Dynamic Pricing to improve Supply Chain Performance

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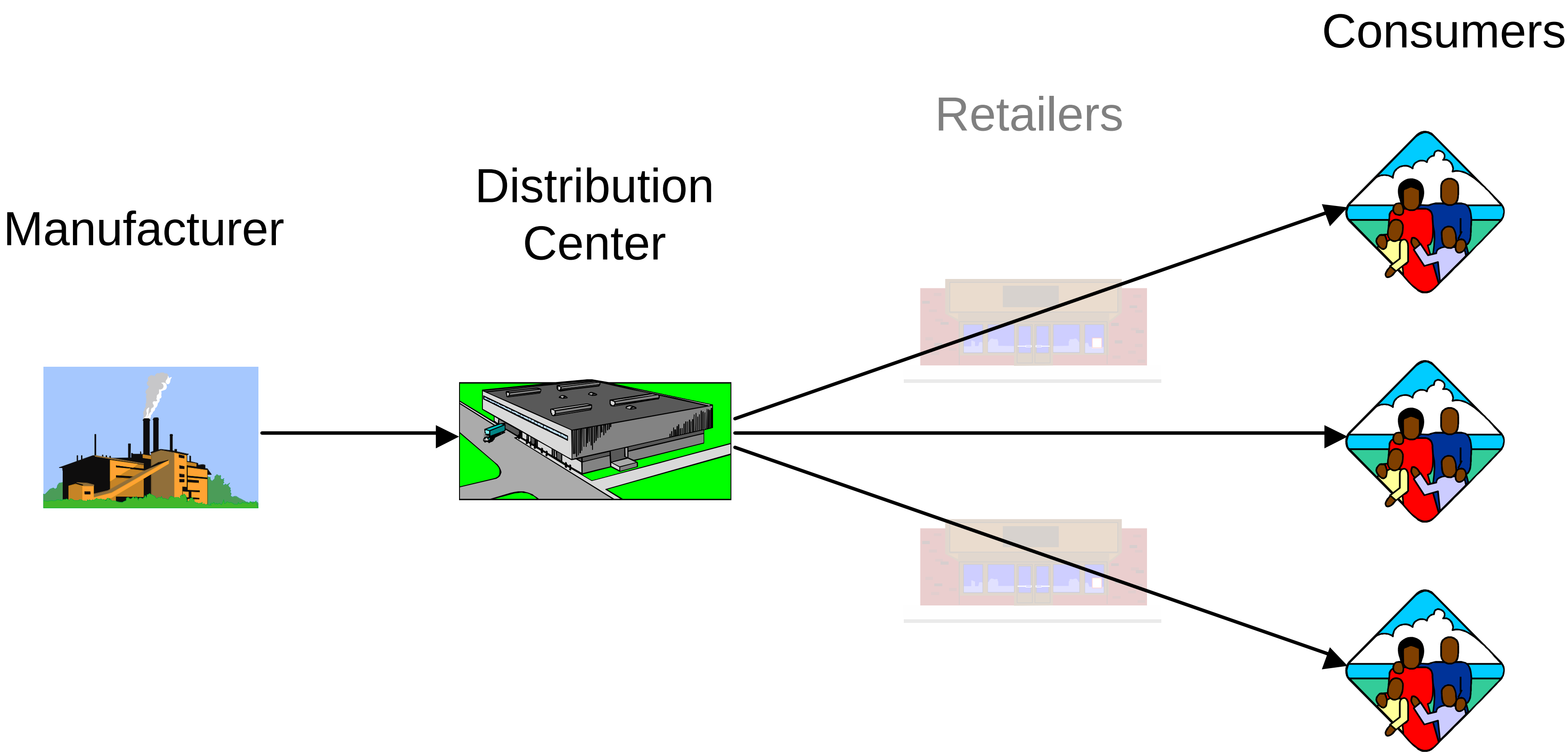
Presentation Outline

- **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**

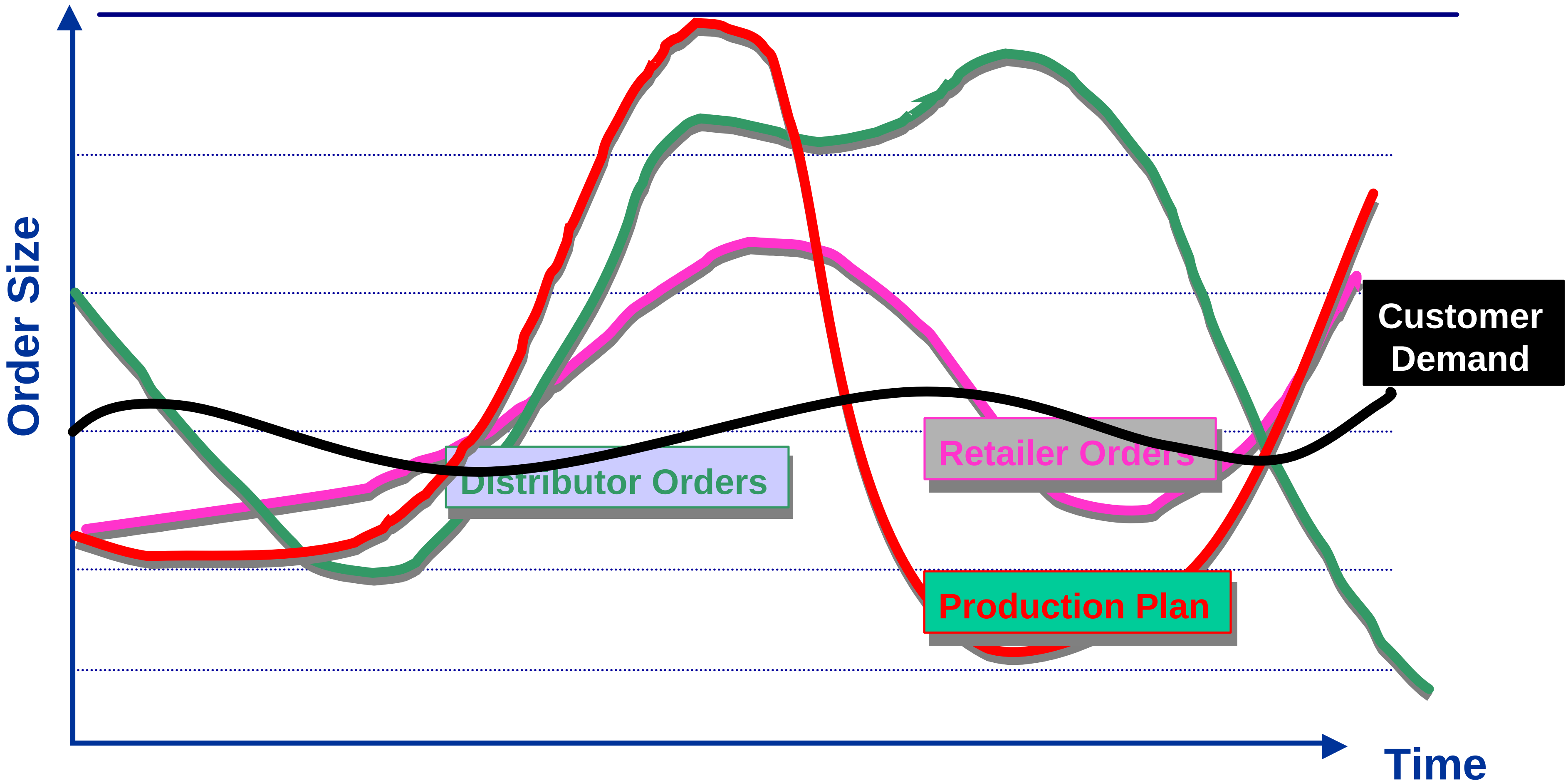
Direct to Consumer (DTC)



