Data-Driven Demand Learning and Dynamic Pricing Strategies in Competitive Markets

Customer Behavior

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Hasso Plattner Institute (EPIC)

April 24, 2017
Outline

• Scheduling & Participation

• Goals of today’s meeting: Customer Behavior

• How to model customer choice: 3 simple approaches

• Recommended Exercise I: Simulation of Customer Choice

• Recommended Exercise II: Dynamic Pricing Duopoly
Motivation

• Big picture: Modelling dynamic pricing competition

• Separable components: Customers, Strategies & Demand Learning

• How to describe Customer Behavior?

• We look for a general model which is simple yet reasonable

• How do you decide?
Example: Buying Books on Amazon

A Course in In-Memory Data Management: The Inner Mechanics of In-Memory Databases (Gebundene Ausgabe)

from Hasso Plattner (Author)

Schreiben Sie die erste Bewertung

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<th>Zustand</th>
<th>Verkäufer-Information</th>
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Data-Driven Demand Learning and Dynamic Pricing Strategies – Customer Behavior
Customer Choice?

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Goals of Today’s Meeting

• Task: Description of Customer Behavior

• Assume: Multiple product features/dimensions (price, quality, etc.)

A list of competitors’ offers, i.e., a market situation \( \vec{s} = (\vec{p}, \vec{q},...) \)

Stream of interested customers (heterogeneous)

• Goal: Quantify the probability \( P(k, \vec{s}) \) that an interested customer chooses the offer \( k, k=1,...,K \) in a given market situation \( \vec{s} \)
How to Model Customer Choice?

- Any ideas?

- Approach I: Always choose the cheapest offer

- Approach II: Use distribution of sales and price rank

- Approach III: Use a randomized scoring function

- Other: Combinations, data-driven, etc.
Approach I: Cheapest Offer

• Idea: An interested customer always chooses the cheapest offer

• Formula for \( P(k, \bar{s}) \), \( k = 1, ..., K \)?

• Answer:

\[
P(k, \bar{s}) = P(k, \bar{p}, ...) = \begin{cases} 
1 & , k = 1, ..., K : p_k = \min_{i=1,\ldots,K} p_i \\
0 & , k = 1, ..., K : p_k > \min_{i=1,\ldots,K} p_i 
\end{cases}
\]
Approach II: Sales vs. Price Rank

- Idea: Relative frequency of sales and price ranks

- Example: 1000 sales → #550 rank 1, #280 rank 2, #100 rank 3, . . .
  
i.e., \( H \) sales - \( h_1, h_2, h_3, \ldots \)

- Formula for \( P(k, \bar{s}) \), \( k = 1, \ldots, K \) ?

- Answer: \( P(k, \bar{s}) = P(k, \bar{p}, \ldots) = \frac{h_{\text{rank}(p_k, \bar{p})}}{\sum_{i=1, \ldots, K} h_i} \)
Approach III: Randomized Scoring

- Idea: Different customers use different scoring functions

- C1: \[ \arg \min_{k=1,...,K} \left\{ p_k - 0.1 \cdot q_k - 0.01 \cdot r_k - 0.01 \cdot f_k^{0.5} + 0.2 \cdot c_k \right\} \]

- C2: \[ \arg \min_{k=1,...,K} \left\{ p_k - 0.15 \cdot q_k - 0.005 \cdot r_k - 0.03 \cdot f_k^{0.5} + 0.1 \cdot c_k \right\} \]

- C3: \[ \arg \min_{k=1,...,K} \left\{ p_k - 0.2 \cdot q_k - 0.05 \cdot r_k - 0.02 \cdot f_k^{0.5} + 0.5 \cdot c_k \right\} \]

  ... 

- We can model the decision of a random customer as follows:

\[ \arg \min_{k=1,...,K} \left\{ p_k - U(0, 0.2) \cdot q_k - U(0, 0.1) \cdot r_k - U(0, 0.05) \cdot f_k^{0.5} + U(0.1, 0.5) \cdot c_k \right\} \]
Approach III: Randomized Scoring

- Idea: Different customers use different scoring functions

- Formula for $P(k, \bar{s})$, $k=1,...,K$?

- Answer: $P(k, \bar{s}) = P(k, \bar{p}, \bar{q}, \bar{r}, \bar{f}, \bar{c}, ...)$

$$= P \left[ k = \arg \min_{i=1,...,K} \left\{ p_i - U(0,0.2) \cdot q_i - U(0,0.1) \cdot r_i - ... \right\} \right]$$

- Note: Simulation of a customer’s choice is easy!
How to Simulate Customer Choice?

- We need: Realisations of (stochastic) buying behavior for various market situations in our models

- Approach I+II: “Inverse Verteilungsmethode for $P(k, \bar{s})$ via $U(0,1)$”

- Approach III: - simulate random scoring coefficients, e.g., $U(0, 0.05)$
  - compute scores for all $K$ offers
  - choose the offer with the best score

- Do you think you can do this?
Recommended Exercise I – Simulate Sales Events

- Create random market situations
  with multiple sellers and multiple features

- Simulate customer’s selection/choice multiple times
  Check for plausibility

- Extension: Model/simulate an arrival process of interested customers
  Simulate whether an interested customer becomes a buyer
Recommended Exercise II – Duopoly Simulation

- Assume $K=2$ sellers. Assume only one feature: price

- Define different price reaction strategies $a(p)$, i.e.,
  
  if the competitor’s current price is $p$, we adjust our price to $a(p)$

  Admissible prices are $a(p) \in \{1, 2, \ldots, 100\}$

- Let the competitor’s response strategy be given by: $p(a) := \max(a - 1, 1)$

- We adjust our prices $a$ at times $t = 1, 2, 3, \ldots$
  
  The competitor adjusts his prices $p$ at times $t = 0.5, 1.5, 2.5, \ldots$
Recommended Exercise II – Duopoly Simulation

- In every interval \((t, t + 0.5)\), \(t = 0, 0.5, 1.0, \ldots\), a sale occurs with probability \(1 - \min(a_t, p_t)/100\). With probability \(\min(a_t, p_t)/100\) no sale takes place.

- If a sale takes place the customer chooses either our offer \((k=1)\) or the competitor’s offer \((k=2)\) with probability \(P(k, \tilde{p})\) according to Approach I, where \(\tilde{p} = (p^{(1)}, p^{(2)}) = (a, p)\), i.e., \(p^{(1)} = a\) (we) and \(p^{(2)} = p\) (competitor).

- Simulate until time \(T=1000\). Start with \(a_0 = p_0 = 20\) at time \(t = 0\).

- Which strategy \(a(p)\) performs best, i.e., maximizes expected revenues?
Overview

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
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<tbody>
<tr>
<td>2 April 24/25</td>
<td>Customer Behavior</td>
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<tr>
<td>3 May 1/2</td>
<td>Demand Estimation</td>
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<td>4 May 8/9</td>
<td>Pricing Strategies I</td>
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<td>6 May 22/23</td>
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<td>7 May 29/30</td>
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<td>8 June 5/6</td>
<td>Workshop / Group Meetings</td>
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