Forecasting and Inventory Management of Short Life-Cycle Products

A. Kurawarwala and H. Matuso

Presented by Guillaume Roels

Operations Research Center

This summary presentation is based on: Kurawarwala, A., and H. Matsuo. "Forecasting and Inventory Management of Short Life-Cycle Products." ***Operations Research*** **44, no.1 (1996).**

Short Life-Cycle Products

(Screenshot of the home page from Dell Inc.:
http://www.dell.com – last accessed June 29, 2004.)

Short Life-Cycles

- Causes
  - Fast Changing Consumer Preferences
  - Rapid Rate of Innovation
- Procurement Issues
  - Forecasting with no historical data
  - Long lead-times
  - Perishable Inventory
- Introduction Time

Outline

- Forecasting new product introduction
- Procurement issues
  - Model Formulation
  - Optimal Control Solution
  - Discussion
- Case Study

New Product Introduction

- No past sales data
  - Time-series useless
- But multiple-product environment
  - Some level of predictability
  - Independence (serve different needs)

Diffusion Theory

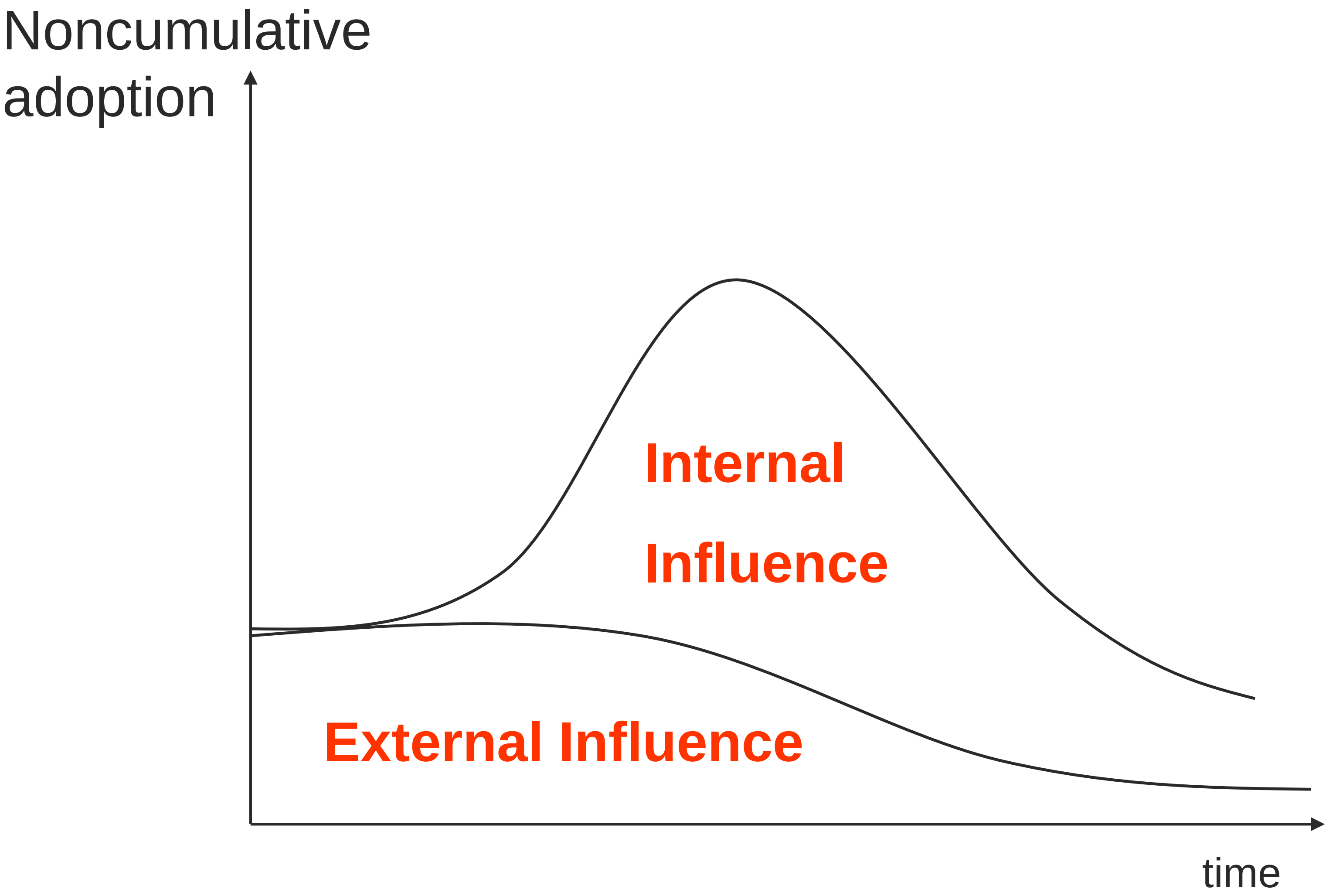
- "[Innovation] is communicated through certain channels over time among members of a social system"

  - Rogers, Everett. *Diffusion of Innovations*. Simon & Schuster, 1982.

    ISBN: 0-02-926650-5.