The Impact of the DTC Model

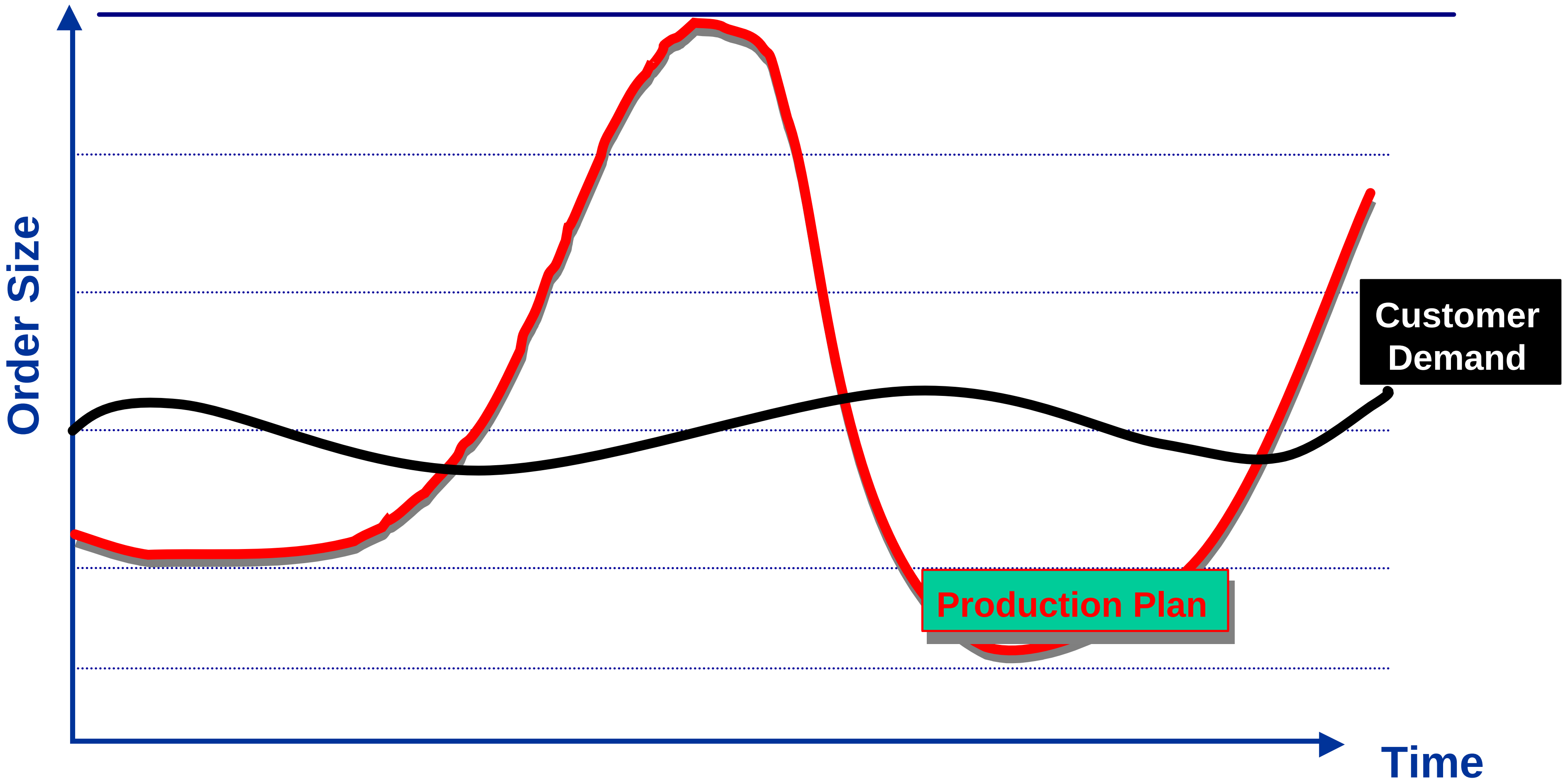
- **Valuable Information for the Manufacturer**
  - **e.g., accurate consumer demand data**

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….

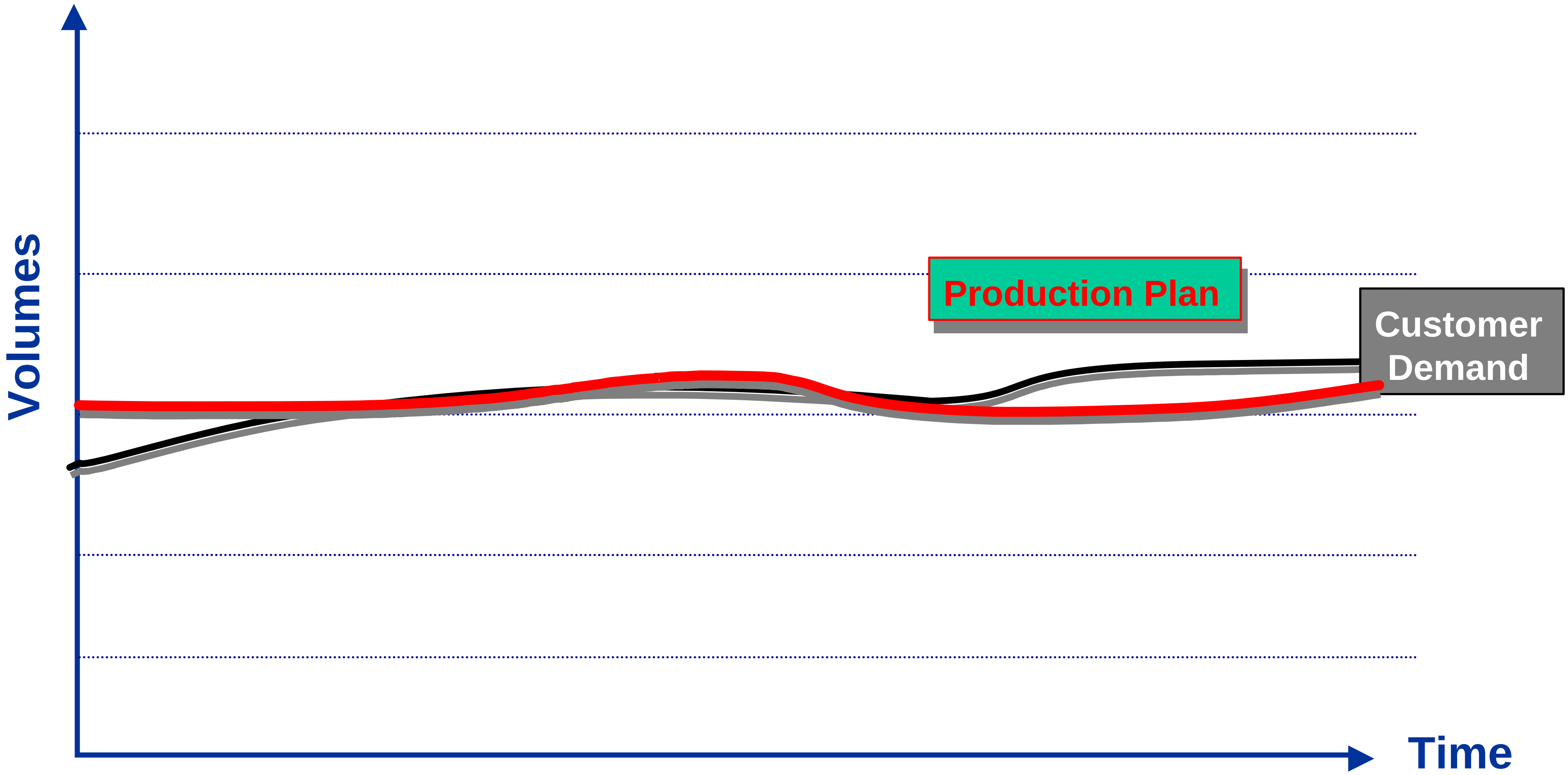
- Order Variability is amplified up the supply chain; upstream echelons face higher variability.

- 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...



