Wind Tunnel for Business

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Motivation

• Design supply chain contracts for HP businesses

• Example: Rebate Programs design
  – Requested by HP US Consumer Marketing
  – HP funded rebate to consumer through retailers
  – Menu of choices and limitations for retailers
Research Issues

• How to design contracts? Analytical modeling? Business meetings?
  
  – How good is the behavioral (risk-neutral utility maximization?) assumption?

• Can economics experiments provide useful information for business?

• How do we scale up model complexity to the real world level? Is it necessary?
Agenda

• Dual Channel Analysis (Kay-Yut Chen, Ozalp Ozer and Murat Kaya)

• HP Channel Management Experiments (Kay-Yut Chen and Gary Charness)

• Survey of HP Labs Experimental Economics Research
Dual Channel Model

Inventory Level

Manufacturer

Retailer

Direct Channel

Customers

Wholesale price $W$

Waiting time $t$

$q$

10/24/2006  Experimental Economics Program

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Customer Preferences

Time sensitivity distribution (uniform)

\[ d=0 \]
\[ d=1 \]

the most patient customer

Expected utility of customer “d”

\[ E(u_r) \quad u_d(d) \quad \text{from not buying} \]

\[ \{ \phi(\beta)(v - p) - k, (v - p) - dt, 0 \} \]

Trade-off
Availability and search cost versus waiting time

Availability
Value to customer
Sales price
Search cost
Time sensitivity index
Waiting time
Customer Decision Tree

Consider the direct channel?
- Yes: $u_d(d) \geq 0$
- No: $u_d(d) < 0$

Buy from the direct channel without visiting the retailer?
- Yes: $u_d(d) \geq E(u_r)$
- No: $u_d(d) < E(u_r)$

Available at the retailer?
- Yes: Buy from Direct Channel
- No: Buy from Retailer

Visit the retailer?
- Yes: $E(u_r) \geq 0$
- No: $E(u_r) < 0$

Available at the retailer?
- Yes: Buy from Retailer, Buy from Direct Channel (Secondary Demand)
- No: Cannot buy (Lost Customers)

Do not buy
Finding Nash

Stage 2: Retailer’s Problem

$$\max_{\beta \in [0,1]} \left\{ \min \{ D_1(\beta), \phi(\beta) \} - w_2(\beta) \right\}$$

where

$$\beta_{\text{max}} = \left\{ \begin{array}{ll}
\beta_{\text{max}}, & \text{for } \beta(\ell) \leq \beta_{\text{max}}, \\
\beta(\ell), & \text{for } \beta(\ell) \in (\beta_{\text{min}}, 1), \\
1, & \text{for } \beta(\ell) \geq 1,
\end{array} \right.$$ 

if $$\Pi_1(\beta') \geq 0$$ holds. Otherwise, $$\beta' = 0$$.

Facts:
- Retailer’s Best Response
- Decreasing in $$\ell$$ and $$\ell'$$

Stage 2: Manufacturer’s Problem

$$\max \left\{ (w-c)\ell + (w-c) \mathbb{E}[D_1 + D_2] - \frac{\pi}{\xi} \right\}$$

substituting, we have

$$\Pi_1(\ell) = \begin{cases}
\frac{\sigma(\ell) - \frac{\pi}{\xi}}{\gamma} & \text{for } \ell \leq \ell', \\
\frac{\sigma(\ell)(1-\beta)}{\xi} + \frac{\sigma(\beta)}{\xi} & \text{for } \ell > \ell',
\end{cases}$$ 

where

$$\sigma(\beta) = \frac{2}{\xi} \left( \frac{k + (w-p) - \beta (1 - \ln(\beta)) (w-p)(1-\beta - 2(w-p))}{2(w-p)} \right)$$

Stage 2: Finding the Nash Equilibrium

The Algorithm (Best Response Dynamics)

1) Set $$\beta_0 = \{\text{seed value} \}$$, $$\ell'_0 = \{\text{a very large number} \}$$
2) For $$j = 1$$ to $$j = N$$ Do
   - Find $$\ell'_j (\beta'_j)$$.
   - Find $$\beta'_j (\ell'_j)$$.
   - If $$(\beta'_j - \beta_{j-1} < \epsilon \text{ and } \ell'_j - \ell'_{j-1} < \epsilon)$$, Then Go To Step 3.
3) The Nash Equilibrium is the pair $$\beta'_j, \ell'_j$$. 

