Dynamic Pricing to improve Supply Chain Performance

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Presentation Outline

• The Direct-to-Consumer Model
  – Motivation
  – Opportunities suggested by DTC
• Flexible Pricing Strategies
• Future Research Directions
Characteristics of the Industrial Partner

• Make-to-stock environment
• Annual revenue in 1998 was about $180 billion
• Annual spending on supply is more than $70 billion
• Huge product variety and a large number of parts
• Inventory levels of parts and unsold finished goods is about $40 billion
Direct to Consumer (DTC)
The Impact of the DTC Model

- Valuable Information for the Manufacturer
  - e.g., accurate consumer demand data
Traditional Supply Chain

Source: Tom Mc Guffry, Electronic Commerce and Value Chain Management, 1998
The Dynamics of the Supply Chain

Source: Tom Mc Guffry, Electronic Commerce and Value Chain Management, 1998
We Conclude:

In Traditional Supply Chains….

• Order Variability is amplified up the supply chain; upstream echelons face higher variability.

• What you see is not what they face.
Consequences....

- Increased safety stock
- Reduced service level
- Inefficient allocation of resources
- Increased transportation costs
In the DTC Model...

Source: Tom Mc Guffry, Electronic Commerce and Value Chain Management, 1998
The Impact of the DTC Model

• **Valuable Information for the Manufacturer**
  – e.g., accurate consumer demand data

• **Product variety for the Consumer**
  – e.g., allows for an assemble-to-order strategy
From Make-to-Stock Model....

Suppliers  Assembly  Configuration
....to Assemble-to-Order Model
A new Supply Chain Paradigm

- A shift from a Push System...
  - Production decisions are based on forecast

- ...to a Push-Pull System
  - Parts inventory is replenished based on forecasts
  - Assembly is based on accurate customer demand
The Impact of the DTC Model

• **Valuable information for the Manufacturer**
  – e.g., accurate consumer demand data

• **Product variety for the Consumer**
  – e.g., allows for an assemble-to-order strategy

• **Flexibility**
  – e.g., price and promotions
Revenue Management

• “Allocating the right type of capacity to the right kind of customer at the right price so as to maximize revenue or yield”

• Traditional Industries:
  – Airlines
  – Hotels
  – Rental Car Agencies
  – Retail Industry

FOR EXAMPLE...

Traditional Requirements

- Perishable inventory
- Limited capacity
- Ability to segment markets
- Product sold in advance
- Fluctuating demand

FOR EXAMPLE...

Dynamic Pricing in Manufacturing

• Non-perishable inventory
• Production schedule needs to be determined
• Production has capacity limitations
• Demand and prices over time are bi-directional
• Lost sales

FOR EXAMPLE…

  – Stochastic demand, allows for backlogging but not lost sales
Flexible Pricing in Manufacturing

• **Goals:**
  – To extend the application of dynamic pricing and revenue management to non-traditional areas
    • Manufacturing industry with non-perishable products
    • *Capacity allocation is the allocation of a perishable resource* (i.e., build or no build decisions)
  – To integrate pricing, production and distribution decisions within the supply chain
• “Allocate product to the right customer at the right price and at the *right time*”
Model Features

- Determines “when” and “how much” to sell
- **Capacity limitations** on production
- Incorporates **lost sales**
- Known, **time-dependent demand curves**
Model Assumptions

• Deterministic model
• Single product of discrete units
• T periods
• Periodically varying parameters:
  – Production Capacity: $Q_t$
  – Holding Cost: $h_t$ per unit
  – Production Cost: $k_t$ per unit
  – Upper and lower bounds on price
  – Concave Revenue Function: $R_t(D_t)$
    • $D_t$: the units of satisfied demand at period $t$
    • Example: Demand is a linear function of price
Revenue Curve

- Revenue curve incorporates lost sales or limits on demand and remains concave with respect to satisfied demand.
The Pricing Problem: Problem PP

Maximize Profit

\[ f(D) = \sum_{1 \leq t \leq T} (R_t(D_t) - h_t I_t - k_t X_t) \]

Subject to:

1. Beginning Inventory: \( I_0 = 0 \)
2. Inventory Balance: \( I_t = I_{t-1} + X_t - D_t, \quad t = 1,2,\ldots,T \)
3. Production Capacity: \( X_t \leq Q_t, \quad t = 1,2,\ldots,T \)
4. Integrality: \( I_t, X_t, D_t, \text{ integer } \geq 0, \quad t = 1,2,\ldots,T \)

At each period \( t \),

- \( X_t \) is the units of product produced
- \( I_t \) is the end of period inventory
- \( D_t \) is the satisfied demand (sales)
When does flexible pricing matter?

- Computational analysis performed to answer the following questions:
  - How much does flexible pricing affect profit?
  - When does flexible pricing have the most impact on profit?
  - What other impacts does flexible pricing have?
  - How many prices in a horizon are needed to obtain significant profit benefit?
Profit Benefit

• Define profit potential due to flexible pricing to be:

\[
\text{Profit Potential} = \frac{\text{Profit with Dynamic Prices}}{\text{Profit with Constant Price}}
\]

• Profit potential is the percentage of profit to be gained from dynamic prices
Computational Details

- Demand curves obtained from an Industrial Partner
- Curves are aggregated over a number of products
- 10 period problem
- Varied capacity, demand, or both
Managerial Insights

- Flexible pricing has the most impact on profit when:
  - *Capacity* is tightly constrained
  - *Variability* in capacity or demand exists
Impact of Changes in Capacity

- As capacity becomes more constrained, the benefit of flexible pricing increases
- As the variability in capacity increases, the benefit of flexible pricing increases

![Graph showing the effect of capacity changes on flexible pricing benefit when demand is constant.](C:\Users\chuck\Documents\Diagram.png)
Impact of Changes in Demand

- As the variability in demand increases, the benefit in flexible pricing increases.
- As capacity becomes more constrained, the benefit in flexible pricing increases.