- Marketing application:
  - Mass Media
  - Word of Mouth

The Bass Model



The Bass Model: Assumptions

- Market potential remains consistent over time
- Independence of other innovations
- Product and Market characteristics do not influence diffusion patterns

- Competition?

The Bass Model: Sales Evolution

Current Sales

Remaining market potential

$$\frac{dN_t}{dt} = \left(p + q\frac{N_t}{m} \right)(m - N_t)\,\alpha_t$$

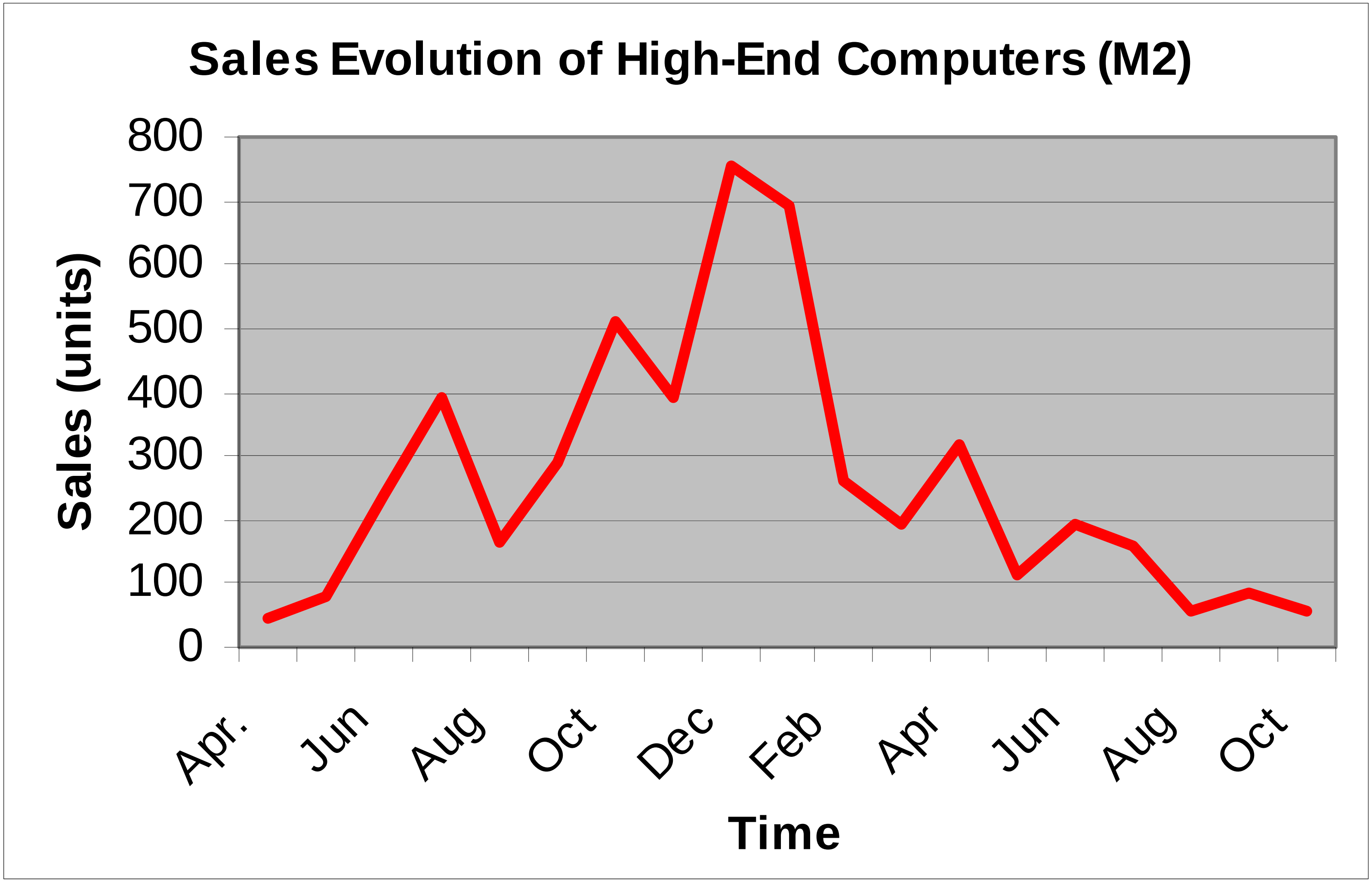
Mass Media **Word-of-Mouth** **Seasonality Coeff.**

Many applications at Eastman Kodak, IBM, Sears, AT&T…

Case-Study: PC Manufacturer

- Monopolist (strongly differentiated)
- Life-cycle: 1-2 years
- Peak sales timing is predictable T^*
  - Christmas peak
- Typical seasonal variation in demand α_t
  - End-of-quarter effect
- Information on total life-cycle sales m

Numerical Example (M2)

