Responding to Shipment Delays:
The Roles of Operational Flexibility & Lead-time Visibility

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Shipment Delays

- Complex Logistics of Global Sourcing

- Port Congestion due to High Trade Volumes

- New Security Measures for Custom Clearance

- External Causes (Weather, Labor Strikes etc)

How do Firms Respond?

- Higher Inventory Levels

- Expediting Shipments

- Back-up Sourcing

Role of Information Technology

Literature (Supply Uncertainty)

- ## Song and Zipkin (1996), Chen and Yu (2005)
  - Stochastic Lead-time, Information Sharing

- ## Anupindi and Akella (1994)
  - Yield and Lead-time uncertainty, Dual Sourcing

- ## Tomlin (2005), Tomlin and Snyder (2006)
  - Mitigation & Contingency Strategies for Supply Chain Disruptions

Basic Model

Supplier — Potential Delay — Firm Location
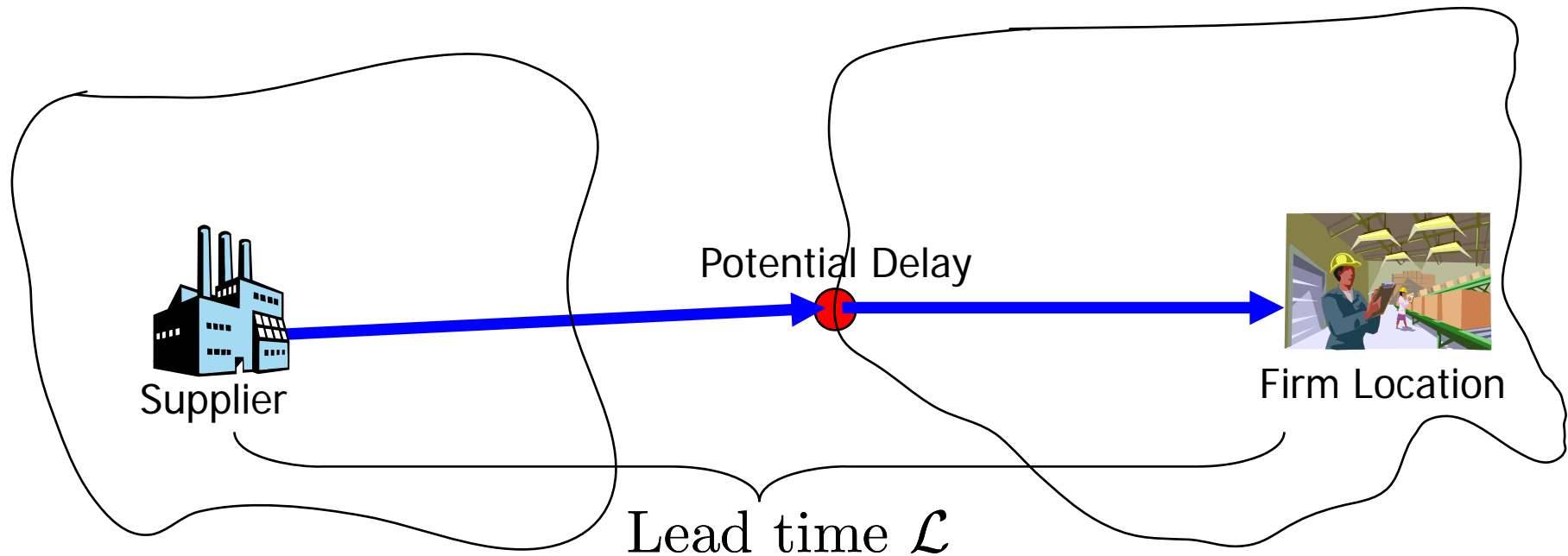
Lead time $\mathcal{L}$

$$\mathbf{Pr}\left(\mathcal{L} = l\right) = \Theta$$
$$\mathbf{Pr}\left(\mathcal{L} = L\right) = 1 - \Theta$$

$$L > l$$

Periodic Review Inventory Policy : Review Period Length T

Stochastic Demand $D_{(t_1, t_2]}$

Response Strategies : Two Dimensions

- **Operational Flexibility**
  - Additional Resources for Faster Replenishment

- **Lead-time Visibility**
 - Information on Lead-time in Advance

Operational Flexibility

- **Zero Operational Flexibility**
  - No additional resources..

- **Logistics Flexibility**
  - Expedite Orders using Faster Transportation Mode

- **Sourcing Flexibility**
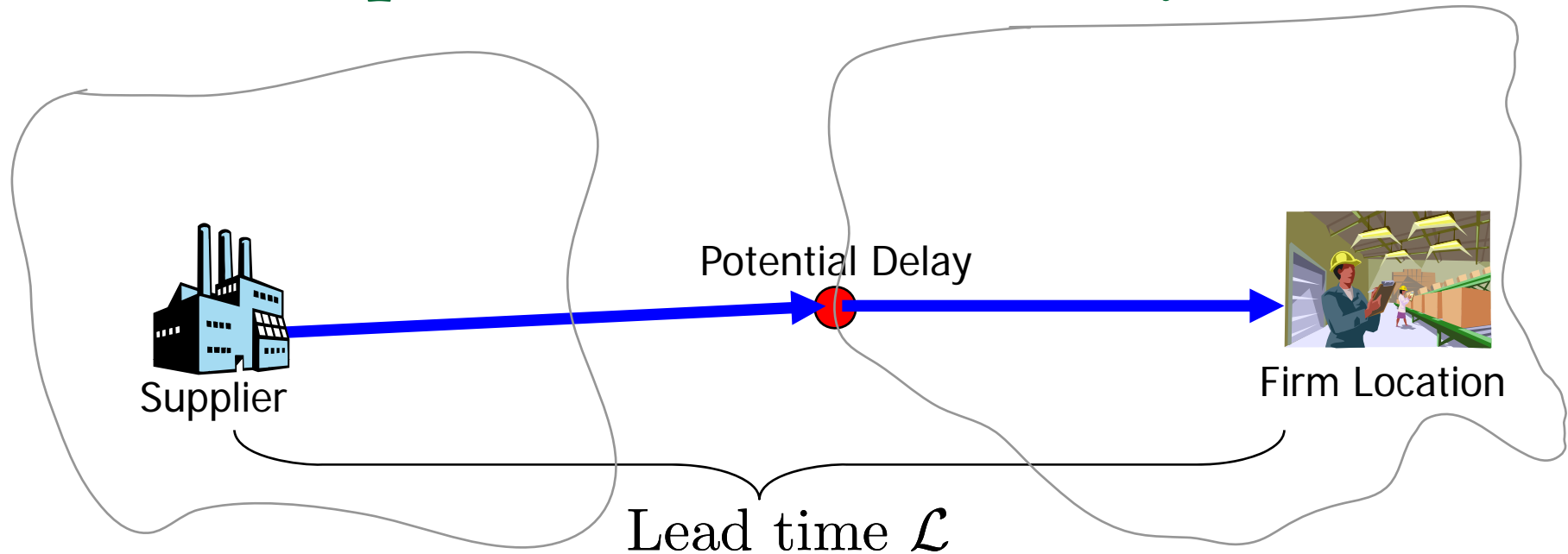 - Order with a Faster and Expensive Alternative Supplier

