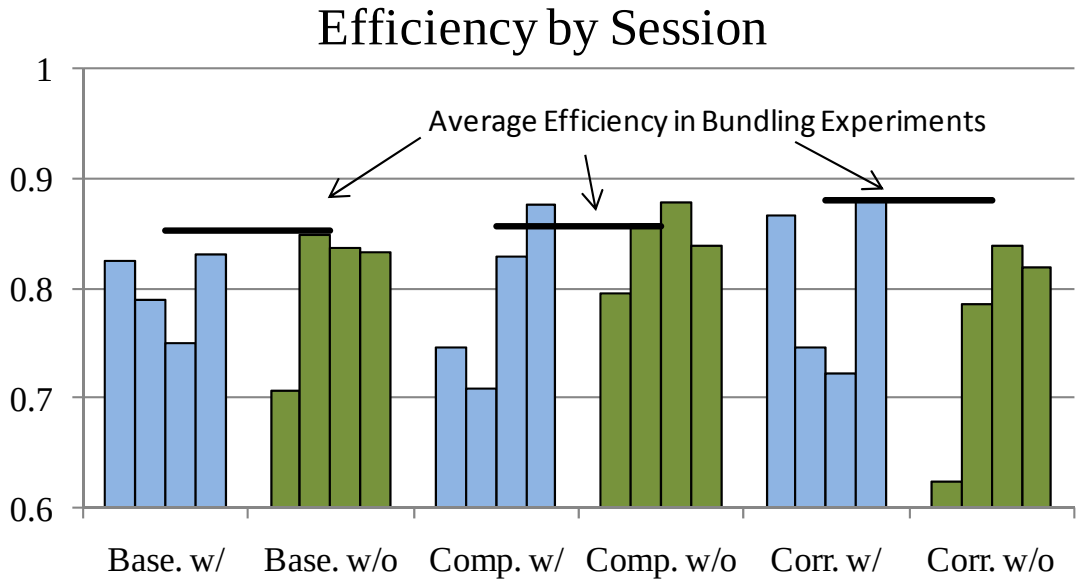




Findings: Comparison with Bundling

Aloysius and Deck (2008) examines bundling using a similar design (parameters, interface, subjects).

- Efficiency is lower with sequential pricing.
- Average within session profits are universally higher with sequential pricing.



Summary

1. Evolving technology will enable sellers to track intended purchases and adjust prices.
2. For a monopolist, sequential pricing is more attractive then bundling for goods that are highly positively correlated or close substitutes.
3. The effects of the ability to discriminate are weakened by competition.
4. There are benefits from this technology (recommendations, etc.) but redefining the problem sequentially has costs and reduces welfare relative to bundling.
5. More research is needed with strategic buyers, different information acquisition, endogenous selection of bundling or sequential pricing.