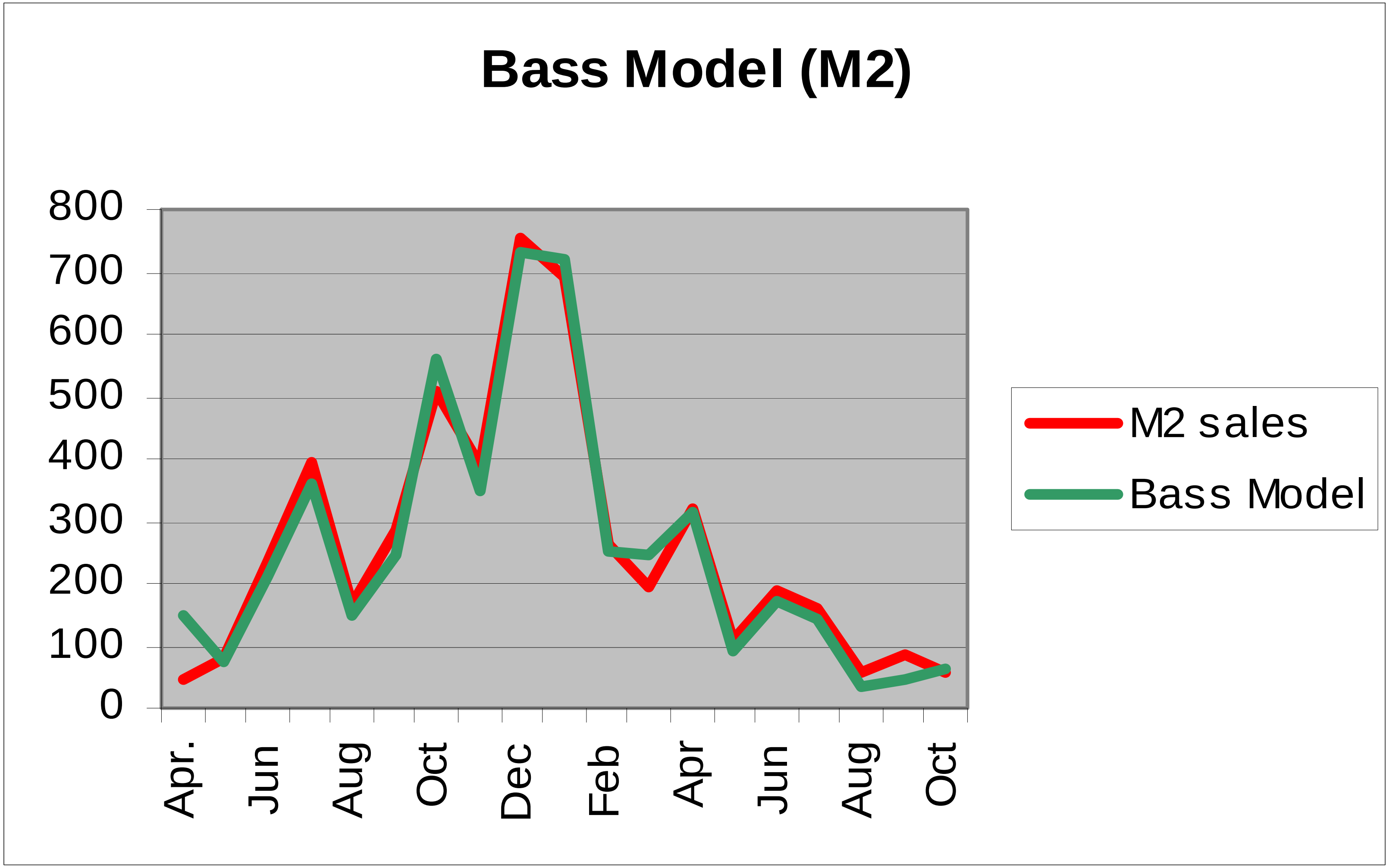


- Data source: Kurawarwala, A., and H. Matsuo. "Forecasting and Inventory Management of Short Life-Cycle Products." *Operations Research* 44, no.1 (1996).

Parameters Estimation

- Estimation of p, q, m, α_t
- Nonlinear Least Squares
- R-squared above .9

Numerical Example (M2)



- Data source: Kurawarwala, A., and H. Matsuo. "Forecasting and Inventory Management of Short Life-Cycle Products." ***Operations Research*** **44, no.1 (1996).**

Outline

- Forecasting new product introduction
- Procurement issues
  - Model Formulation
  - Optimal Control Solution
  - Discussion
- Case Study

Procurement Issues

- Need to place orders in advance
  - Long lead-times
  - Cost advantage, timely delivery
- Inventory/Backorder costs
- Schedule the procurement to meet the (random) demand, evolving according to Bass’ Model

Model Description

- State: Cumulative Procurement V_t
- Control: Instantaneous Procurement u_t
- Transition function

$$V_t = u_t \qquad V_0 = 0$$

- Finite-Horizon T Optimization
- Discounted cost at rate r

Cost Parameters

- Instantaneous trade-off between
  - Inventory holding costs $h(V_t - N_t)^+$
  - Backorder costs $p(N_t - V_t)^+$

$$P_t(V_t - N_t)$$

- Terminal trade-off between
  - Salvage inventory loss $l(V_T - N_T)^+$
  - Shortage costs $s(N_T - V_T)^+$

$$Q_T(N_T - V_T)$$

Optimal Control Model

$$\min_{u} J = \int_0^T e^{-rt} \int_{N_t} P_t (V_t - N_t) \psi(N_t) dN_t dt + e^{-rT} \int_{N_T} Q_T (V_T - N_T) \psi(N_T) dN_T$$

$$\text{such that: } \dot{V}_t = u_t \text{ and } u_t \geq 0$$

- Timely delivery of customer orders?
- What if we do not want to serve all the demand?
- Why no chance constraints instead?