Lead-time Visibility

Supplier

Potential Delay

Firm Location
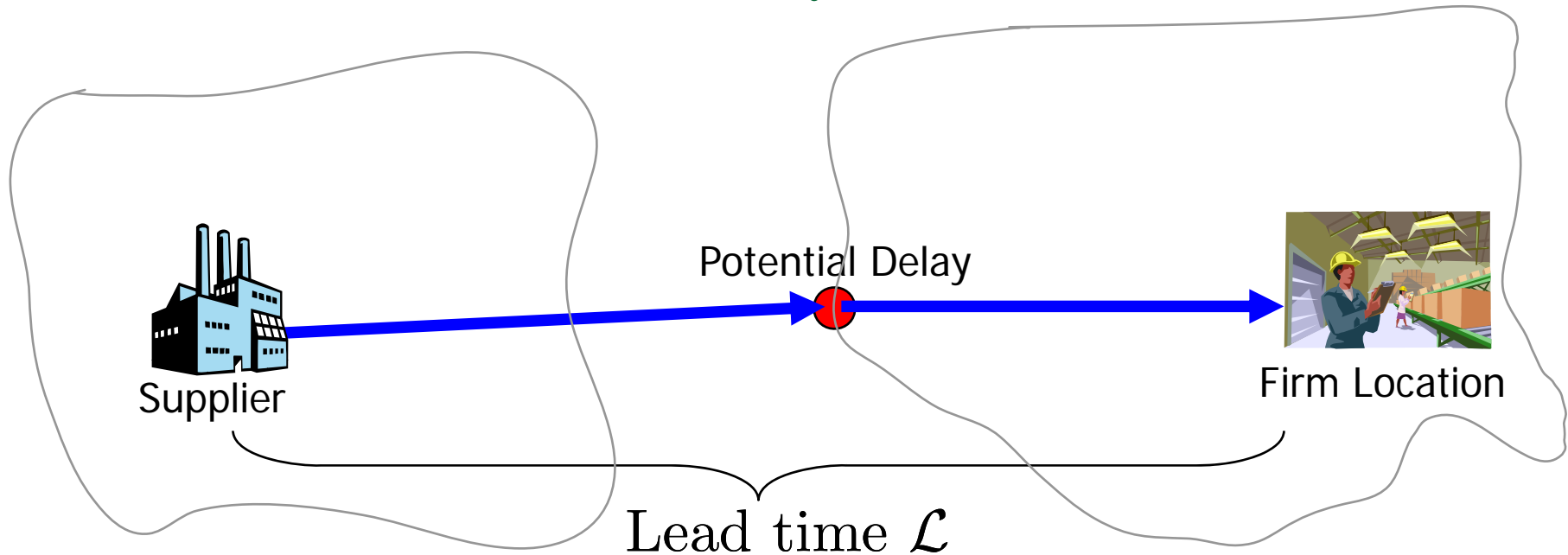
Lead time $\mathcal{L}$

L_i : Time at which the realization of lead-time is learned

$\mathcal{L} = l$
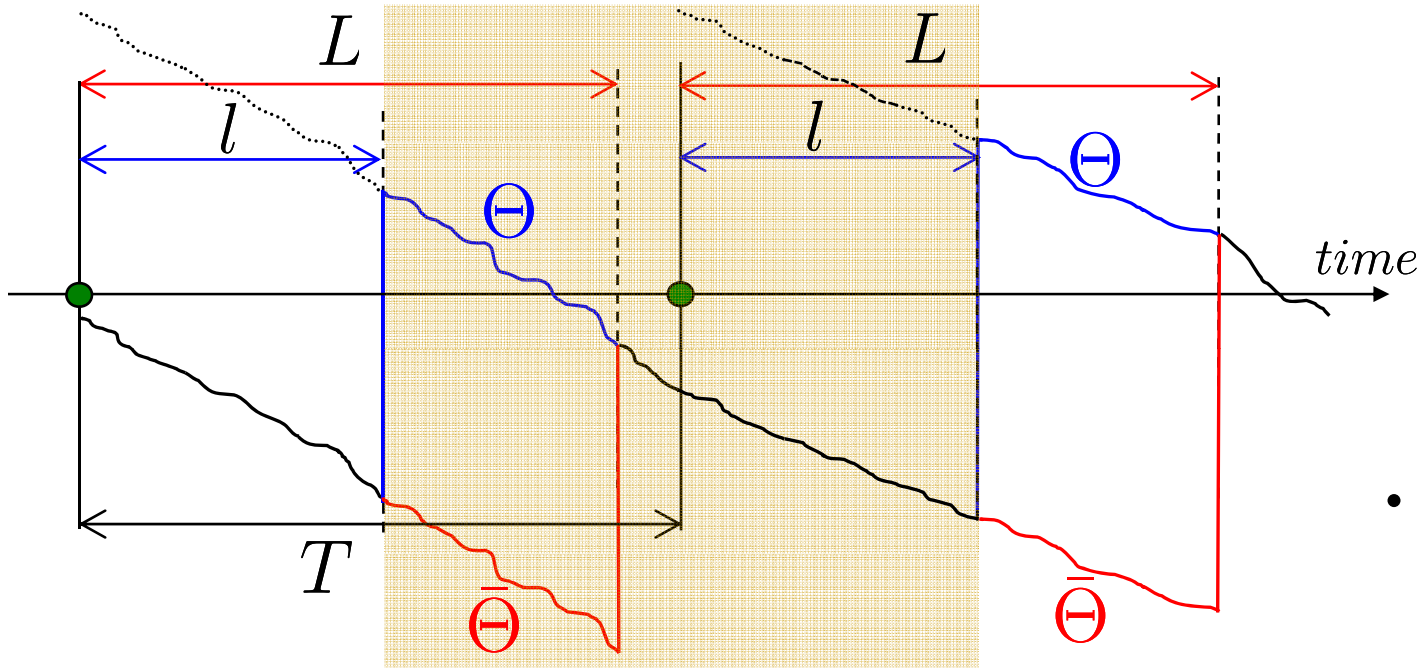
L_i

$\mathcal{L} = L$
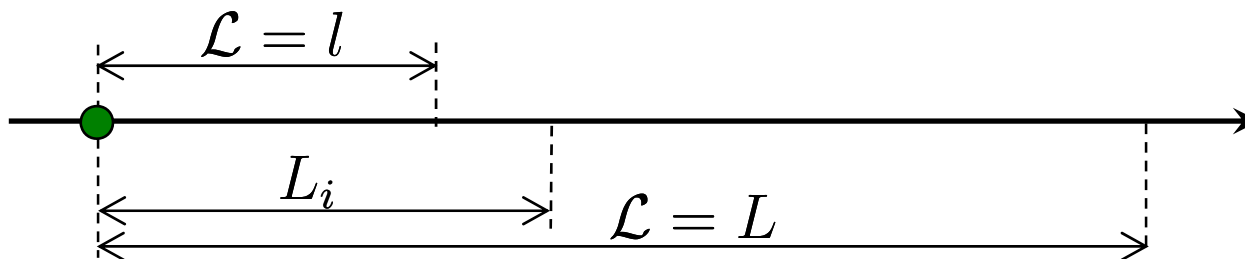
Zero Operational Flexibility