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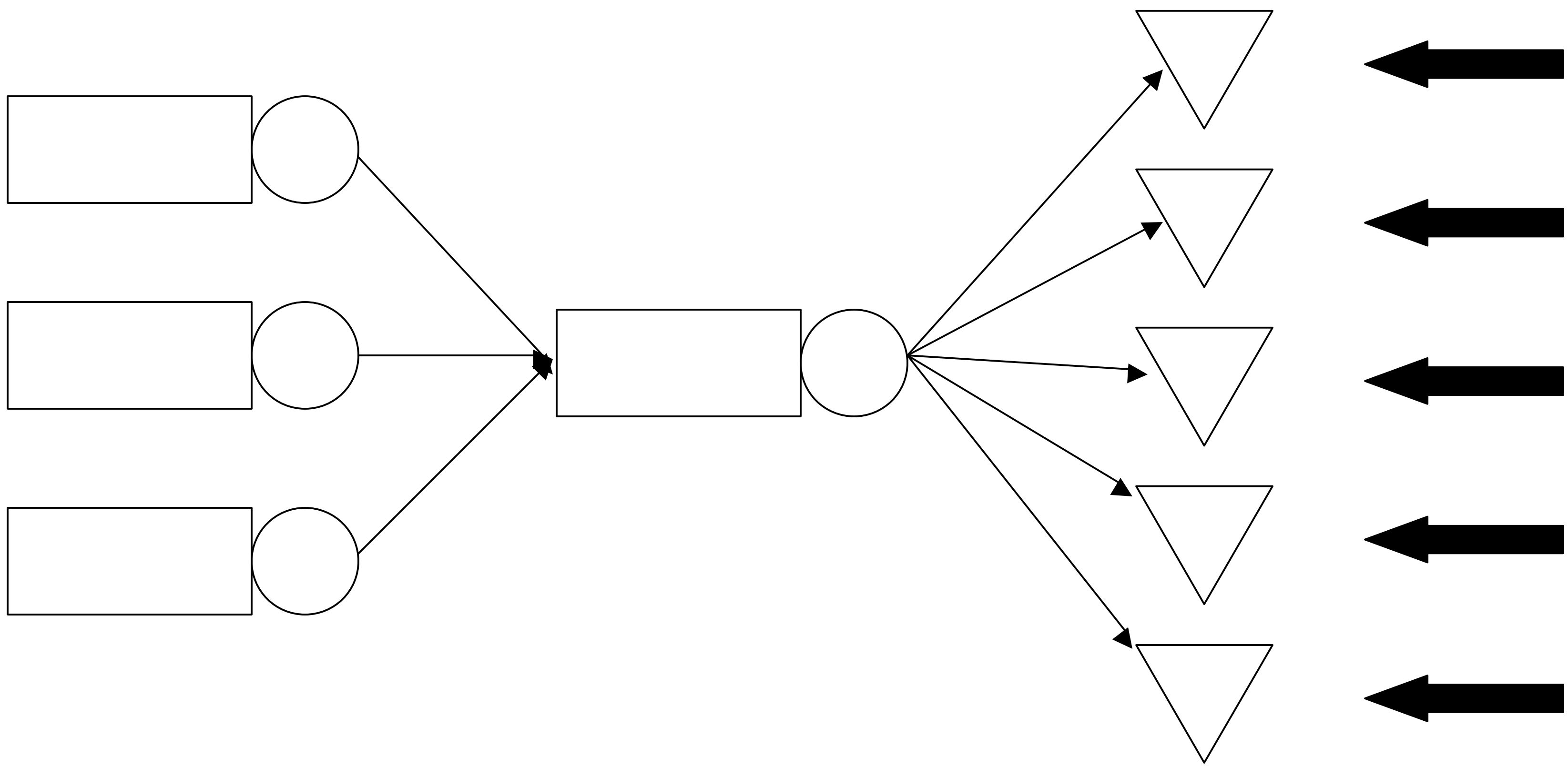
The Impact of the DTC Model

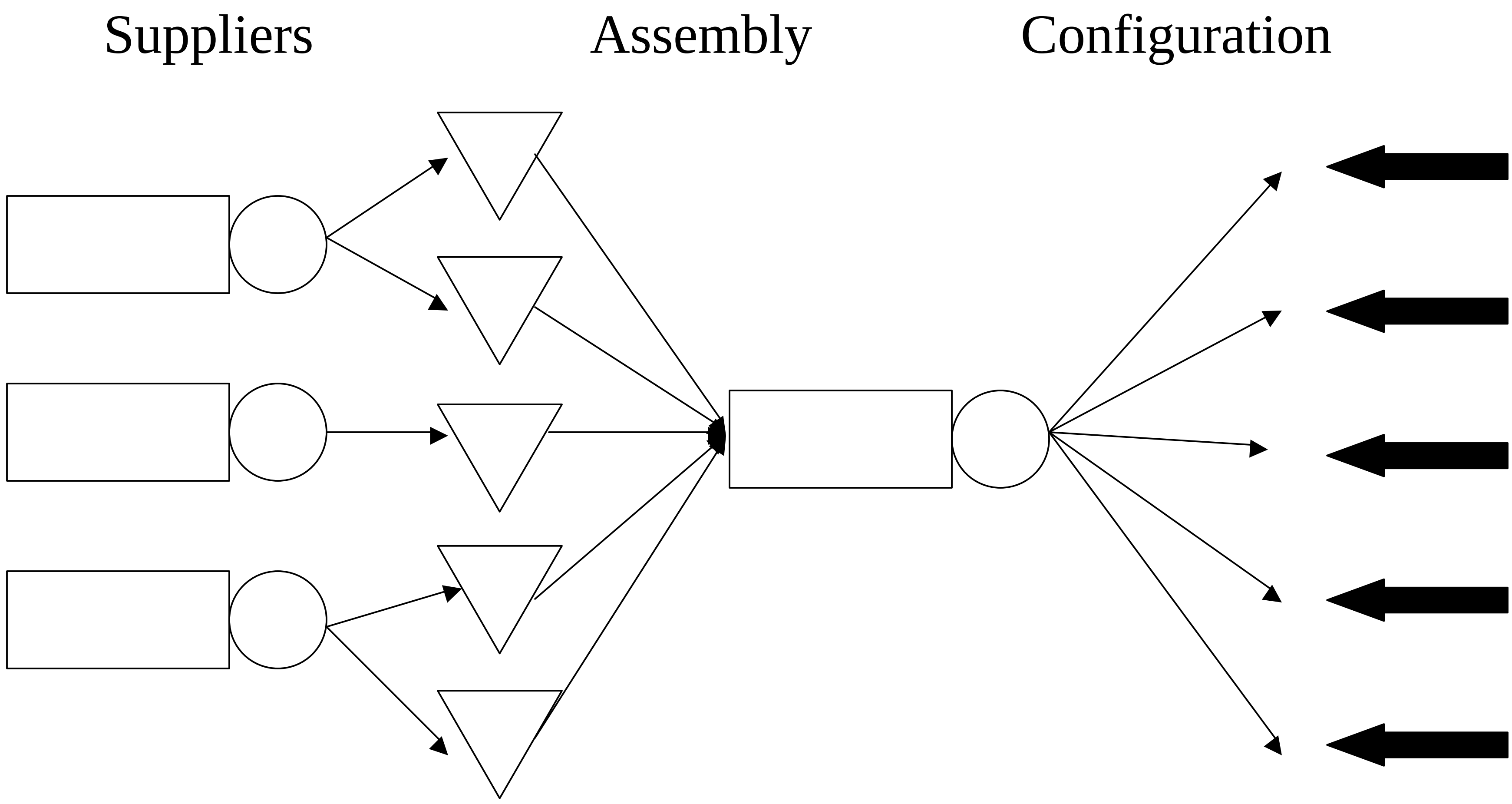
- **Valuable Information for the Manufacturer**
  - **e.g., accurate consumer demand data**
- **Product variety for the Consumer**
  - **e.g., allows for an assemble-to-order strategy**

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…

- **McGill, J. and G. van Ryzin (1999), Revenue Management: Research Overview and Prospects. *Transportation Science*, 33, 2, pp. 233-256.**

Traditional Requirements

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

FOR EXAMPLE…

- **Weatherford, L. and S. Bodily (1992), A Taxonomy and Research Overview of Perishable-Asset Revenue Management: Yield Management, Overbooking, and Pricing. *Operations Research* 40, 5, pp. 831-844.**

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…

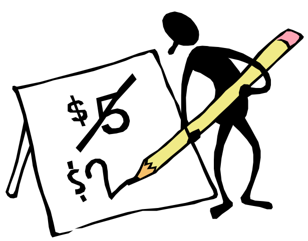
- **Federgruen, A. and A. Heching (1999), Combined Pricing and Inventory Control under Uncertainty.** ***Operations Research*****,** 47**, 3, pp. 454-475.**
  - **Stochastic demand, allows for backlogging but not lost sales**

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**

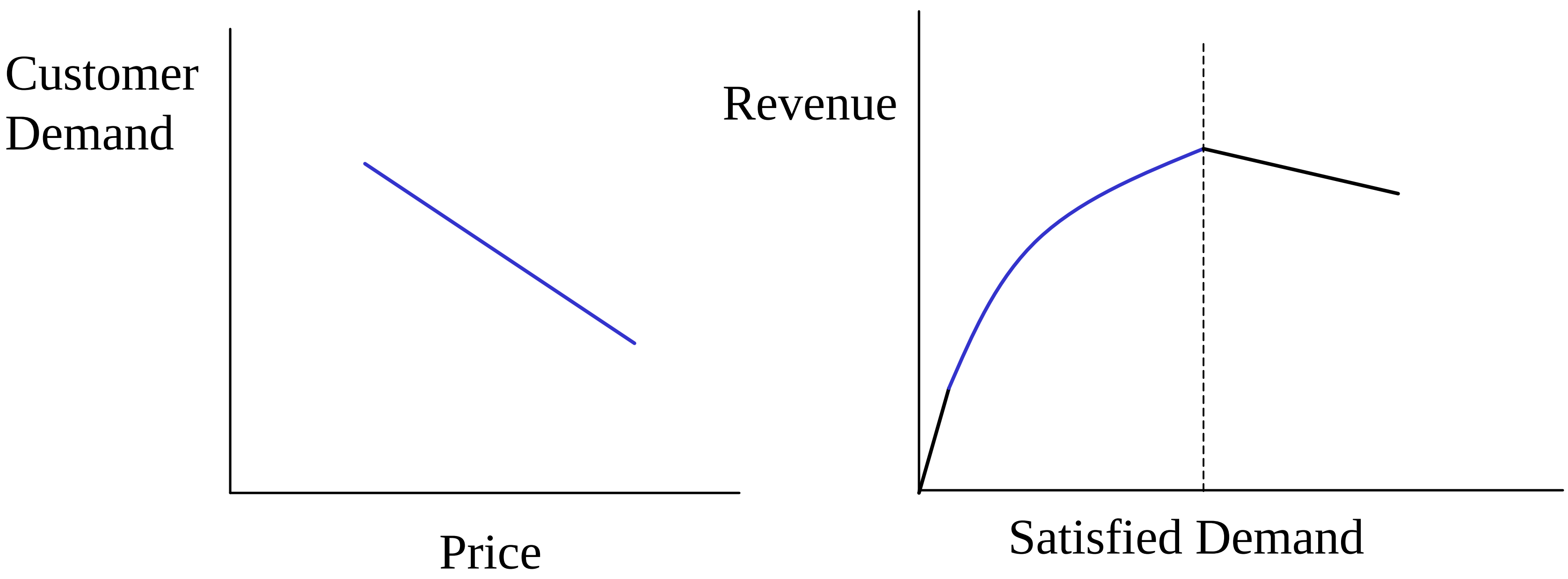


Model Assumptions

- **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 $f(D) = ?_{1 \underline{<} t \underline{<} T} (R_t(D_t) - h_t I_t - k_t X_t)$