Hamiltonian function

Define

$$\lambda_t = \nabla_V J^*(t, V_t^*)$$

Hamiltonian

$$H(\mathrm{V}, u, \lambda) = P_t(\mathrm{V}, u) + \lambda u$$

Pontryagin Minimum Principle

1. Adjoint Equation

$$\lambda_t = -\frac{\partial H(V_t^*, u_t^*, \lambda_t)}{\partial V_t}$$

2. Boundary Condition

$$\lambda_T = \frac{d}{dV_T}\left[\int_{N_T} Q_T(N_T - V_T)\psi_T(N_T)dN_T\right]$$

3. Optimality of Control

$$u_t^* = \arg\min_{u \geq 0} H(V_t^*, u, \lambda_t)$$

Case I: $\frac{b}{b+h} \le \frac{s}{s+l}$

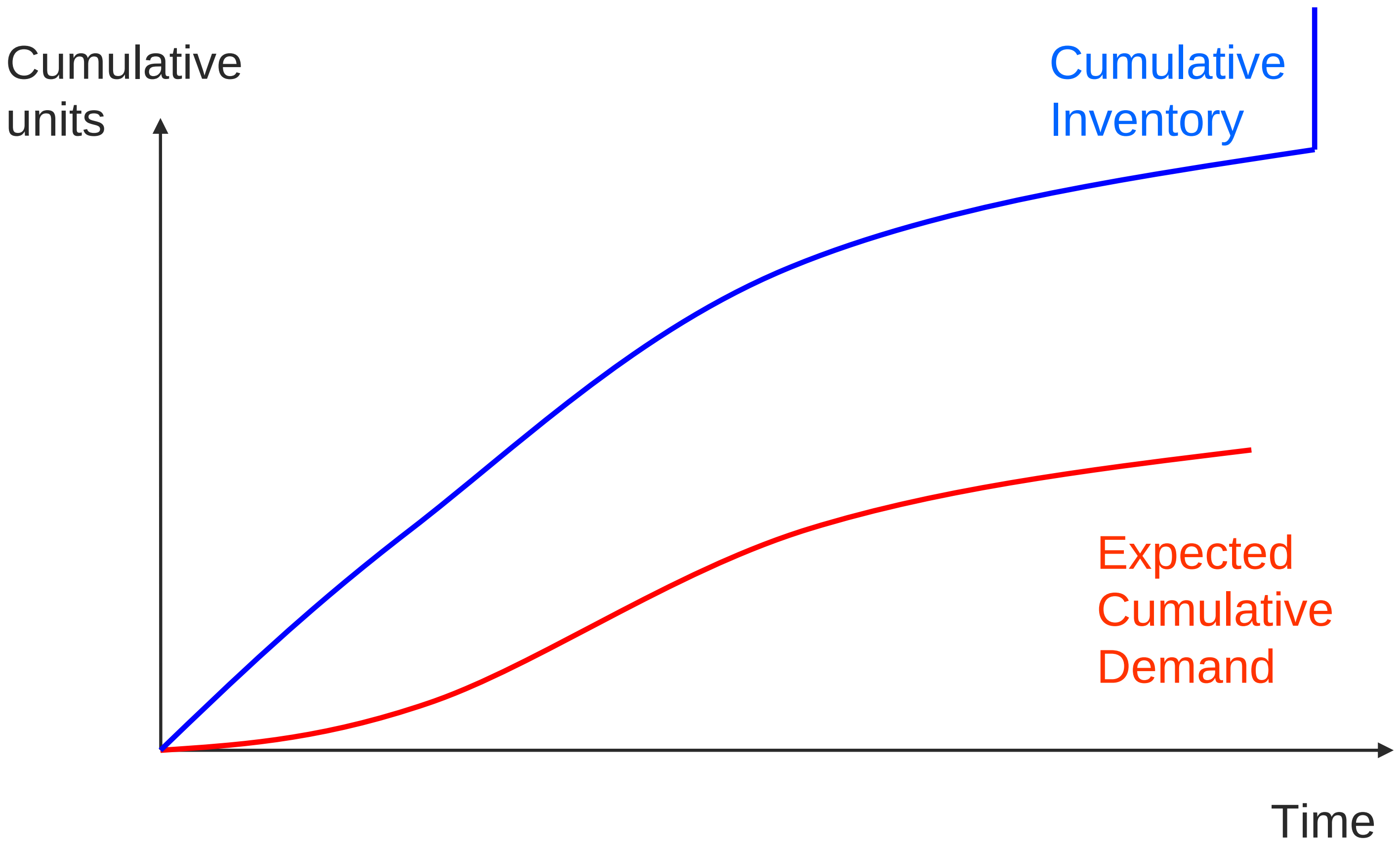
- Maintain the same service level

$$\Psi_t(V_t) = \frac{b}{b+h}$$

- Impulse at the end of horizon

$$\Psi_T(V_T) = \frac{s}{s+l}$$

Procurement Policy



Case II: $\frac{b}{b+h} > \frac{s}{s+l}$

- For $0 \le t \le \hat{t}$, keep the same service level

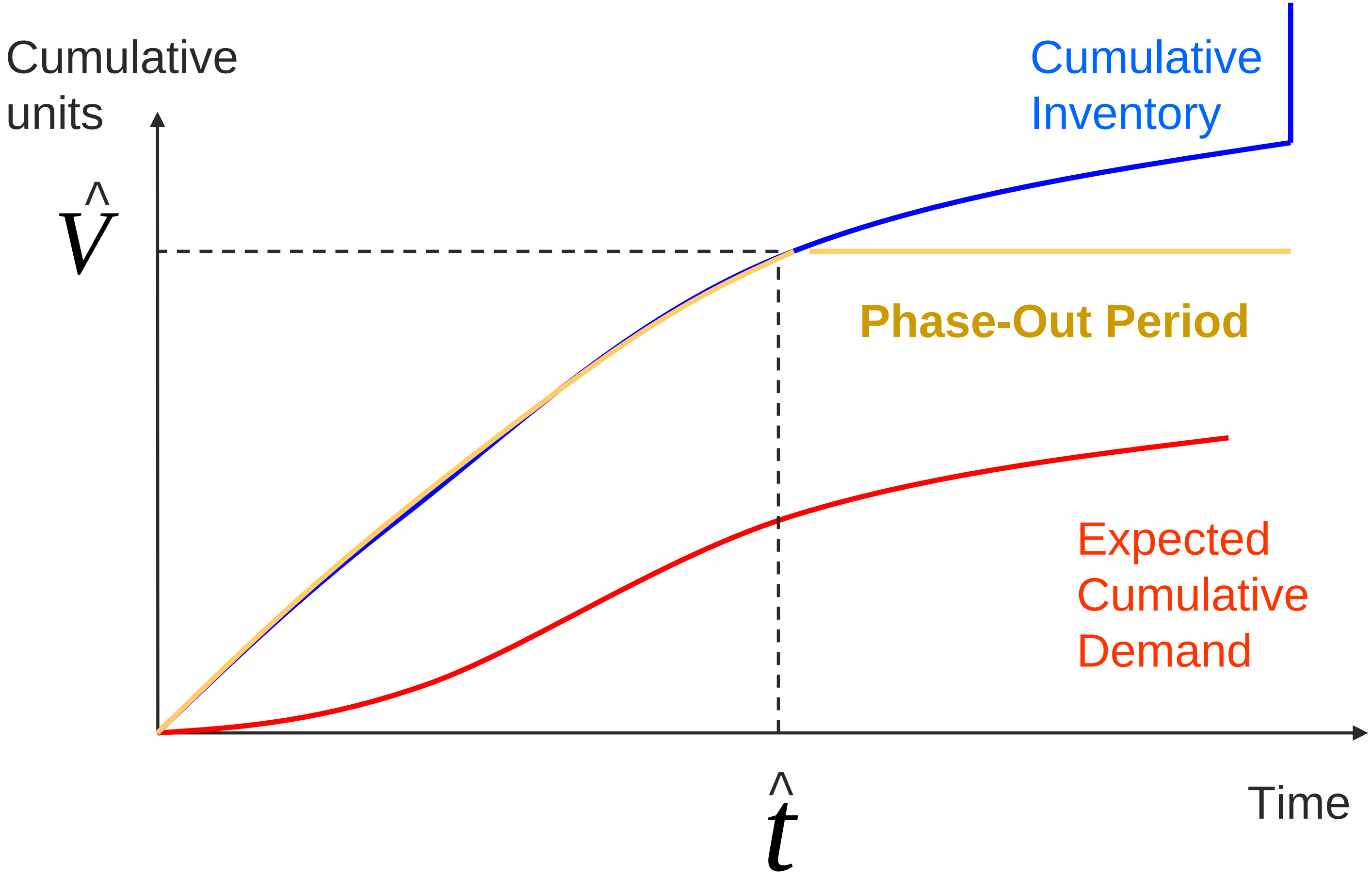
$$\Psi_t(V_t) = \frac{b}{b+h}$$

- For $\hat{t} \le t \le T$,
  - Do not purchase anymore
  - Decrease gradually the service level down to $\frac{s}{s+l}$