$L_i > 0$ No Lead-time Visibility

$L_i = 0$ Full Lead-time Visibility: Place Orders with Full Information
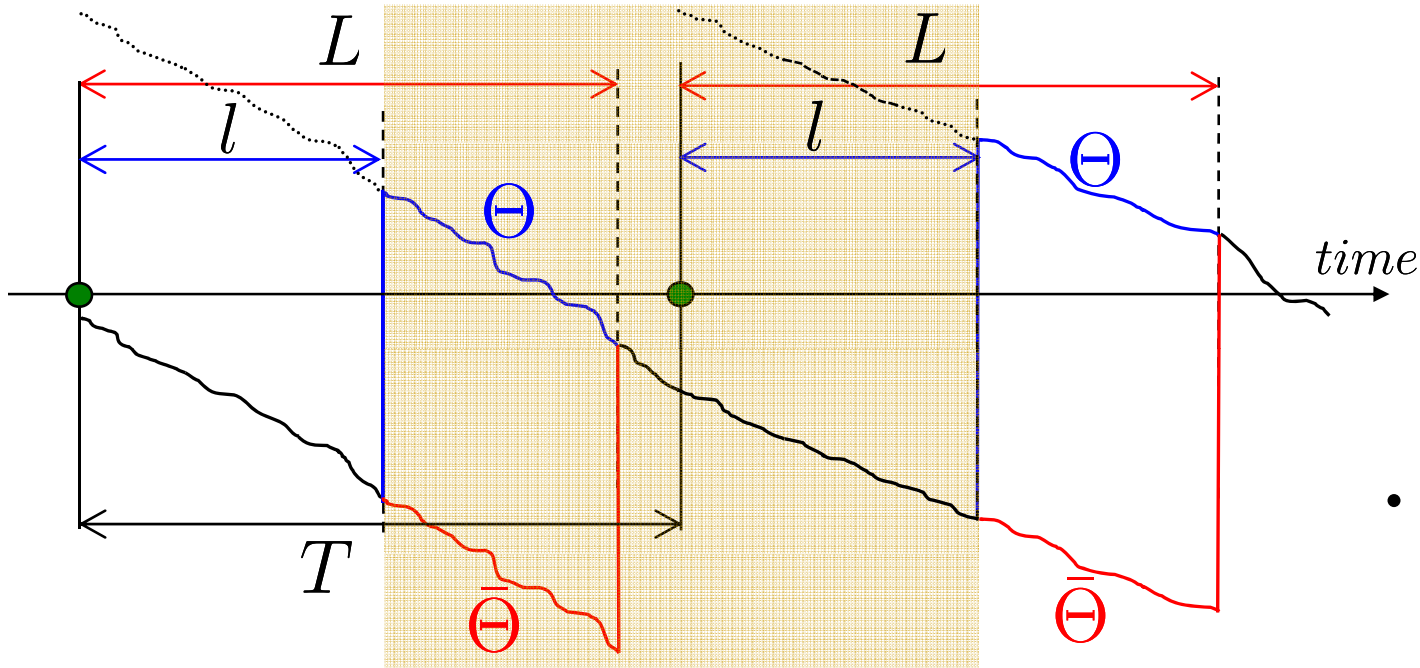
No Lead-time Visibility (Base Case ZN)

• Base-stock policy

$$\text{Cost} = \Theta \int_l^L G\left(S, D_{(0,t]}\right) dt + \bar{\Theta} \int_l^L G\left(S - D_{(-T,0]}, D_{(0,t]}\right) dt + \int_L^{l+T} G\left(S, D_{(0,t]}\right) dt$$

$$\text{where} \quad G\left(S, D_{(0,t]}\right) = \mathbb{E}\left[h(S - D_{(0,t]})^+ + p(D_{(0,t]} - S)^+\right]$$

No Lead-time Visibility (Base Case ZN)

- Base-stock policy

$$\text{Cost} = {\color{blue}\Theta \mathcal{G}_{(l,l+T]}(S)} + {\color{red}\bar{\Theta} \mathcal{G}_{(L,L+T]}(S)}$$
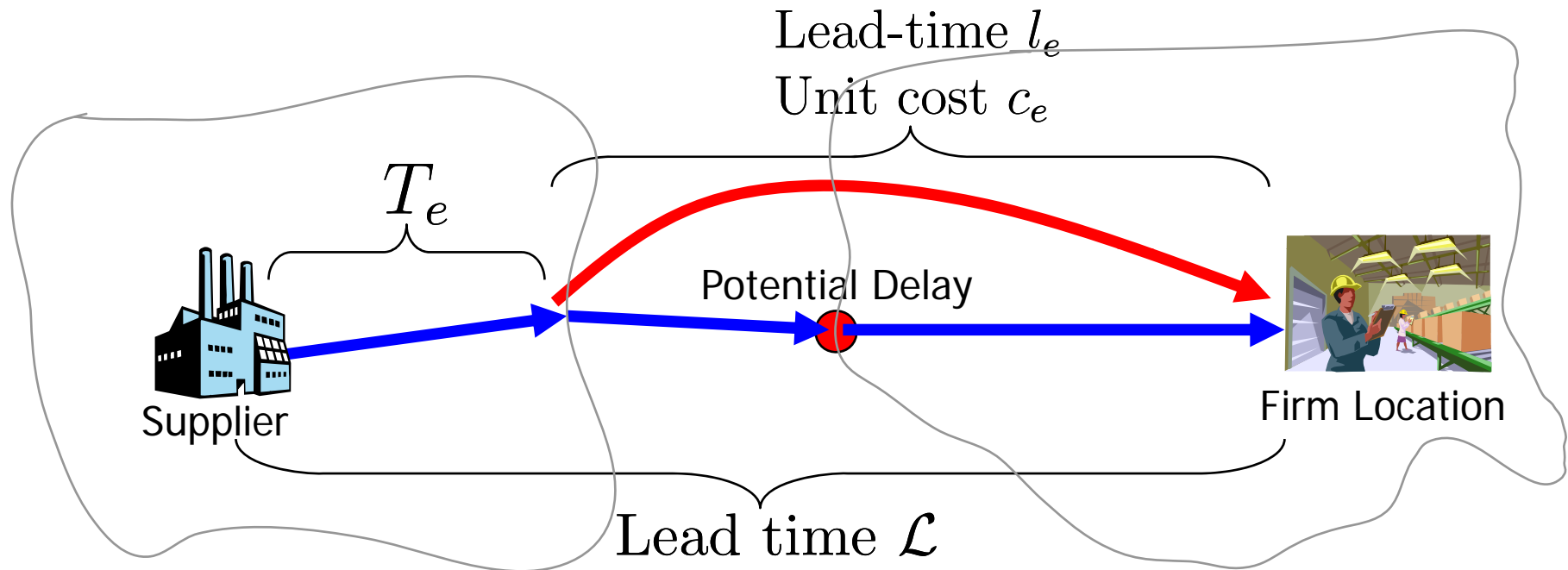
$$\text{where} \quad \mathcal{G}_{(t_1,t_2]}(S) = \int_{t_1}^{t_2} G(S, D_{(0,t]}) dt$$
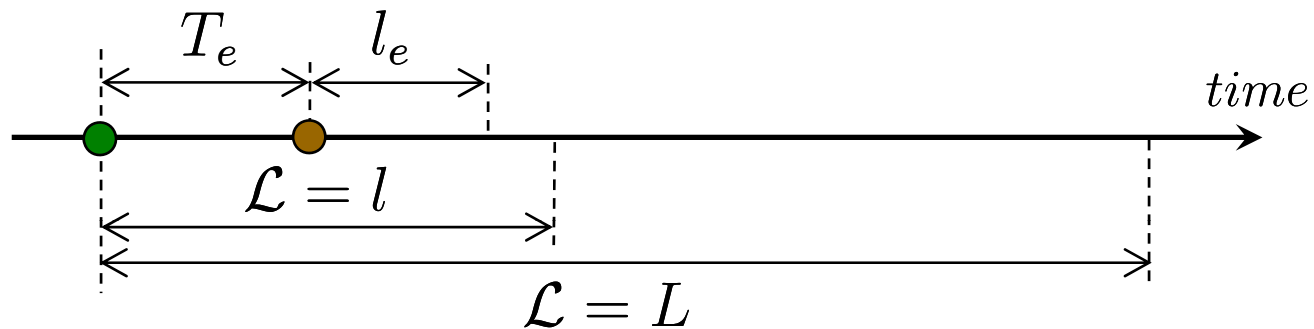
Full Lead-time Visibility (Strategy **ZF**)