Subject to:

(1) Beginning Inventory: $I_0 = 0$

(2) Inventory Balance: $I_t = I_{t-1} + X_t - D_t$, $t = 1,2,\ldots,T$

(3) Production Capacity: $X_t ? Q_t$, $t = 1,2,\ldots,T$

(4) Integrality: I_t, X_t, D_t, integer $? \ 0$, $t = 1,2,\ldots,T$

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:**

$$\text{Profit Potential } ? \ \frac{\text{Profit with Dynamic Prices}}{\text{Profit with Constant Price}} \ ? \ \mathbf{1}$$

- **Profit potential is the percentage of profit to be gained from dynamic prices**

Computational Details

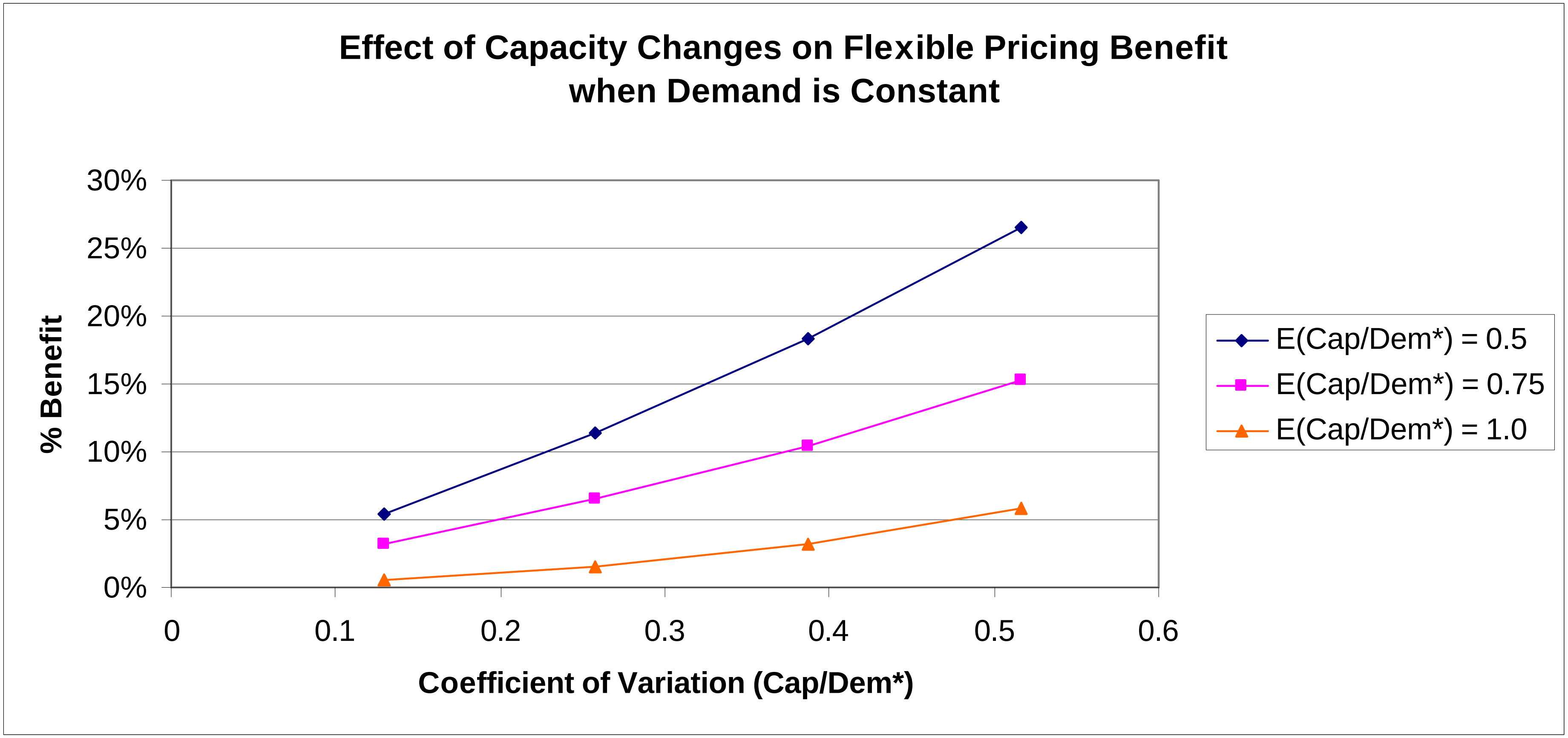
- **Demand curves obtained from an Industrial Partner**
- **Curves are aggregated over a number of products**
- **10 period problem**
- **Varied capacity, demand, or both**