![Effect of Demand Changes on Flexible Pricing Benefit when Capacity is Constant](chart.png)
Other Potential Impacts

• Reduction of *variability* in sales or production schedule
• Increase in average *sales*
• Reduction of *inventory*
• Reduction in average (or weighted average) *price*
Impact on Variability of Sales

- When demand is variable and capacity is constant, flexible pricing reduces the variability in sales compared to fixed pricing policies.

![Diagram showing the effect of pricing policy on variability of sales when capacity is constant.](image-url)
Impact on Production Schedule

• When demand is variable and capacity is constant, flexible pricing often results in a smoother production schedule than that obtained using fixed pricing policies.
Impact on Average Sales

- Flexible pricing policies increase average sales compared to fixed pricing policies.

![Effect of Pricing Policy on Average Sales when Capacity is Constant](chart.png)
Impact on Inventory

- Flexible pricing policies decrease the average inventory level compared to fixed pricing policies.
Impact on Price

- Flexible pricing policies decrease the weighted average price compared to fixed pricing policies.
Number of Prices

• How many prices in a horizon are needed to obtain significant profit benefit?

• 12 periods analyzed
  – Considered 1, 2, 3, 4, 6, and 12 prices

• Test cases:
  – Varied capacity over the horizon, fixed demand curves
  – $E(\text{Capacity}) = 0.50 \times \text{Optimal Uncapacitated Demand}$
  – For all patterns shown, Coefficient of Variation (Capacity) = 0.25
Number of Prices

- Usually 1 price every 3 periods gives 75% of the potential profit increase
- Less is sometimes more
Number of Prices

- Number of prices needed varies depending on the pattern of variability
- The potential profit benefit varies depending on the pattern of variability

![Graph showing the increase in profit due to flexible pricing policies](image.png)
Multiple Products

- Deterministic multi-product model
- Multiple products share common production capacity
- Finite time horizon
- Each product uses the same amount of the resource per unit production
- Time varying, product dependent parameters
  - Production and inventory costs
  - Demand curves
Multiple Products: Computational Results

- 12 period horizon
- Demand curves based on typical products
- Demand Scenarios:
  - Seasonality (car): low demand at beginning, increases in middle, decreases at end of horizon
  - Decreasing Mean (laptop): demand steadily decreases from beginning to end of horizon
- Each product experiences the same seasonality effect
Profit Potential with Multiple Products

- The percentage of profit potential often decreases as the number of products increases
Future Research Directions

- **Multiple Products and Multiple Parts**
  - Shared production capacity
  - Limited supply of common parts
  - Determine the most general model that can be solved by the greedy algorithm
Future Research Directions

• **Realistic Demand:**
  – Stochastic Demand
    • Computational analysis
  – Demand Diversions
    • Price changes in one product influence customers to divert from or to other products

• **Production Set-up cost**
  – Consecutive policy is optimal
  – DP that incorporates the MAA
Multiple Products, Part II

• Stochastic Demand

• Assumptions:
  – Single period, n products
  – Production cost and salvage value
  – Products share limited production capacity
  – Demand for each product j is an r.v. with a known cumulative probability distribution, $F_{j\text{,P,D}}$, which is independent of the other products

• Goal: Set prices and production for all products to maximize expected profit
Problem Definitions

• For product j set at price P, let $M^j_p(X)$ be the marginal expected profit to increase production from X-1 to X
  - $M^j_p(X) = S^j F^j_{p,d}(X-1) + P[1-F^j_{p,d}(X-1)]$
  - with $M^j_p(0) = 0$, where $S^j$ is salvage value

• Define expected profit of producing X units of product j:

$$R^j(X) = \max_{p} \max_{x?X} M^j_p(x)$$
Problem Formulation

• Problem PPE:
  – Max \( F^E(X) \) \( \leq \) \( (\sum_{j=1}^{n} R^j(X^j) \times k^j X^j) \)
  – Subject to
    \[ \forall j \in \{1, 2, ..., n\}, \quad X^j \leq Q_j \]
    \[ X^j \text{ integer } \leq 0, \quad j \in \{1, 2, ..., n\} \]

• Result:
  – If \( R_j(X) \) is a concave function of \( X \) for all \( j \), then
    problem PPE can be solved by MAA
  – Otherwise, PPE can be solved by a DP.
Problem Formulation

Max $F^E(X) = \max_{1 \leq j \leq n} (R_j(X_j) - k_j X_j)$

Subject to:

(1) Production Capacity: $\sum_j X_j \leq Q$

(4) Integrality: $X_j$ integer $\geq 0$, $j = 1,2,\ldots, n$

Theoretical Result:

If $R_j(X)$ is a concave function of $X$ for all $j$, then problem PPE above can be solved by MAA.
If not, problem PPE can be solved by a DP.
Multiple Products/Demand Scenarios

Demand Scenarios

% of Base Demand

Time

Seas
DecMean