$L_i = 0$ Lead-time Dependent Base-stock Policy is Optimal
(Song and Zipkin 1996)

Order-up-to S_l^{zf}
Order-up-to S_L^{zf}

Logistics Flexibility

Lead-time l_e
Unit cost c_e

T_e

Potential Delay

Supplier

Firm Location
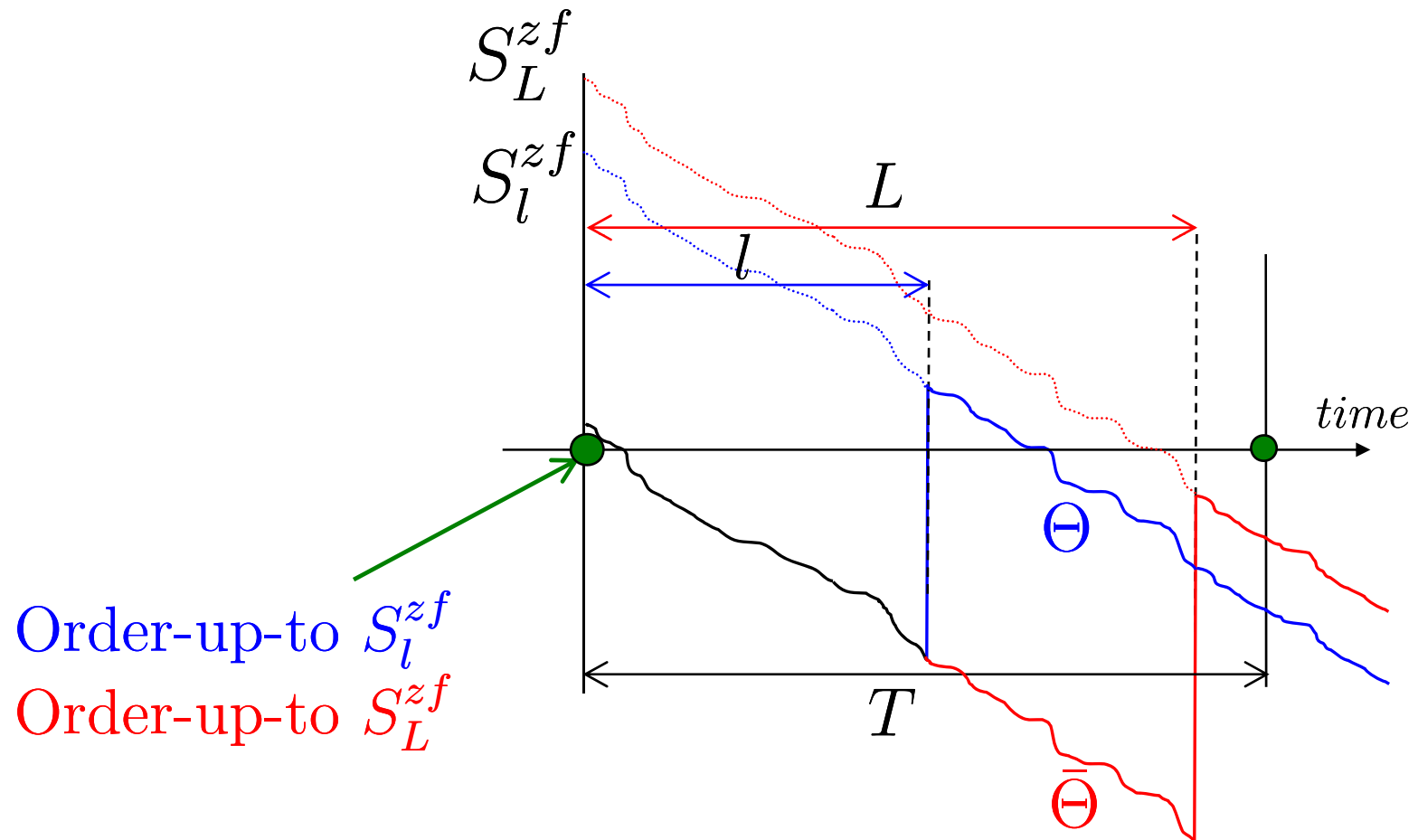
Lead time $\mathcal{L}$

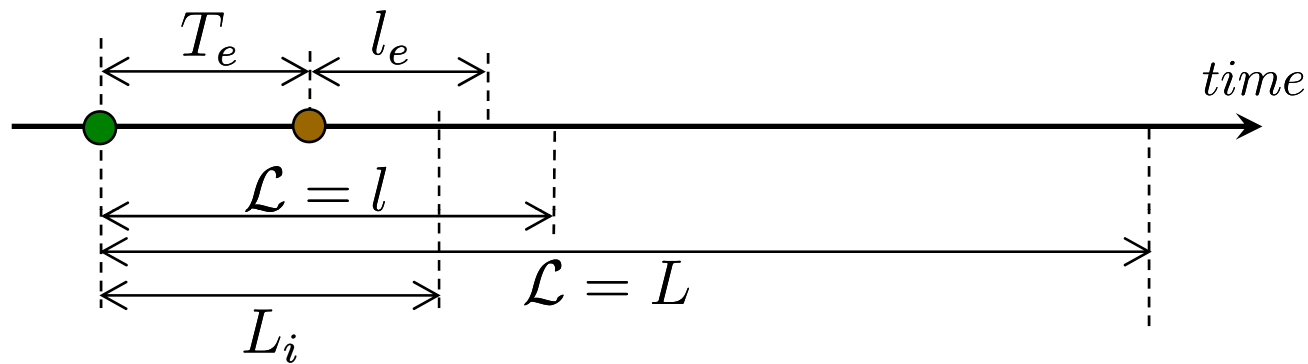# Logistics Flexibility: Time Line

Ordering Decision

Expediting Decision

Logistics Flexibility