Managerial Insights

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

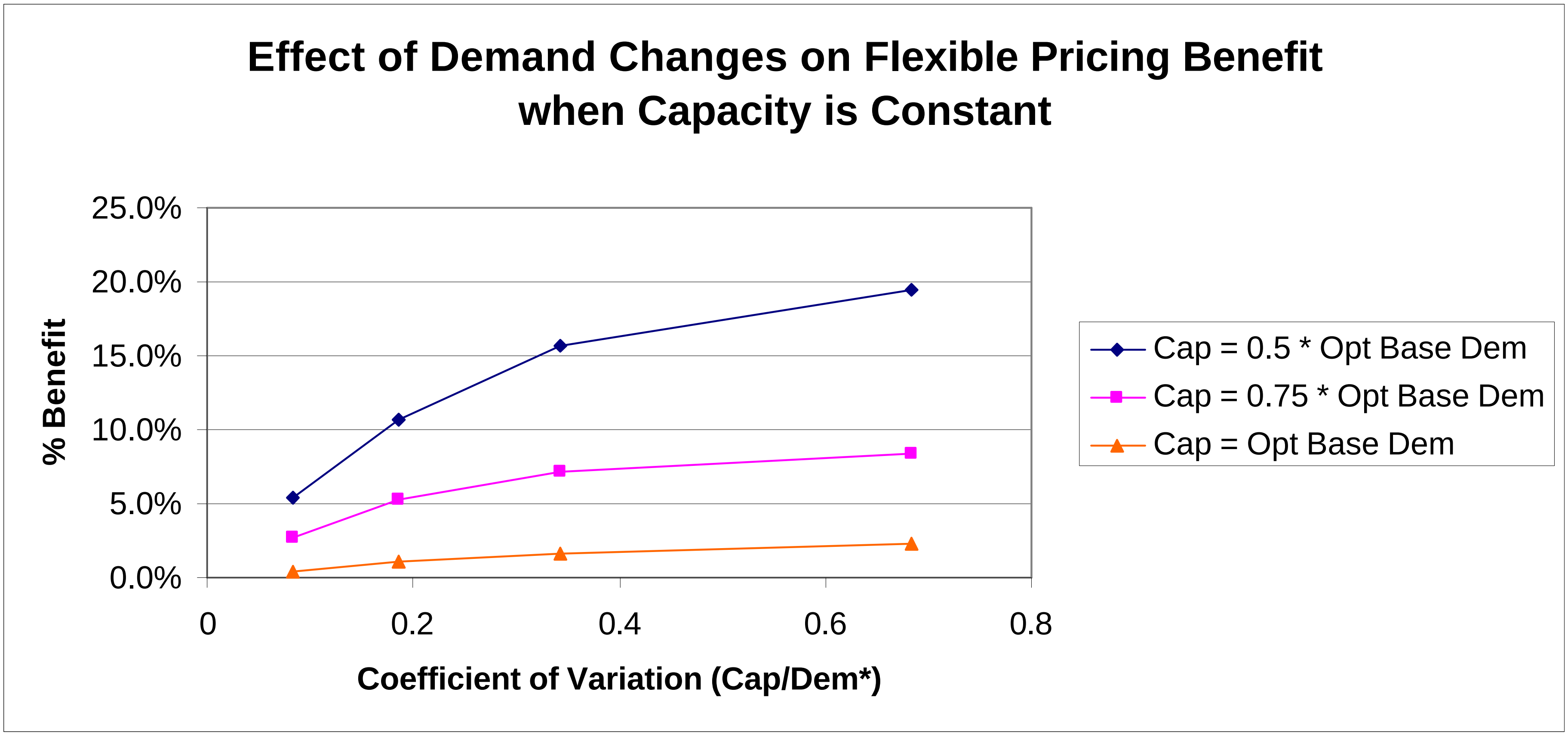
Impact of Changes in Capacity

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



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**

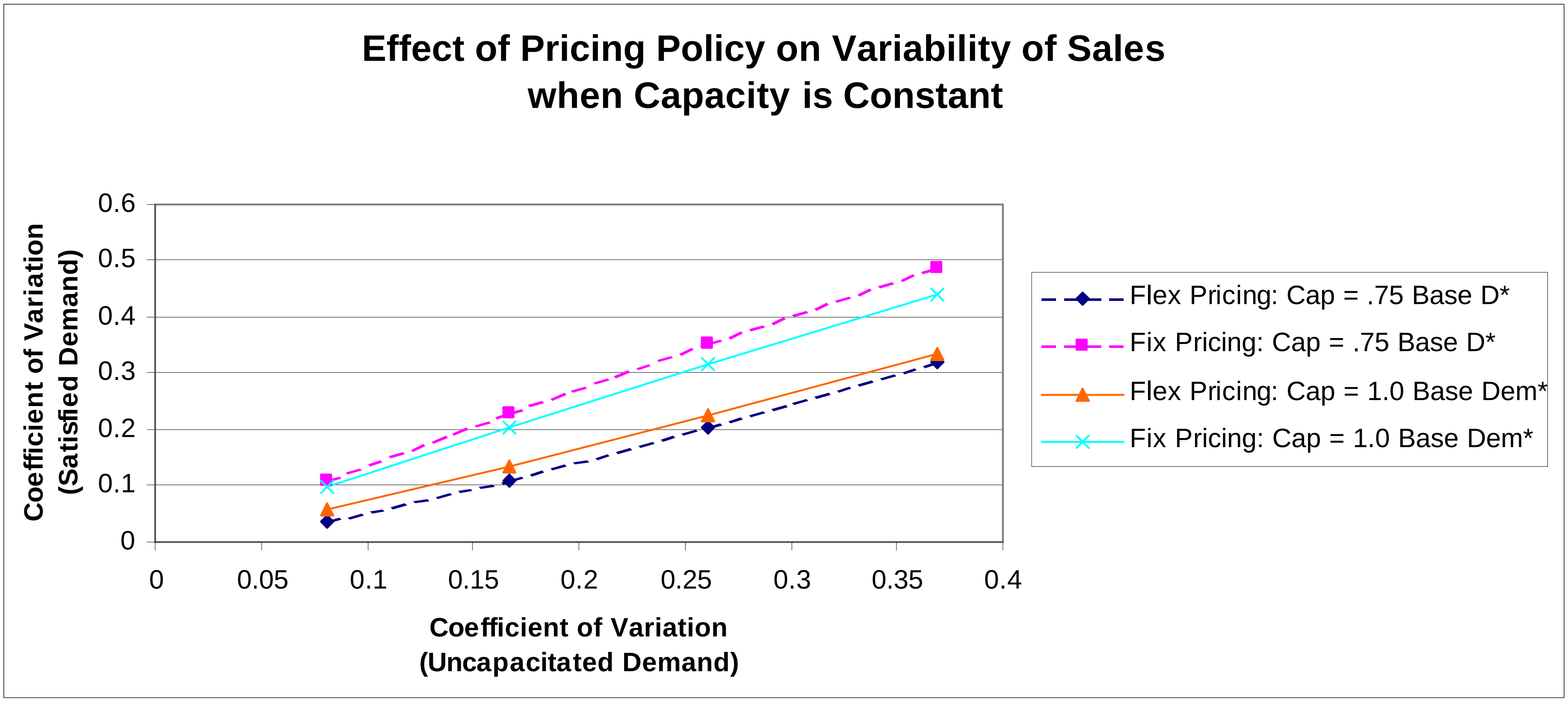


Other Potential Impacts

- **Reduction of variability in sales or production schedule**
- **Increase in average sales**
- **Reduction of inventory**
- **Reduction in average (or weighted average) price**