Desired/Effective Service Level

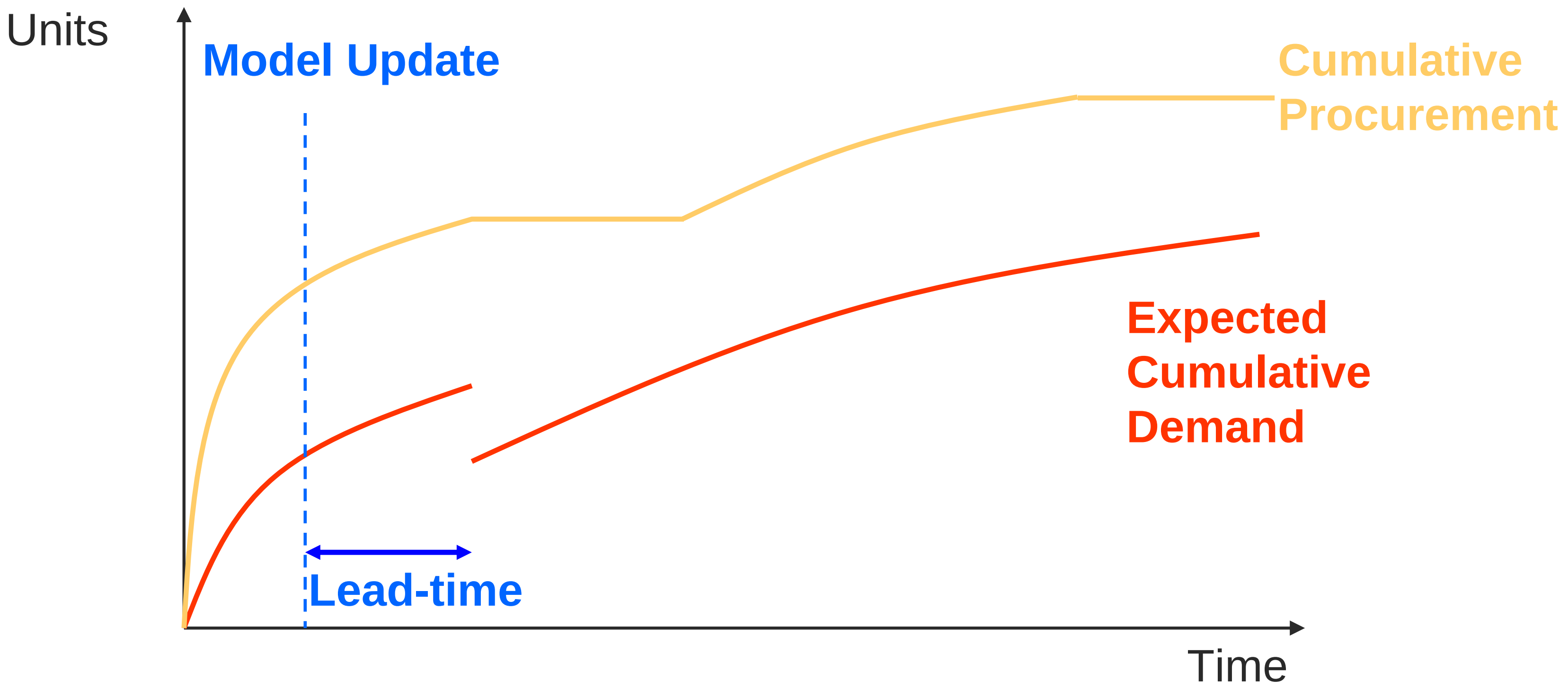
- In practice, backorder costs are hard to evaluate…
- Instead, evaluate the desired SL $\frac{b}{b+h}$
- Terminal service level: switch the customers to an upgraded model
  - Loss of goodwill
  - Higher cost
- Case II is typical in practice
  - Terminal SL < Lifetime SL

Procurement Policy



Revised Multiple-Period Implementation

- Update the estimation of p, q, m



Time-varying costs

- Time-varying costs
  - Decreasing purchase costs
  - 30% in less than 6 months

- Underage Costs
  - Backorder penalty b
  - Save the cost decrease c_t
  - Save from the cost of capital $-rc_t$
    - Decreasing over time
    - Hence, increasing service level

Outline

- Forecasting new product introduction
- Procurement issues
  - Model Formulation
  - Optimal Control Solution
  - Discussion
- Case Study

PC Manufacturer: New Product Introduction

1. When should it be launched?

   May or August?