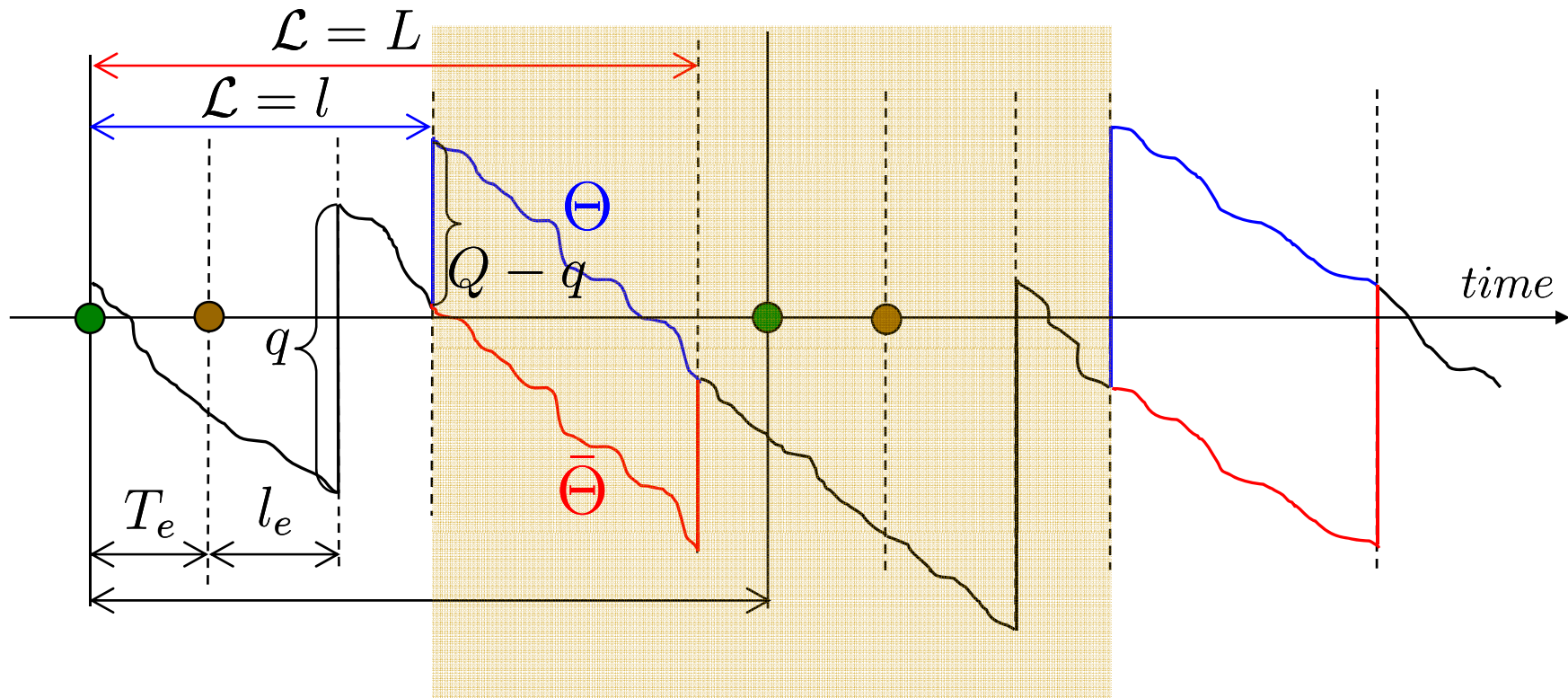## No Lead-time Visibility (Strategy **LN**)

$$T_e < L_i$$

Ordering Decision

Expediting Decision

Both Decisions are made
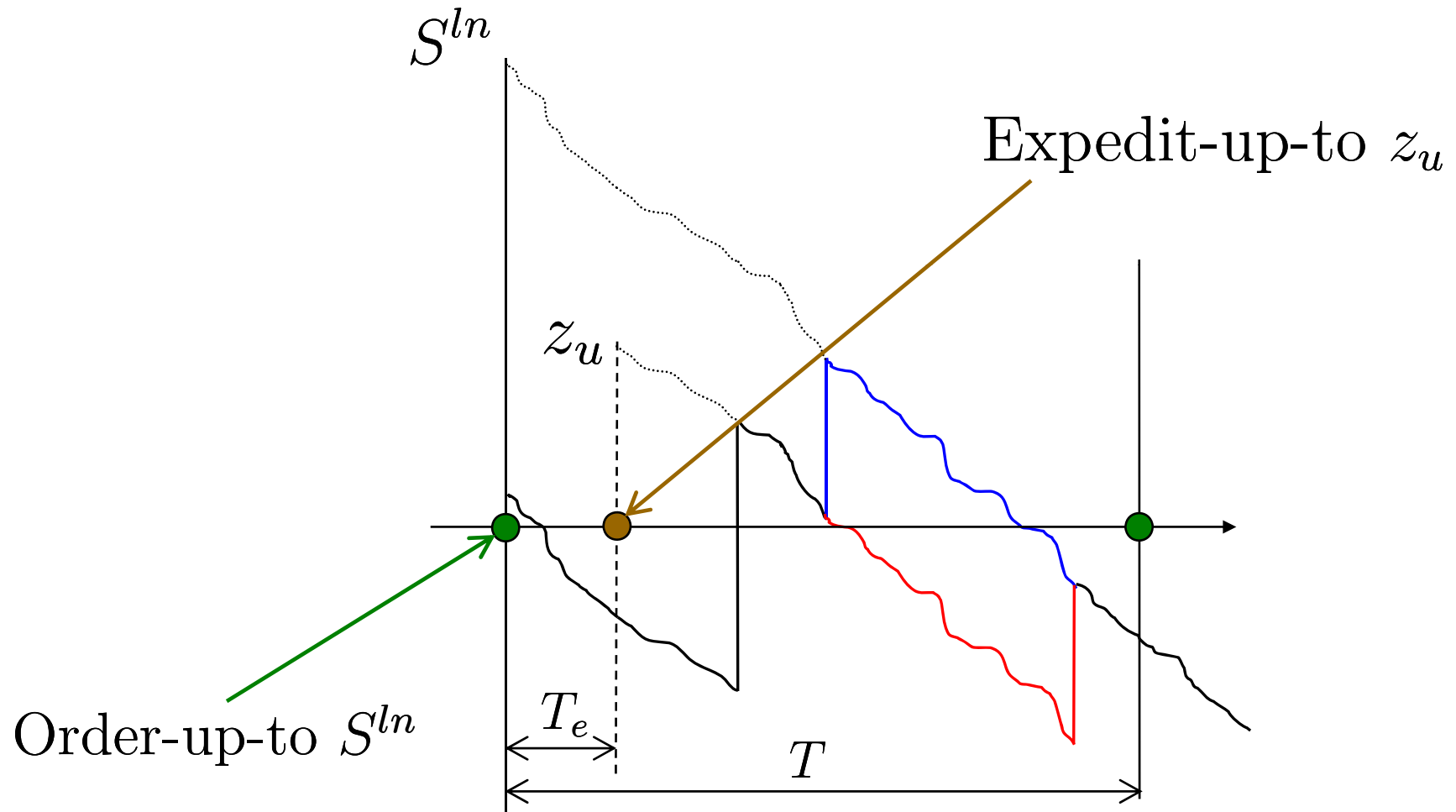without Lead-time Information

No Lead-time Visibility (Strategy **LN**)

Single Period Cost

$$\mathcal{G}_{(T_e+l_e,l]}(x+q) + \Theta\mathcal{G}_{(l,L]}(x+Q)$$
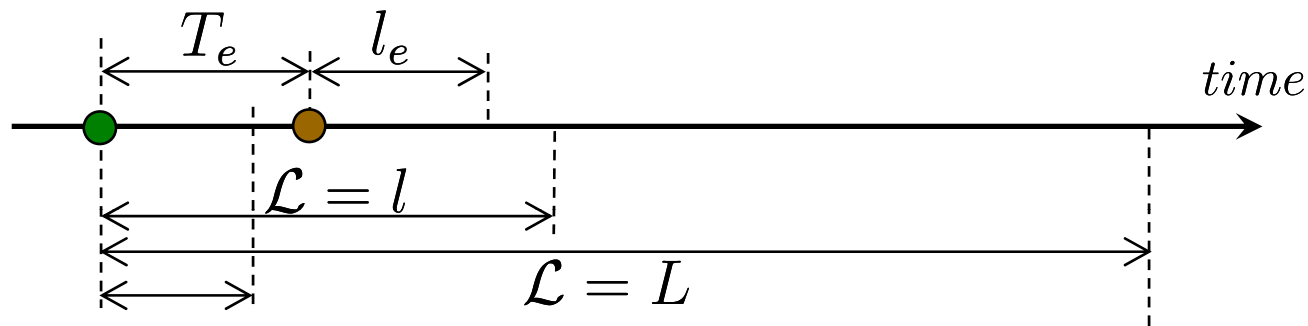$$+\bar{\Theta}\mathcal{G}_{(l,L]}(x+q) + \mathcal{G}_{(L,T+T_e+l_e]}(x+Q)$$