Manufacturer’s Best Response

- $$\ell' = \frac{2m}{\sigma(\beta)}$$
- $$\ell' = \ell'$$
- $$\ell' = \ell'$$
- $$\ell' = \ell'$$
Dual Channel Model

STAGE-3

Customers

Inventory Level

q

Wholesale price

W

Retailer

Manufacturer

Direct Channel

Waiting time

\( t \)
Economics Experiment

• Treatment: Three types of manufacturer policies depending on parameters
  – M receives all profits from direct channel
  – M receives most profits from both channels
  – M shares profits with R

• Methodology
  – human subjects recruited from Stanford student body
  – monetary compensation according to game performance
  – web-based instructions & quiz before experiment
  – implemented in HP Experimental Economics software platform
  – experiments conducted at HP Labs
<table>
<thead>
<tr>
<th>Game</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role</td>
<td>Retailer</td>
</tr>
<tr>
<td>Stage</td>
<td>Stock Level Decision</td>
</tr>
<tr>
<td>Value of Product</td>
<td>20</td>
</tr>
<tr>
<td>Retail Price of Product</td>
<td>10</td>
</tr>
<tr>
<td>Search cost at the Retailer</td>
<td>6</td>
</tr>
<tr>
<td>Wholesale Price / Unit</td>
<td>5</td>
</tr>
</tbody>
</table>

**Last Role**
- Retailer Stock Level
- Units sold: Direct=
- Retail=
- This payoff
- Cumulative Payoff

**Total Demand**

| Total Demand | 20 |
| Availability | 10 |
| Unsold | 98.7% |

**Decision Support Tool**
(Note: Values entered in this area are only for temporary calculations. Only the value submitted in “your decision” box matters.)

If manufacturer’s shipping time is 15, and my stock level is 500:

<table>
<thead>
<tr>
<th>Units Sold Direct</th>
<th>Units I Sold</th>
<th>My Inventory Unsold</th>
<th>Customers I Lost</th>
<th>Total Customers Lost</th>
<th>Manufact. ’s Profit</th>
<th>My Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2055.6</td>
<td>-2500.0</td>
</tr>
<tr>
<td>100</td>
<td>41</td>
<td>59</td>
<td>441</td>
<td>0</td>
<td>2465.6</td>
<td>-1910.0</td>
</tr>
<tr>
<td>200</td>
<td>82</td>
<td>118</td>
<td>382</td>
<td>0</td>
<td>2875.6</td>
<td>-1320.0</td>
</tr>
<tr>
<td>300</td>
<td>123</td>
<td>177</td>
<td>323</td>
<td>0</td>
<td>3285.6</td>
<td>-730.0</td>
</tr>
<tr>
<td>400</td>
<td>163</td>
<td>237</td>
<td>263</td>
<td>0</td>
<td>3685.6</td>
<td>-130.0</td>
</tr>
<tr>
<td>500</td>
<td>204</td>
<td>296</td>
<td>204</td>
<td>0</td>
<td>4095.6</td>
<td>460.0</td>
</tr>
<tr>
<td>600</td>
<td>245</td>
<td>355</td>
<td>145</td>
<td>0</td>
<td>4505.6</td>
<td>1050.0</td>
</tr>
<tr>
<td>700</td>
<td>286</td>
<td>414</td>
<td>86</td>
<td>0</td>
<td>4915.6</td>
<td>1640.0</td>
</tr>
<tr>
<td>800</td>
<td>327</td>
<td>473</td>
<td>27</td>
<td>0</td>
<td>5325.6</td>
<td>2230.0</td>
</tr>
<tr>
<td>900</td>
<td>362</td>
<td>500</td>
<td>0</td>
<td>0</td>
<td>5875.6</td>
<td>2500.0</td>
</tr>
<tr>
<td>1000</td>
<td>448</td>
<td>500</td>
<td>0</td>
<td>0</td>
<td>6535.6</td>
<td>2500.0</td>
</tr>
<tr>
<td>258</td>
<td>105</td>
<td>153</td>
<td>347</td>
<td>0</td>
<td>3105.6</td>
<td>-970.0</td>
</tr>
</tbody>
</table>