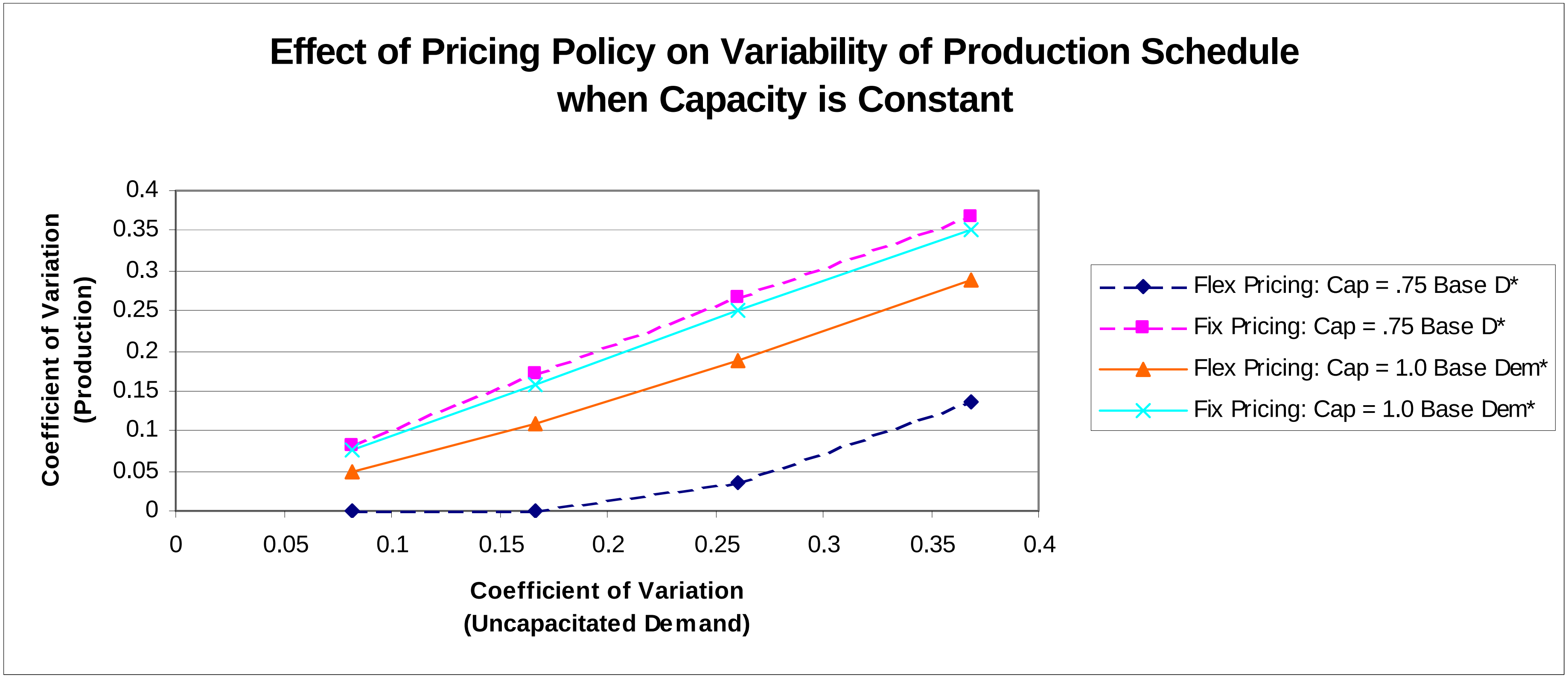
Impact on Variability of Sales

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



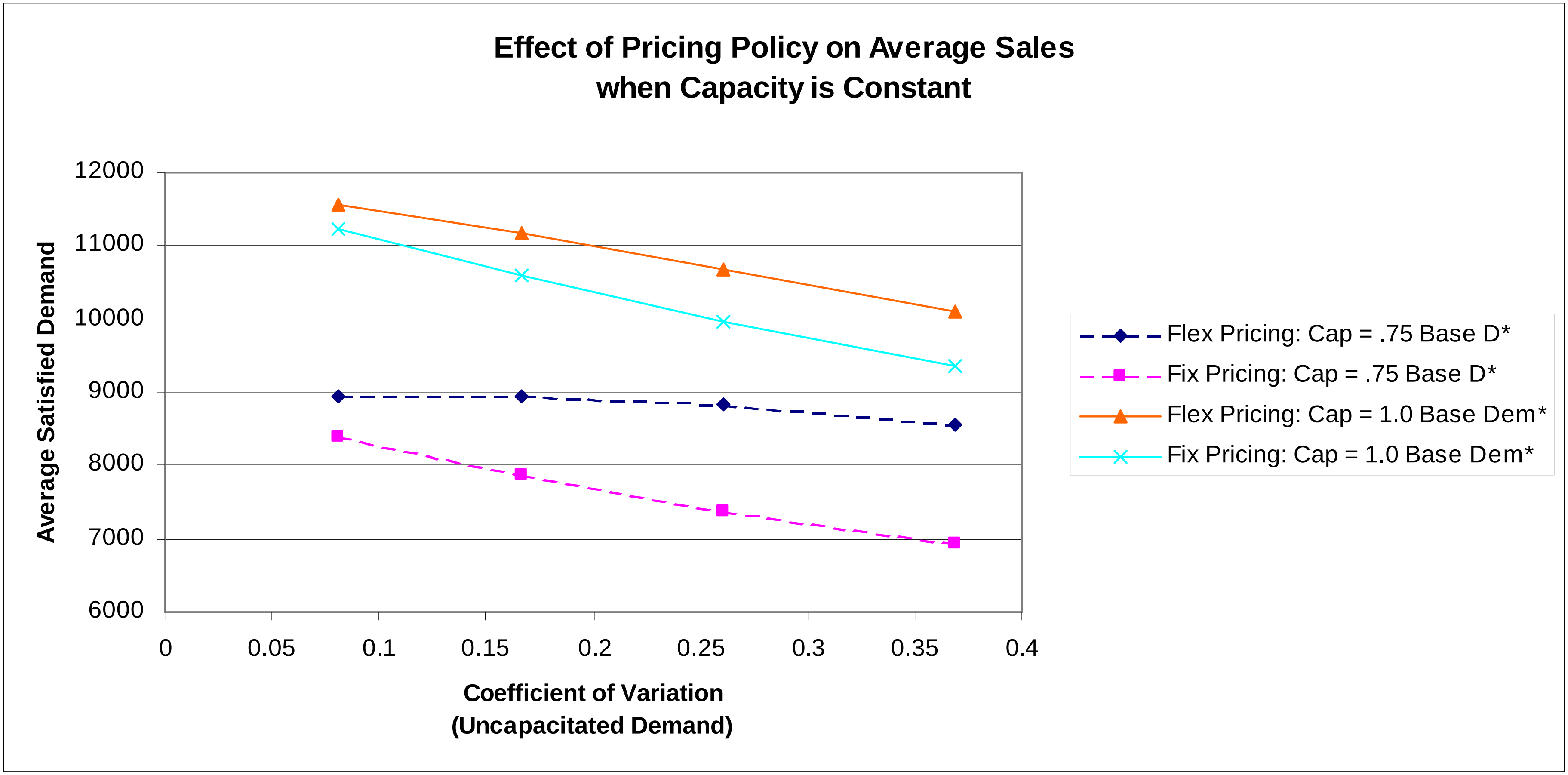
Impact on Production Schedule

- **When demand is variable and capacity is constant, flexible pricing often results in a smoother production schedule than that obtained using fixed pricing policies.**