No Lead-time Visibility (Strategy **LN**)

- Optimal Policy

S^{ln}

Expedit-up-to z_u

z_u

Order-up-to S^{ln}

T_e

T

Logistics Flexibility

Partial Lead-time Visibility (Strategy **LP**)

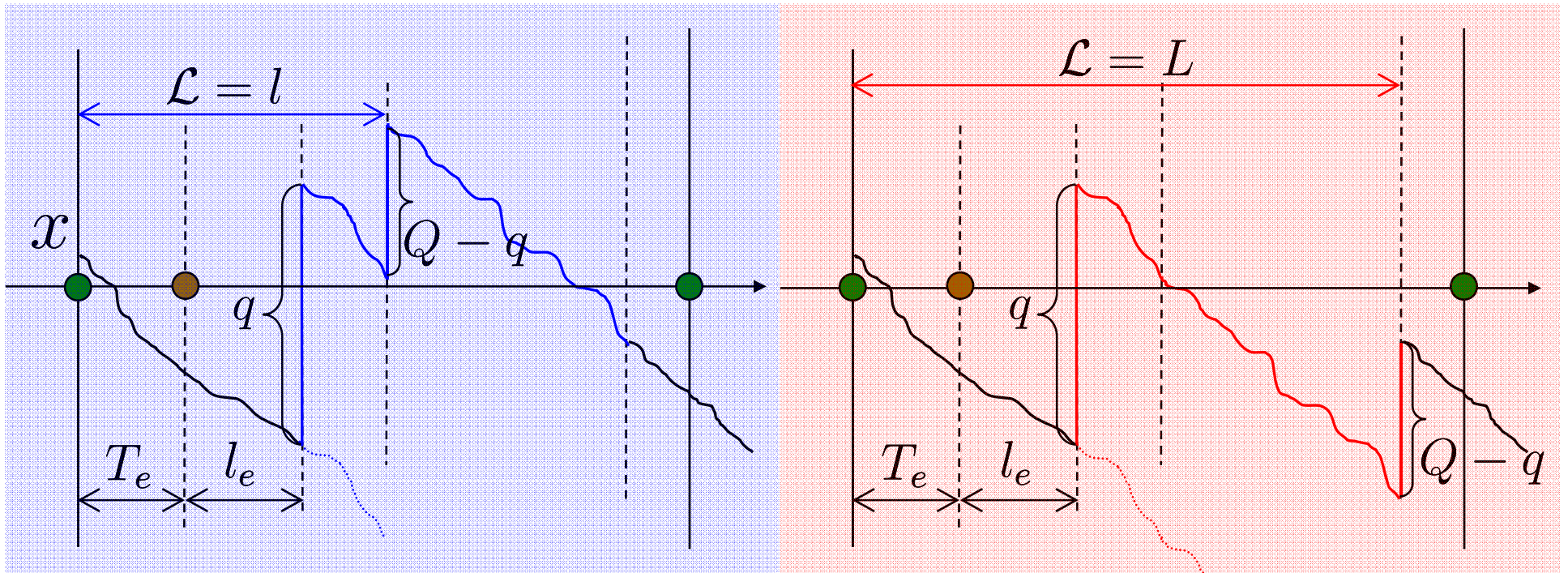$$0 < L_i \leq T_e$$

Ordering Decision	Made without Lead-time Information
Expediting Decision	Made with Lead-time Information

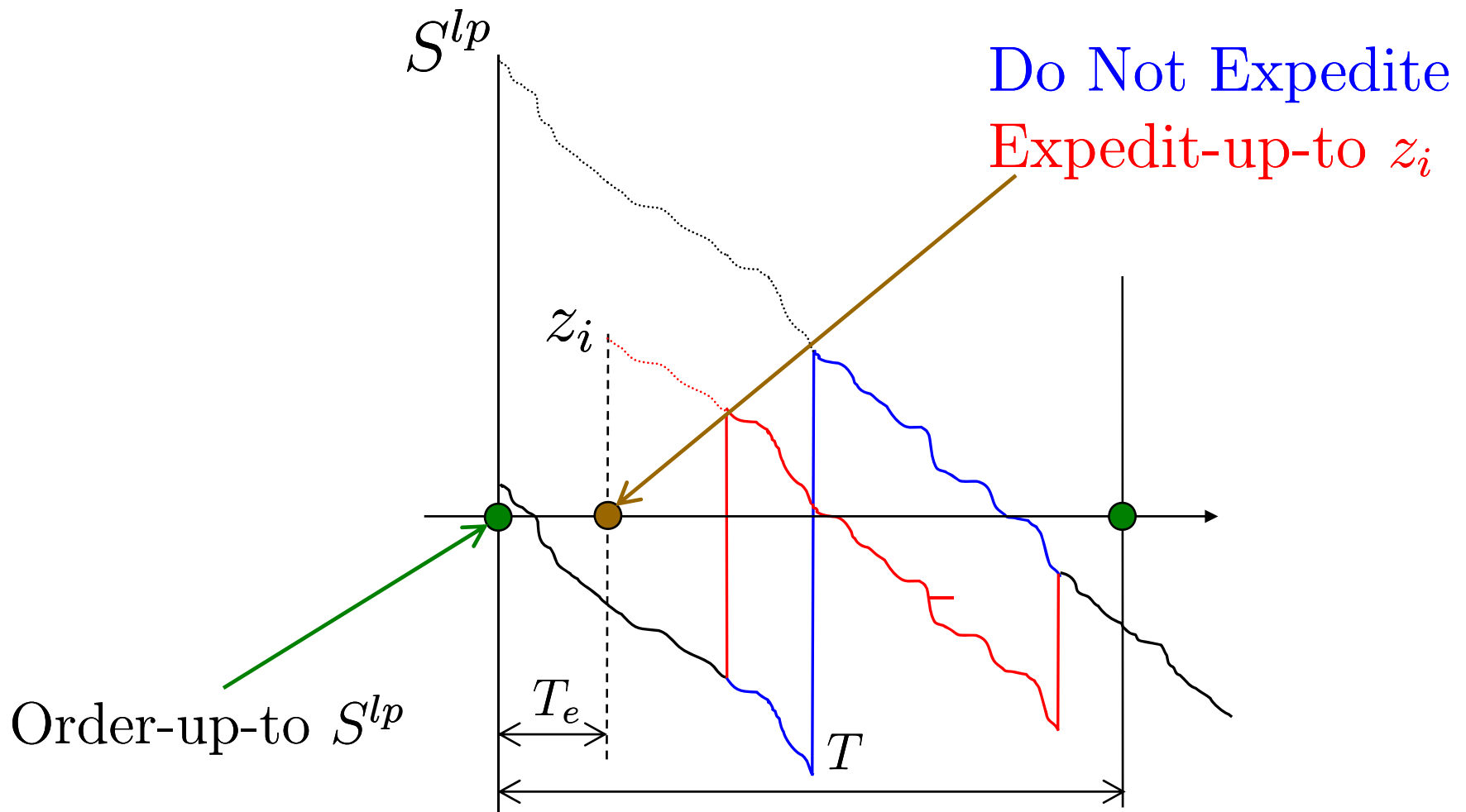# Partial Lead-time Visibility (Strategy **LP**)