**Your decision**
- Units to stock: 0
## Summary

<table>
<thead>
<tr>
<th>Session</th>
<th># of Subjects</th>
<th># of Periods</th>
<th>Eq.</th>
<th># of Periods</th>
<th>Eq.</th>
<th># of Periods</th>
<th>Eq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session 1</td>
<td>12</td>
<td>30</td>
<td>t=55.6, q=656</td>
<td>30</td>
<td>t=8.0, q=0</td>
<td>18</td>
<td>t=15.6, q=465</td>
</tr>
<tr>
<td>Session 2</td>
<td>14</td>
<td>25</td>
<td>t=16.2, q=510</td>
<td>25</td>
<td>t=42.2, q=335</td>
<td>25</td>
<td>t=8.0, q=0</td>
</tr>
</tbody>
</table>

Randomized roles & pairings for each period
Result

### Session 1 All Data

<table>
<thead>
<tr>
<th></th>
<th>Mean M Profit</th>
<th>Mean R Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp 1</td>
<td>2744</td>
<td>-189</td>
</tr>
<tr>
<td>Exp 2</td>
<td>5101</td>
<td>-168</td>
</tr>
<tr>
<td>Exp 3</td>
<td>3476</td>
<td>792</td>
</tr>
</tbody>
</table>

Exp 1: M <- most profits from both channels
Exp 2: M <- all profits from direct channel
Exp 3: M shares profits with R
Result

### Session 2 All Data

<table>
<thead>
<tr>
<th></th>
<th>Mean M Profit</th>
<th>Mean R Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp 1</td>
<td>2590</td>
<td>1002</td>
</tr>
<tr>
<td>Exp 2</td>
<td>2291</td>
<td>-313</td>
</tr>
<tr>
<td>Exp 3</td>
<td>4961</td>
<td>-180</td>
</tr>
</tbody>
</table>

Exp 1: M shares profits with R
Exp 2: M <- most profits from both channels
Exp 3: M <- all profits from direct channel
## Test Results

<table>
<thead>
<tr>
<th></th>
<th>Exp 1</th>
<th>Exp 2</th>
<th>Exp 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K-S Test $^{1st}$ vs $^{2nd}$ half</td>
<td>T-test from eq</td>
<td>K-S Test $^{1st}$ vs $^{2nd}$ half</td>
</tr>
<tr>
<td>Session 1</td>
<td>t 0.95 0.05</td>
<td>q 0.00 0.00</td>
<td>t 0.04 0.00</td>
</tr>
<tr>
<td>Session 2</td>
<td>t 0.73 0.99</td>
<td>q 0.02 0.00</td>
<td>t 0.01 0.00</td>
</tr>
</tbody>
</table>
Conclusion & Implication

• Major results
  – comparative static confirmed
  – substantial biased in quantitative predictions
  – dispersion

• Possible explanation
  – basic economics forces drive behavior in right direction
  – risk aversion
  – difficulties in coordinating an equilibrium (if they can actually find one)
  – heterogeneity in risk attitudes & learning

• Business Implications & future work
  – Analytics may be able to predict direct of policy changes
  – Need to test policies with “scale-up” experiments
  – Incorporate rebate design into the model
Extension

- Incorporate first stage of the game (w)
- Find optimal w given behavior
- Repeated game
- Cheap talk
- ....
Channel Management Business Background