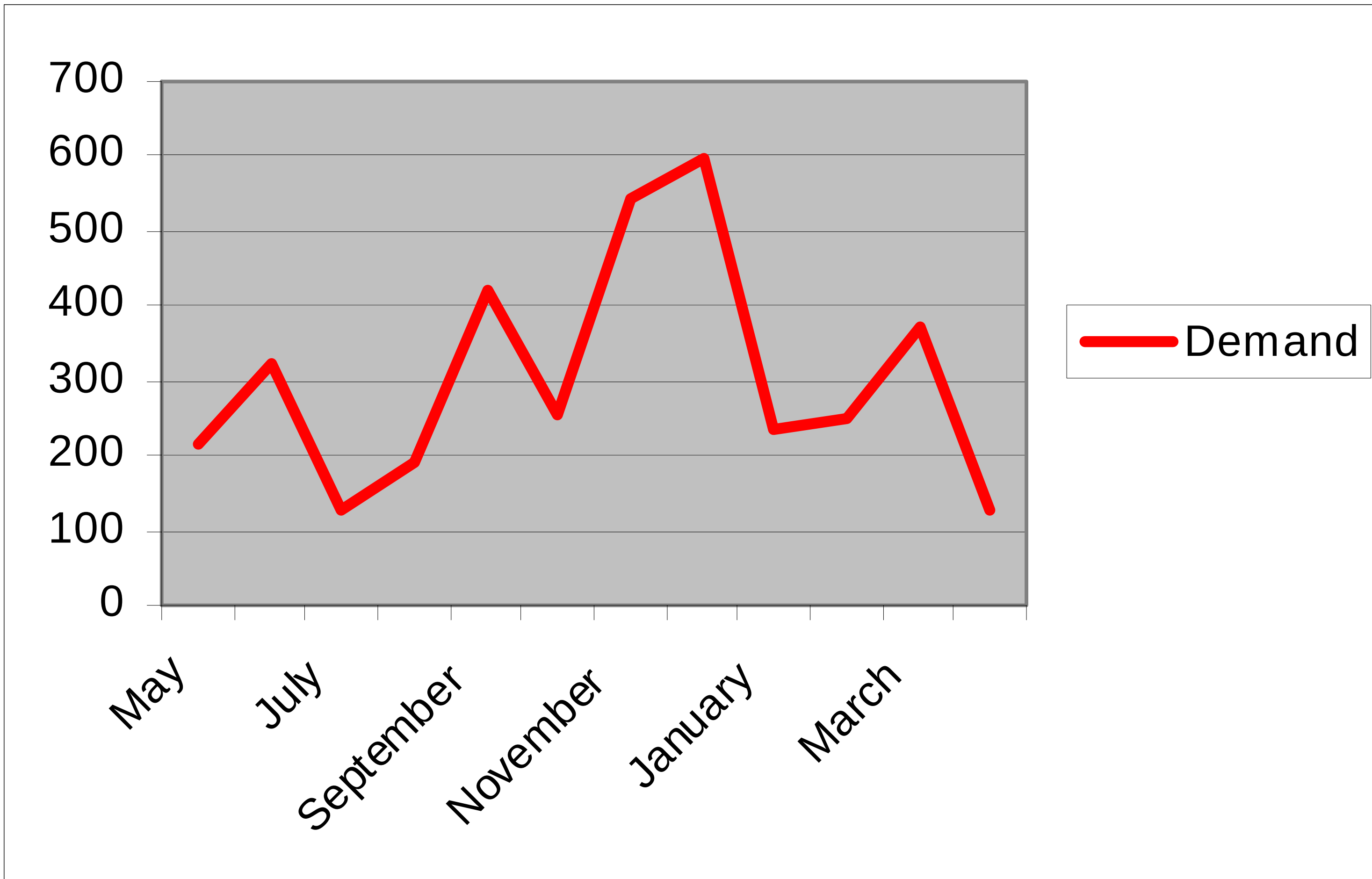
2. How much and when should we order?

   Sensitivity Analysis on the Lifetime Service Level

Parameters Estimation

- Randomness summarized in m, p, q
- Estimation of the size of the market m
- Estimation of the peak time T^*
  - Relation between p and q
- Past Product Introductions (M1-M4)
  - Estimation of the distribution of q
  - Sensitivity Analysis on variance

Demand Estimation (May)



- Data source: Kurawarwala, A., and H. Matsuo. "Forecasting and Inventory Management of Short Life-Cycle Products." *Operations Research* 44, no.1 (1996).

