THE NEW FRONTIER IN PRICE OPTIMIZATION

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About Dr. David Simchi-Levi

- Professor of Engineering Systems at MIT, Co-Director of Leaders for Global Operations, and the Director of Accenture-MIT Alliance in Business Analytics
- He is considered one of the premier thought leaders in supply chain management and business analytics
- His research focuses on developing and implementing robust and efficient techniques for operations management
- Recipient of the 2014 INFORMS Wagner Prize for Excellence in Operations Research Practice; 2014 INFORMS Revenue Management and Pricing Section Practice Award; and Ford 2015 Engineering Excellence Award
- Chairman of OPS Rules, an operations analytics consulting company and Opalytics, a cloud analytics platform provider
- He was the founder of LogicTools which provided software solutions and professional services for supply chain optimization. LogicTools became part of IBM in 2009
The New Frontier in Price Optimization

David Simchi-Levi
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Motivation – Online Retail

- ~$300B industry with ~10% annual growth (Last 5 years)
  - Excludes online sales of brick & mortar stores

- Have additional information compared to brick & mortar stores
  - Real-time customer purchase decisions (buy / no buy)
A Few Stories ...

- **Forecasting & Price Optimization**
  - Rue La La
- **Learning & Price Optimization**
  - Groupon
- **Forecasting, Learning & Price Optimization**
  - B2W
- **Conclusions**
A Few Stories ...

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Online Fashion Sample Sales Industry

- Offers extremely limited-time discounts ("flash sales") on designer apparel & accessories
- Emerged in mid-2000s; ~$4B industry with ~17% annual growth in last 5 years (US)
“Style”

Saucony "Triumph 10" Running Shoe
$430.00  $79.90

Saucony "Grid Guide 6" Running Shoe
$410.00  $65.90

Saucony "Triumph 10" Running Shoe
$430.00  $79.90
"SKU"

Saucony "Progrid Guide 6" Running Shoe

$440.00  $65.90

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Add to Bag  Sign up for Quick! Buy It.  Never miss out on something you love.

Massachusetts Institute of Technology
Flash Sales Operations

1. Merchants purchase items from designers.
2. Designers ship items to warehouse.*
3. Merchants decide when to sell items (create “event”).
4. During event, customers purchase items.
5. Focus on first time this happens.
6. Sell out of item?
   - Yes: End
   - No: Proceed to next event.

*Sometimes designer will hold inventory.
Sell-Through Distribution of New Products

- 
  - 1st Exposure
  - Sell-Through Distribution of New Products

- % of Items
- % Inventory Sold (Sell-Through)

- Department 1
- Department 2
- Department 3
- Department 4
- Department 5

- SOLD OUT (100%)

- suggests price may be too high
- suggests price may be too low

- suggests price may be too low
Approach

Goal: Maximize expected revenue from new products

Demand Forecasting

Challenges:
- Predicting demand for items that have never been sold before
- Estimating lost sales

Techniques:
- Clustering
- Machine learning models for regression

Price Optimization

Challenges:
- Structure of demand forecast
- Demand of each style is dependent on price of competing styles → exponential # variables

Techniques:
- Novel reformulation of price optimization problem
- Creation of efficient algorithm to solve daily
Forecasting Model: Explanatory Variables Included

- Tested several machine learning techniques
  - Regression trees performed best
Regression Trees: Illustration and Intuition

If condition is true, move left; otherwise, move right

Why regression trees?
- Use features to partition styles sold in past, and only use relevant styles to predict demand
- Allow for non-monotonic price/demand relationship
Approach

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**Demand Forecasting**

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**Price Optimization**

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**Techniques:**
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Field Experiment

• Goals
  – Would implementing the tool’s recommended price increases cause a decrease in demand?
  – What impact would the price increases have on revenue?
• Identified ~6,000 styles where tool recommended price increase
  – Divided styles into 5 categories based on price point; for each category…
    • Raised prices on ~half of styles (treatment group)
    • Did not raise prices on other ~half of styles (control group)
Sell-Through Analysis

Comparison of Sell-Through: Treatment vs. Control Groups

styles with lowest price point
styles with highest price point
Revenue Impact

% Increase in Revenue with 90% Confidence Interval

A  B  C  D  E  Overall

-20% -10% 0% 10% 20% 30% 40% 50%
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Example: Online Daily Deals Retailer

- Selling thousands of deals from local merchants everyday
- Demand prediction before launch is quite inaccurate
- Collecting lots of sales data but not using them to adjust price
- Product life is short
  - 50% of deals are sold within first 4 days after launch
  - 70% sold within first month
“Online” Revenue Management

• **Online = Online Retail**
  - Many products face demand uncertainty and short product life cycle
  - Collects huge amount of sales data
  - Easy to adjust price dynamically