- Partner: HP US Consumer Marketing

- $13.5B in 2005 (US Consumer & Supplies)

- Most business goes through a small number of retailers

- ~150 hardware products + several hundreds supply products

- Multiple product lines: PCs, All-in-one Printers, Deskjet Printers, Laser printers, photo-printers, cameras, PDAs …
Dual Channel Model

- **Retailer**
  - Wholesale price: $W$
  - Inventory Level: $q$

- **Manufacturer**

- **Direct Channel**
  - Waiting time: $t$

- **Customers**
Printed Retail Channel Experimental Model

Wholesale price
Rebate Program
Return Policy
Min Ad Price
Demand Gen Funds

Price/Rebate Promotion
Order (stock level)
Returns

CESS (Best Buy)
OPSS (Off Depot)
Mass Mer (Walmart)
Club (Costco)
Direct (HP Shopping)

Inventory carryover
Multiple products
Product life cycle
Heterogeneity

Customers

HP
Epson
Canon
Lexmarkr
Retail Channel Management Policy Design Business Applications

<table>
<thead>
<tr>
<th>Policy Design</th>
<th>Business Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return /Price Protection Policy Evaluation</td>
<td>• Validate Technology</td>
</tr>
</tbody>
</table>
| Minimum Advertised Price Policy Design (Sep 99) | • Identify necessary modifications & design new MAP policy  
• New policy implemented in CPBO in Oct 99 |
| MAP Product/Channel Portfolio Evaluation (Feb 00) | • Validate policy implemented in CPBO  
• Recommend no change in application of policy |
| Soft-Fund Policy Design (Mar 2001) | • Alternative Policies Found ineffective  
• CBO abandoned alternatives as recommended |
| Derivative Strategy Evaluation (Nov 2001) | • Validate one alternative strategy  
• Alternative strategy implemented by CBO as recommended |

“The beauty of the model is its ability to allow us to "test" a number of different variations, and see the effects, without creating a "disturbance" in the marketplace.”
- Jacky Churchill, Vice President and General Manager, CPBO

“Kay-Yut Chen, a project scientist at Hewlett - Packard, says the lab allows him to test changes in corporate policy to examine the effect on market structures before the change is introduced.”
- Wall Street Journal, Oct 2, 2000
Min Ad Price Enforcement Policy

Test 4 scenarios
- pull product
- future shipment based financial punishment

Key Finding
- Identify escalating violations at end of life-cycles
- Identify issue with category pull

Business Results
- New MAP design
  - 3% funds pull on SKU next 30 days sell-thru
  - 3% funds pull on SKU past 30 days shipment
- New design rolled out 1999
- Current standard HP MAP policy
Recent Research

- **Business Applications**
  - Strategic Behavior in Re-structuring of Supply Chains (Ford) 2004
    - Experimental evaluating a new fixed price system on top of auctioning off used vehicles
  - IPG Elite Program Design & Evaluation (HP IPG/UC Berkeley) 2004
    - Design incentives for investing in new solutions & products
  - Currency Hedging & Pricing Strategy (HP Treasury) 2005 – ongoing
    - Studying the effect of competition in currency hedging
    - Evaluating different rebate program design

- **Research in New Economics Mechanism**
  - Sales compensation design 2005-ongoing
    - Solving the sand-bagging problem with properly design incentive mechanisms
  - Information aggregation/BRAIN 2002
    - use economics “games” to predict the future
  - Reputation mechanisms & dynamics 2002
    - understand dynamics of reputation and find ways to “sell” it
  - Quantum Economics 2002-ongoing
    - creating new economics with quantum information processing technology
    - Experiments funded by DARPA

- **Basic Technology Development**
  - HP Experimental Economics Software Platform
    - Licensed to UC Berkeley
Future of Business Engineering

• Theory to provide insight & guidelines

• Simple experiments to validate principles

• Scaled up experiments to bridge the gap between models and the real world