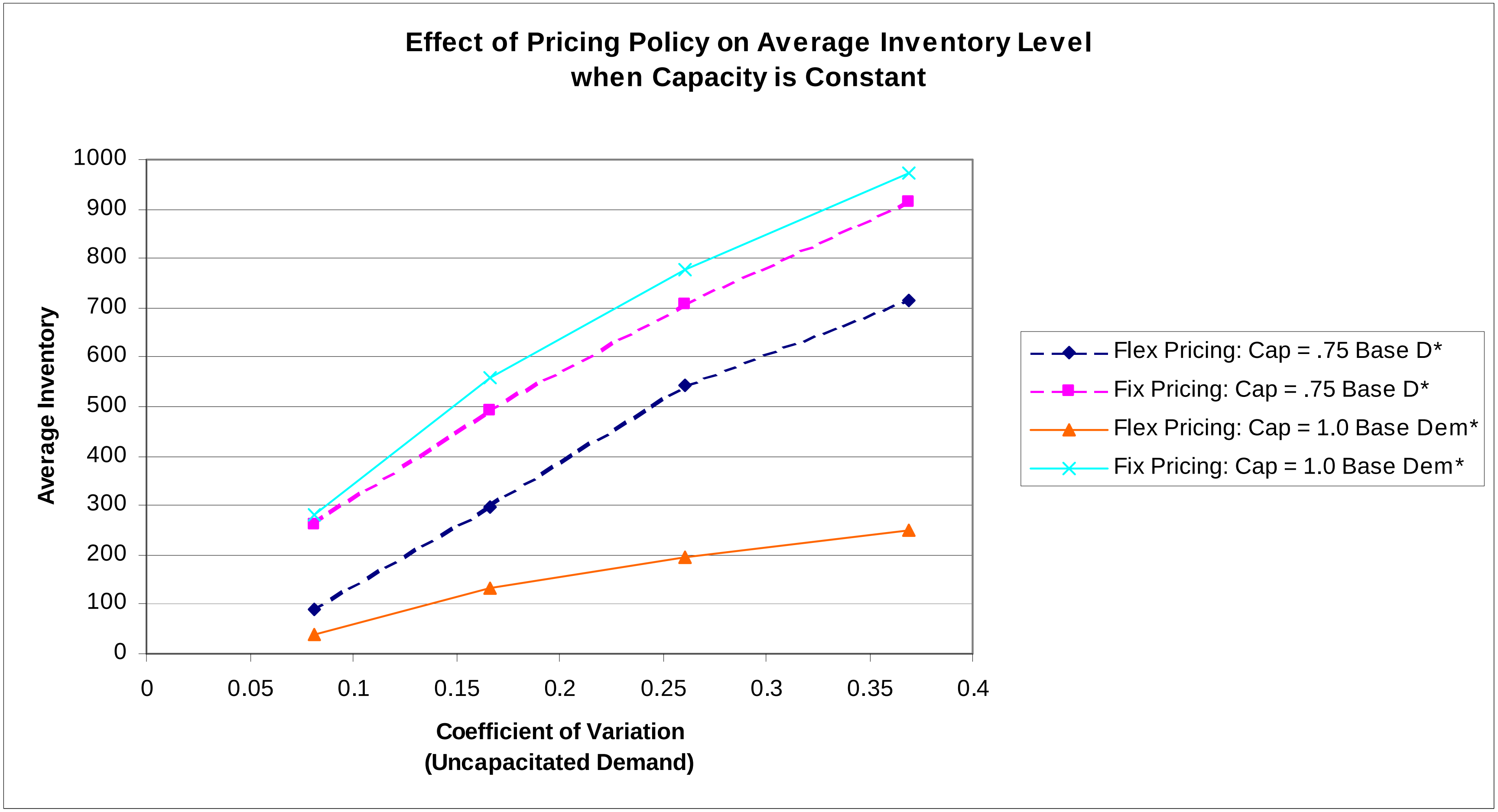
Impact on Average Sales

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



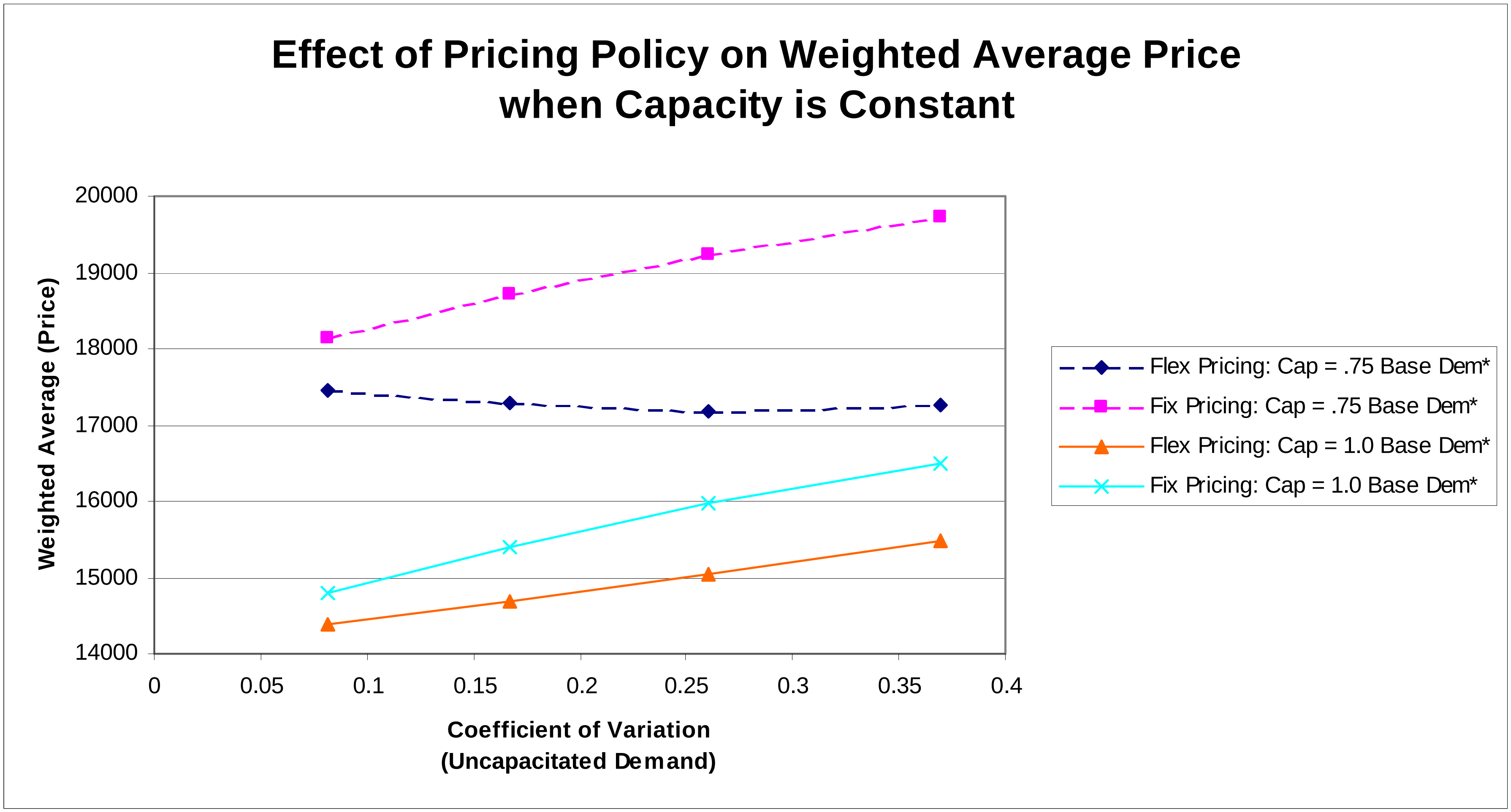
Impact on Inventory

- **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.**

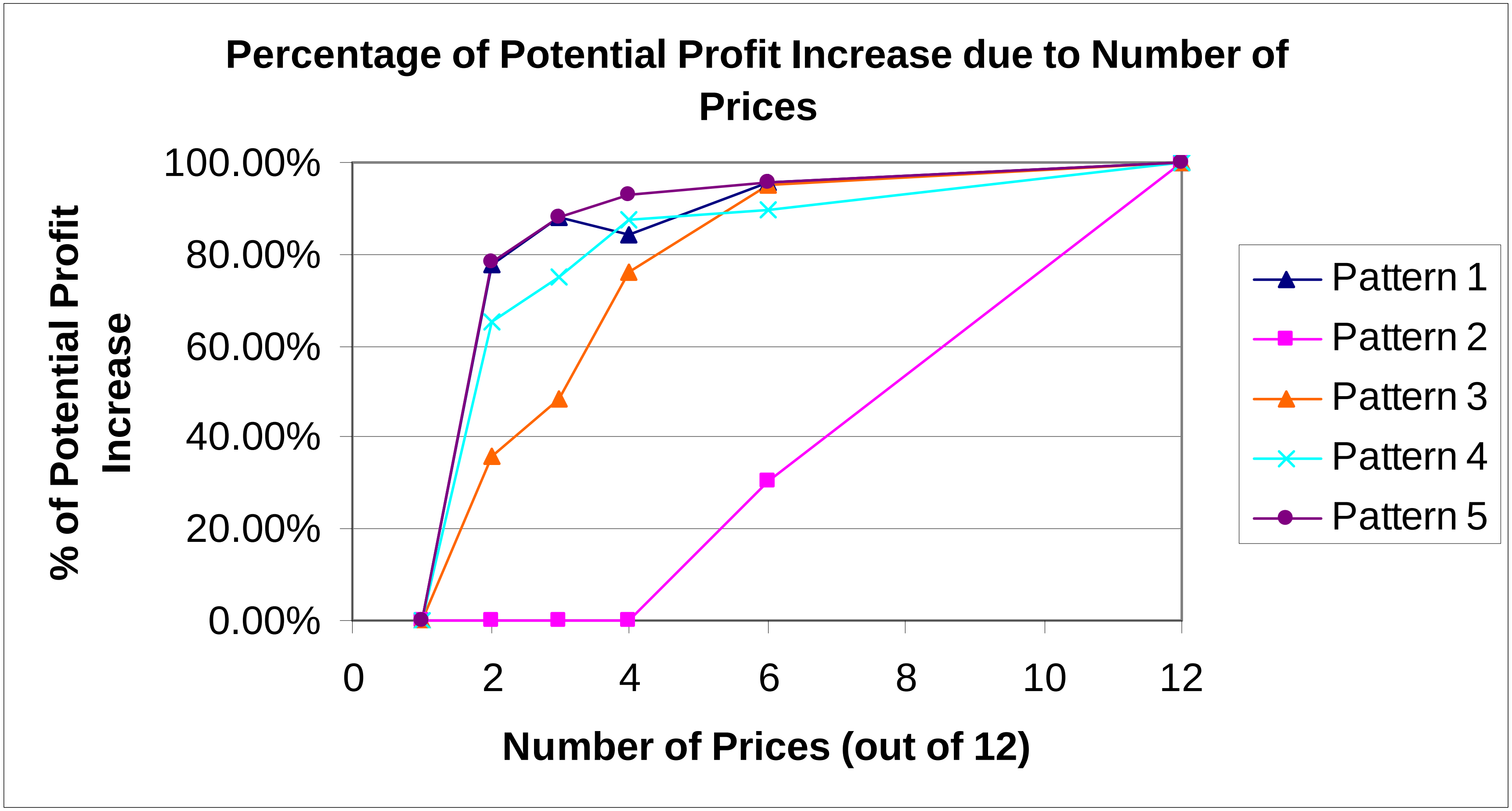


Number of Prices

- **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(Capacity) = 0.50 * Optimal Uncapacitated Demand**
  - **For all patterns shown,**
    Coefficient of Variation (Capacity) = 0.25