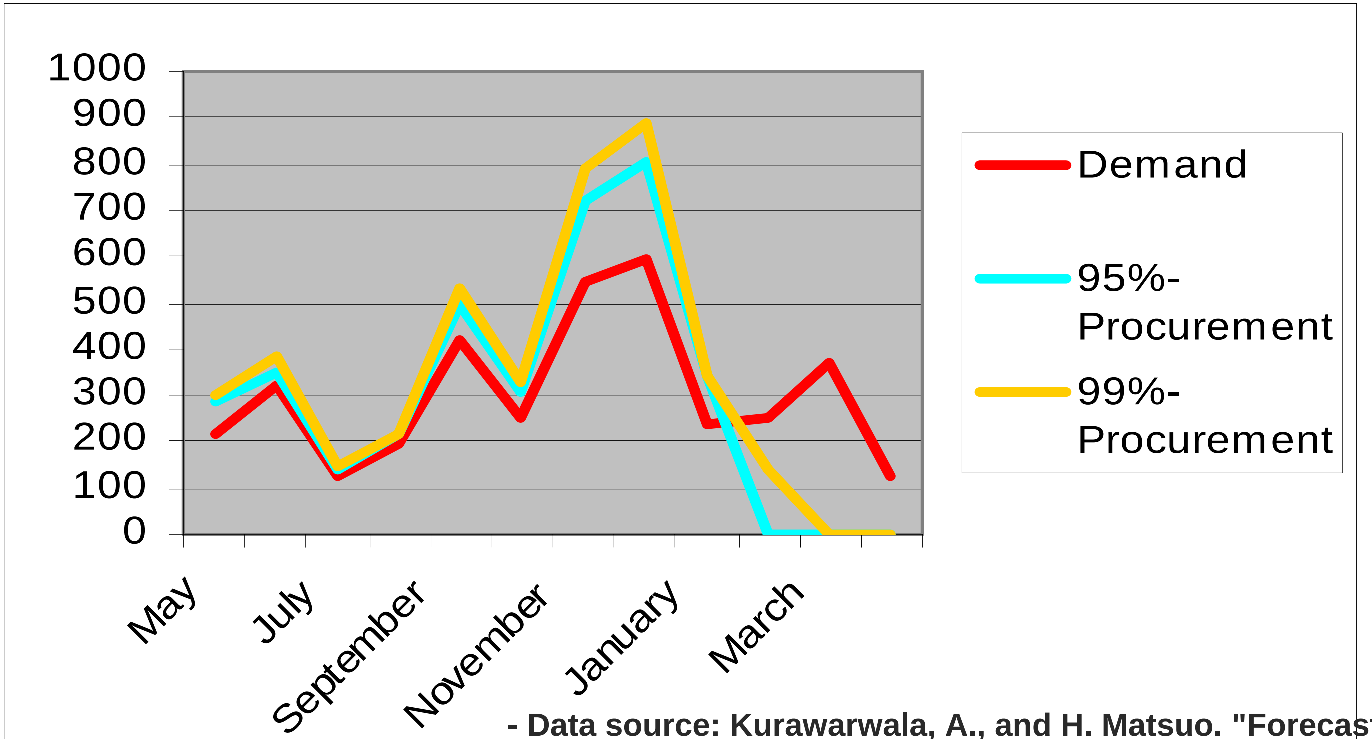
Service Levels

- Lifetime service level
  - 95% vs. 99%?
- Terminal service level: 33%

- Hence, Case II, i.e.
  - Purchase period
  - Phase-out period

Procurement Decisions (May)

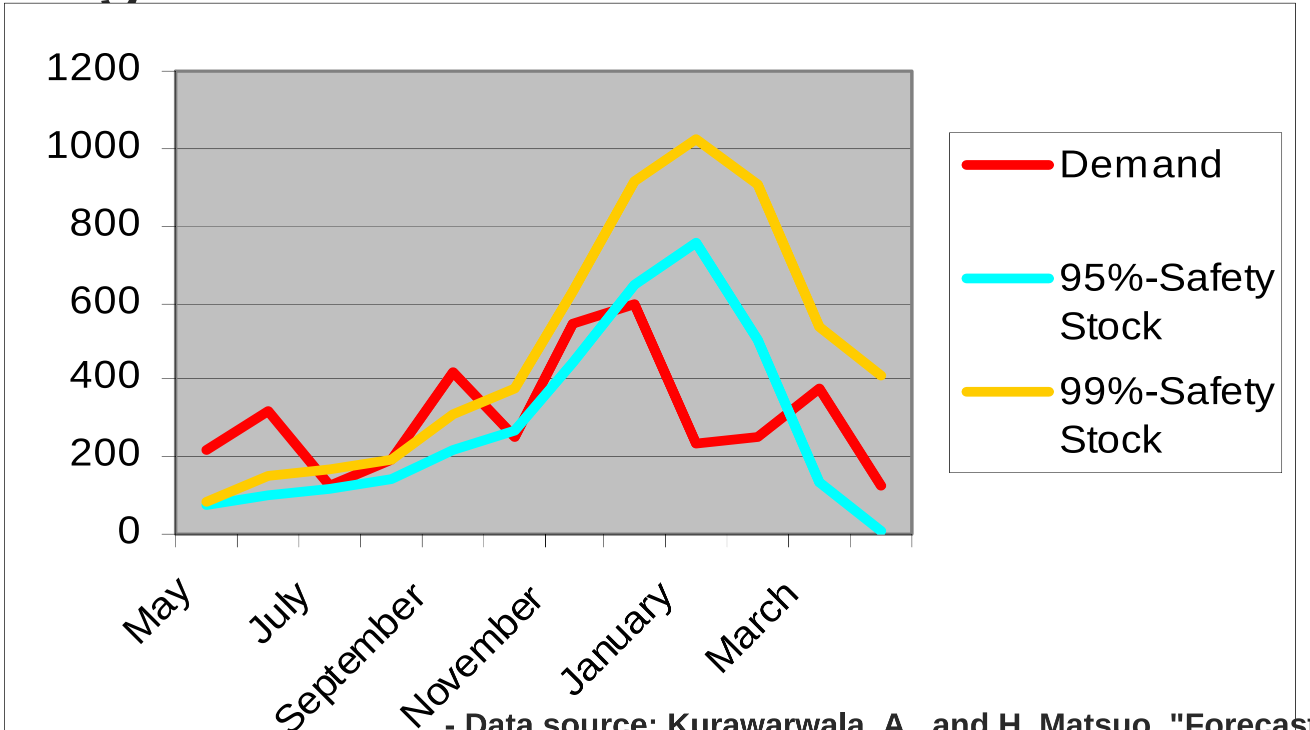
- Longer Phase-Out with low SL
- Reduce Procurement after peak season



- Data source: Kurawarwala, A., and H. Matsuo. "Forecasting and Inventory Management of Short Life-Cycle Products." *Operations Research* 44, no.1 (1996).

Safety Stock Evolution

- Deplete SS in the last quarter
- Avg SS=5 or 8 weeks of demand



- Data source: Kurawarwala, A., and H. Matsuo. "Forecasting and Inventory Management of Short Life-Cycle Products." ***Operations Research*** **44, no.1 (1996).**

Additional Insights

- Launching the product early requires less inventories
- With decreasing costs,
  - Reduced service levels (but increasing over time); hence, less inventory
  - Delayed procurement cutoff time

Conclusions

- Application-driven research
  - Adapt Bass' Model
  - Optimal Control
- Additional issues:
  - Effectiveness of Bass' Model?
  - Backorder costs vs. Service Level?
  - Terminal shortage penalty vs. Stopping time?

Thank you

Questions?