No Shipment Delay

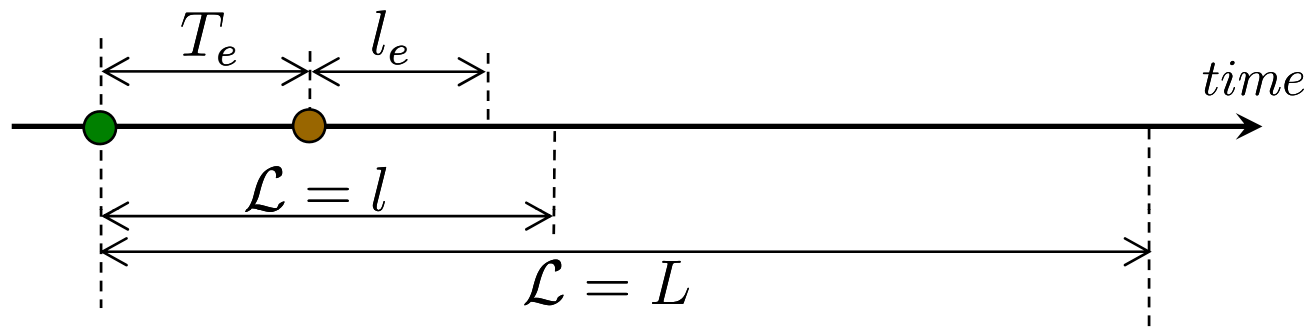Not Optimal to Expedite

Shipment Delay

Optimal to Expedite

Partial Lead-time Visibility (Strategy **LP**)

- Optimal Policy

S^{lp}

Do Not Expedite

Expedit-up-to z_i

z_i

Order-up-to S^{lp}

T_e

T

Logistics Flexibility

Full Lead-time Visibility (Strategy **LF**)
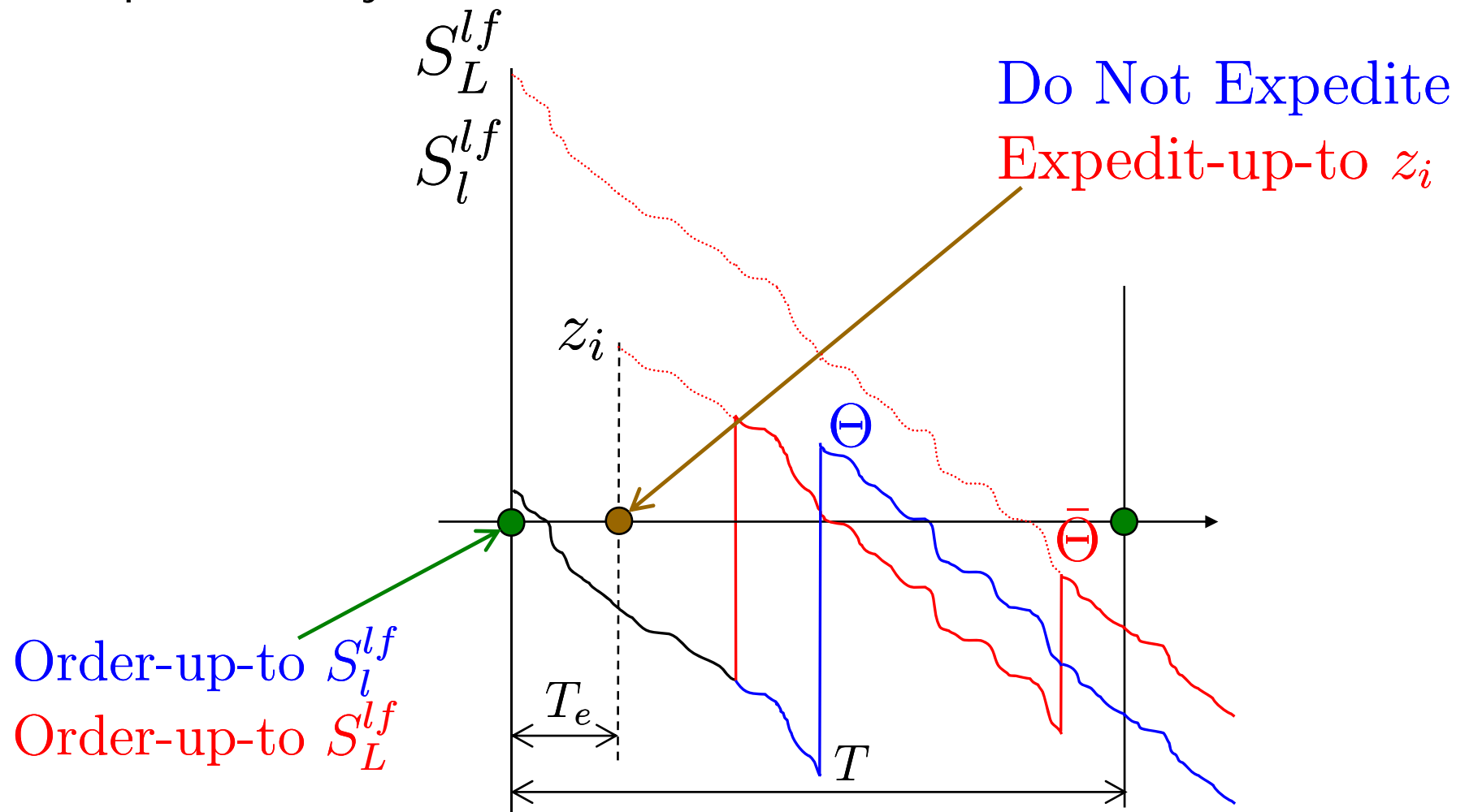

$$L_i = 0$$

Ordering Decision

Expediting Decision

> Both Decisions are made
> with Lead-time Information

Full Lead-time Visibility (Strategy **LF**)