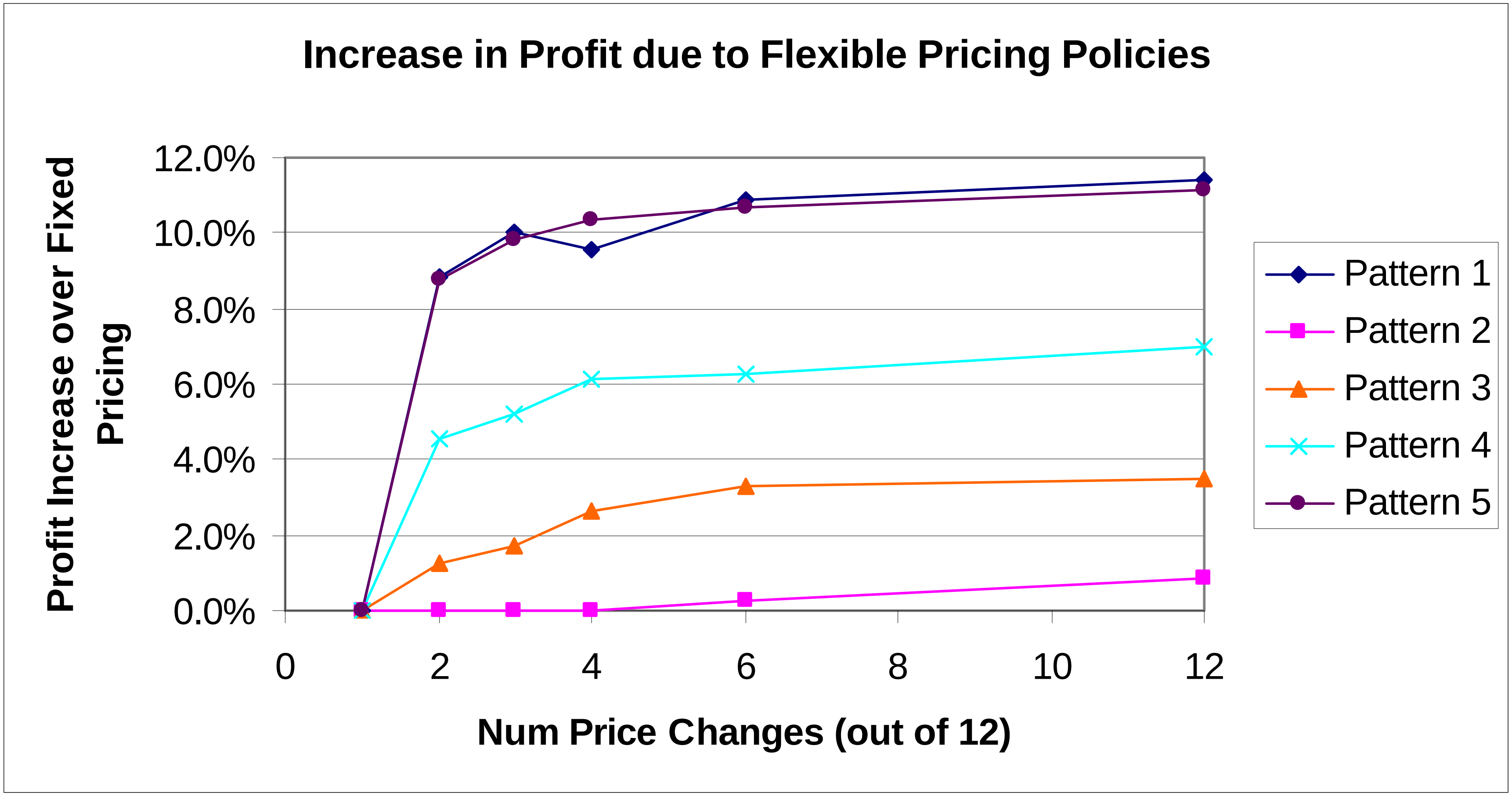
Number of Prices

- **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**



Multiple Products

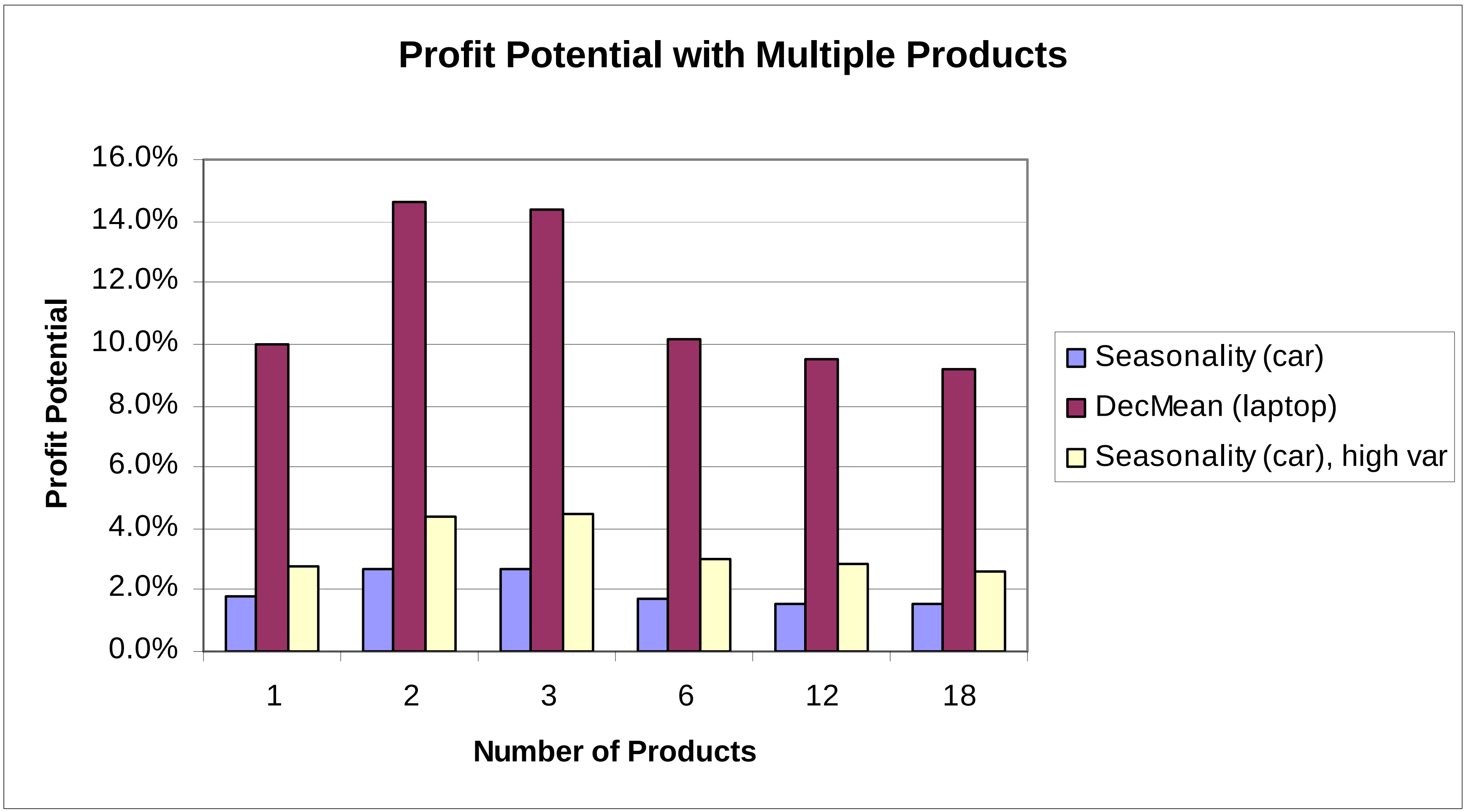
- **Deterministic multi-product model**
- **Multiple products share common production capacity**
- **Finite time horizon**
- **Each product uses the same amount of the resource per unit production**
- **Time varying, product dependent parameters**
  - **Production and inventory costs**
  - **Demand curves**

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**

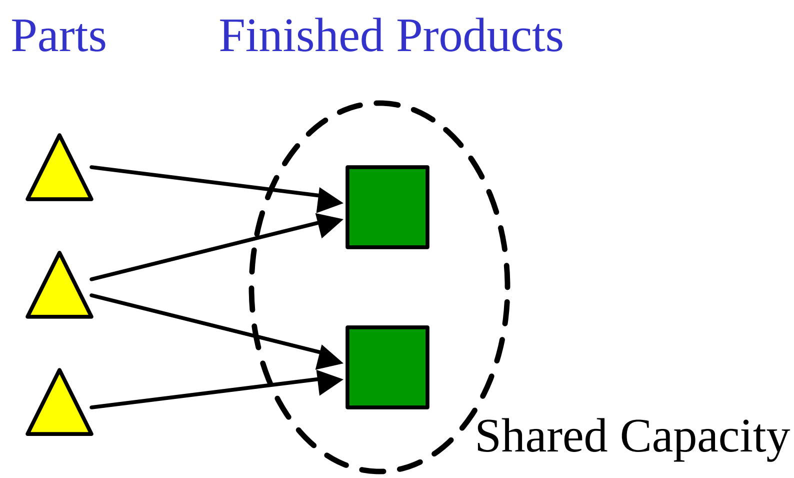
Profit Potential with Multiple Products

- **The percentage of profit potential often decreases as the number of products increases**



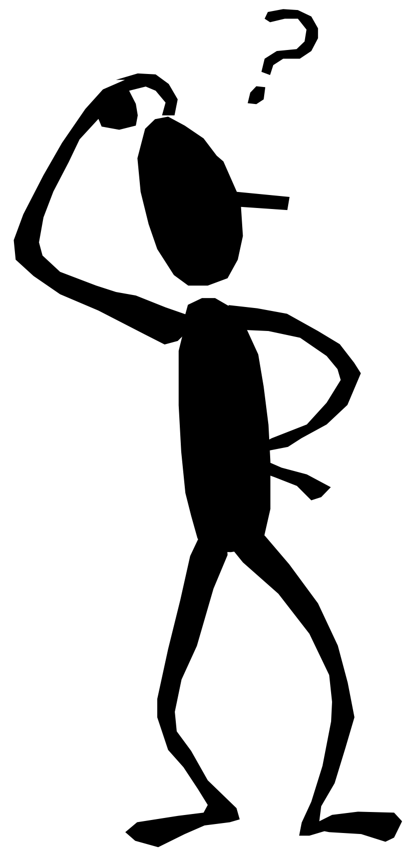
Future Research Directions

- **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, $F^j_{P,D}$, 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:**

$$R^j(X) \, ? \, \underset{P}{Max} \underset{x ? X}{?} M^j_P(x)$$

Problem Formulation

- **Problem PPE:**
  - **Max** $$F^E(X) = \sum_{1 \le j \le n} \left(R^j(X^j) - k^j X^j\right)$$
  - **Subject to** $$\sum_j X^j \le Q$$ $$X^j \text{ integer } \ge 0, \quad j = 1,2,\ldots,n$$
- **Result:**
  - **If Rj(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 $F^{E}(X) = ?_{1\underline{<j<n}} (R_j(X_j) - k_j X_j)$

Subject to:

(1) Production Capacity: $?_j X_j ? Q$,

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

Theoretical Result:

If Rj(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