• **Online = Online Learning & Optimization**
  - Learning demand on the fly using data
  - Exploration vs. Exploitation
Exploration vs. Exploitation Tradeoff

- Test multiple prices to estimate demand
- Offer price estimated from data to maximize revenue

Learning

Exploration vs. Exploitation

Earning
Demand Hypotheses

- $m$ demand function hypotheses:
  \{d_1, \ldots, d_m\}

- $d_i(p)$ is the probability that a customer will purchase at a price $p$

Fig: An example with 3 hypotheses
Demand Hypotheses

- \( m \) demand function hypotheses:
  \( \{d\downarrow 1, \ldots, d\downarrow m\} \)
- \( d_i(p) \) is the probability that a customer will purchase at a price \( p \)
- If hypothesis \( i \) holds, customer buys with probability \( d_i(p) \)
- The retailer *does not* know the true hypothesis

*Fig: An example with 3 hypotheses*
The Algorithm: Single Learning Price

Initial price $p_{↓1}$

Using data, choose demand $i$, set $p_{↓2} = p_{↓i}^*$
Implementation at Groupon

- We applied the one-learning price algorithm
  - The initial price is **negotiated** by Groupon with merchant
  - Allow **decrease** by (5%, 30%)
  - Merchant gets a **fixed** share

- $\Phi = \{d_1 \downarrow , \ldots , d_K \downarrow \}$ is generated from historical data by clustering
Implementation at Groupon

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Groupon: $7$
Restaurant: $10$
Implementation at Groupon

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Groupon: $5$

Restaurant: $10$

Edamame Japanese Restaurant

Watertown

$30$

$15$
Pilot Live Experiment
Impact by Deal Category

- Beauty / Wellness / Healthcare: Bookings 149%, Revenue 44%
- Food & Drink: Bookings 107%, Revenue 17%
- Leisure Offers / Activities: Bookings 60%, Revenue -18%
- Services: Bookings 85%, Revenue -2%
- Shopping: Bookings 335%, Revenue 140%
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B2W Overview

- Largest online retailer in Latin America
- Offers the widest selection of products across categories such as Mobile Phones, TVs, Domestic appliances, Games and Fashion
- Launched in 1999 as an extension to the physical store business
- 30% annual revenue growth for the last 3 years
- Competitors include Amazon, Walmart, Ponto Frio, Extra

B2W Brands

[Logos for Americanas, Submarino, Shoptime, SouBarato]
## Dynamic Pricing Approach

### Demand Curve Generation

Extract sensitivity of quantity sold with change in price

**Challenge:**
Historical data has multiple factors that influence quantity sold

**Method:**
Random Forest (Bagging)

### Learning via Product Clustering

Identify clusters of products having similar characteristics

**Challenge:**
Wide range of characteristics in which products differ

**Method:**
K-Means

### Optimization

Maximize revenue (margin) of a cluster subject to a min margin (revenue) constraint

**Challenge:**
Solving efficiently

**Method:**
Mixed Integer Linear Programming
Implemented Solution Provides Real Time Decision Support to the Commercial Team
Dynamic Pricing--Operations

- Algorithm now runs twice a day;

- Typically, the first few hours of the day generate the traffic prediction, which is an input to the Random Forest;

- No manual intervention. All prices are pushed directly to the web-site.
Cluster 1: Low Price Products

Aug 3 – Oct 07 (Excludes Events)
Cluster 2: Fast Selling Products

Estimated Revenue
- Control: $1.5M
- Treatment: $1.6M (17% increase)

Estimated Profit
- Control: $300K
- Treatment: $390K (30% increase)

Estimated Unit Sales
- Control: 2,800 units
- Treatment: 3,192 units (14% increase)

Aug 26 – Oct 07 (Excludes Events)
Cluster 3: Premium Products

Aug 26 – Sep 21 (Excludes Events)
Cluster 3: Premium Products-with Margin Optimization

- Estimated Revenue: 471%
- Estimated Profit: 366%
- Estimated Unit Sales: 391%

Sep 25 – Oct 07
Competitive Benefits: Dynamic Pricing is Also a Powerful Tool for Market Positioning

Model sold 40% more unique SKUs everyday (chart below). Will help in positioning B2W as ‘better price every time, for everything’
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Summary

• **New Challenges** from emerging online retail business (e.g. flash sale, daily deals)
  - High demand uncertainty, short product life cycle and limited inventory

• **Combine Forecasting, Learning and Optimization techniques** to impact bottom line
  - Exploration vs. Exploitation Tradeoff

• **Our proposed methods** are supported by theory, simulation results and **Practice**
Acknowledgement

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• — OPS Rules
For Q&A

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