- Optimal Policy

S_L^{lf}

S_l^{lf}

Do Not Expedite

Expedit-up-to z_i

z_i

Θ

$\bar{\Theta}$

Order-up-to S_l^{lf}

Order-up-to S_L^{lf}

T_e

T

Sourcing Flexibility

Alternative Supplier — Lead-time l_a, Unit cost c_a

Potential Delay

Supplier

Firm Location

Lead time $\mathcal{L}$
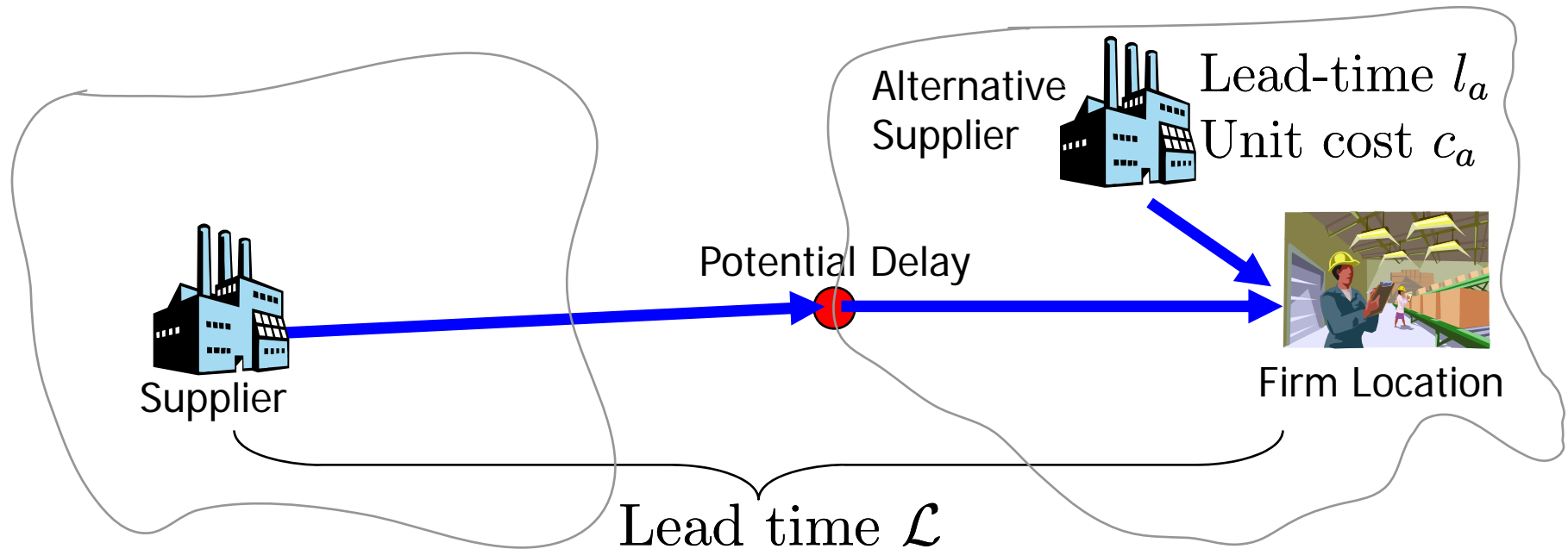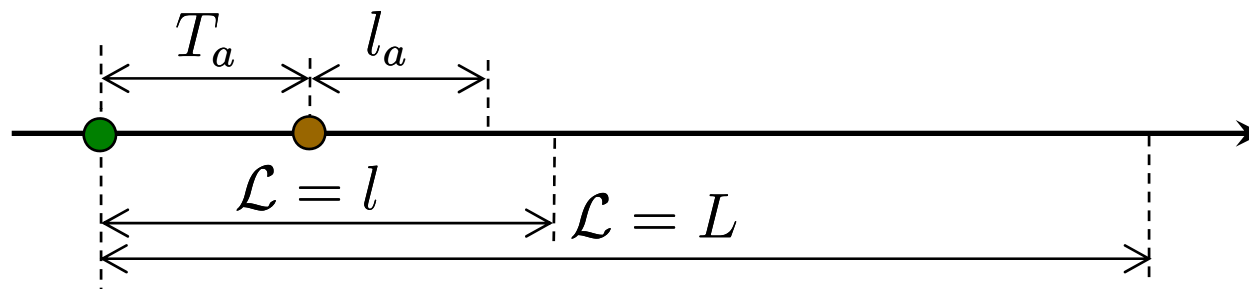
Sourcing Flexibility: Time Line

Simplifying Assumption :
   Ordering Decision with Alternative Supplier at time T_a

Ordering Decision with Regular Supplier

Ordering Decision with Alternative Supplier

Sourcing Flexibility

- **Three Models with**
  - No Lead-time Visibility (Strategy SN)
  - Partial Lead-time Visibility (Strategy SP)
  - Full Lead-time Visibility (Strategy SF)

- **Optimal Policies are Not Base-Stock Policies**

- **Solutions with Dynamic Programs**
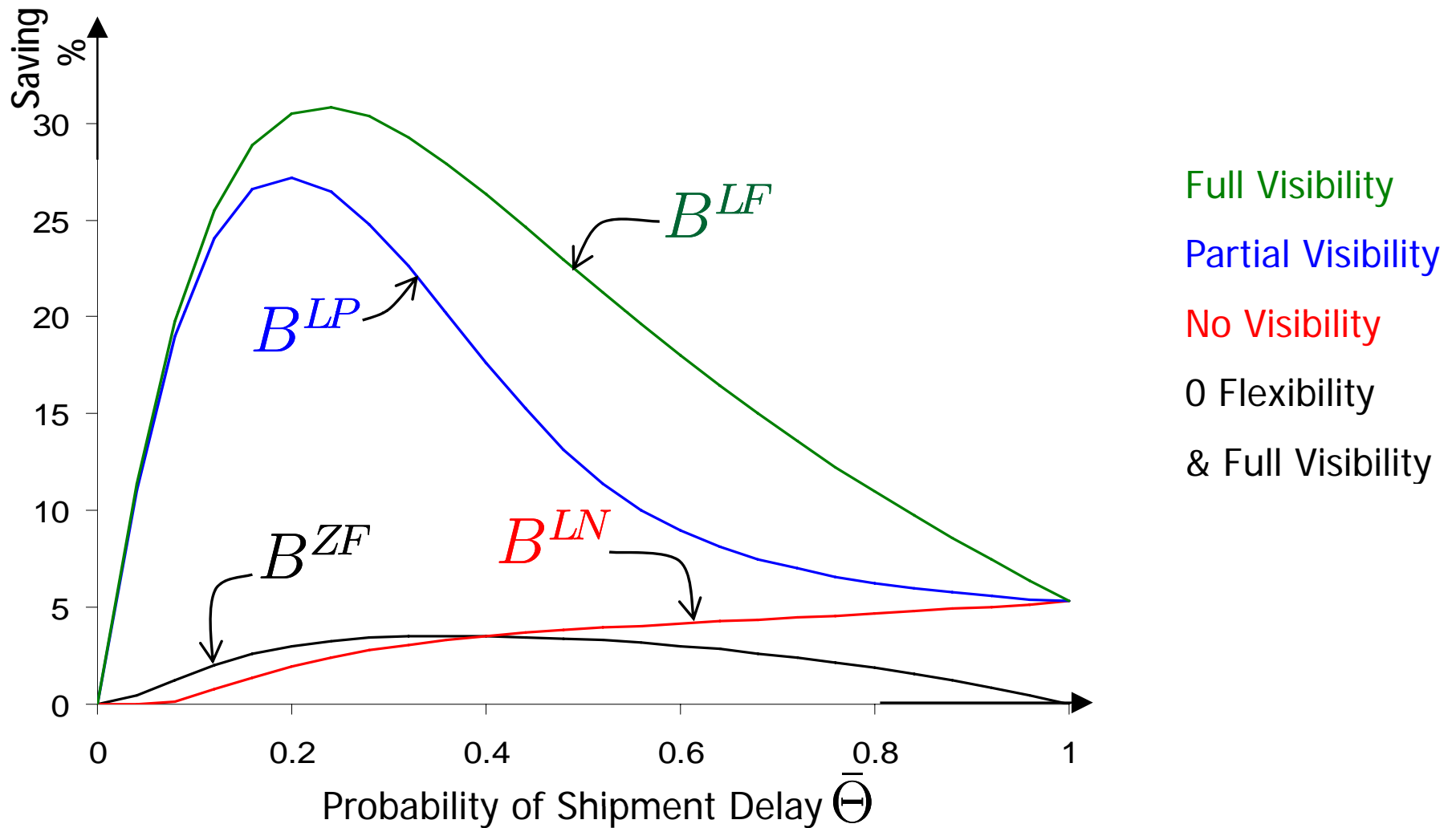
Numerical Comparison

Cost Saving with Strategy M

Optimal Cost with Strategy M

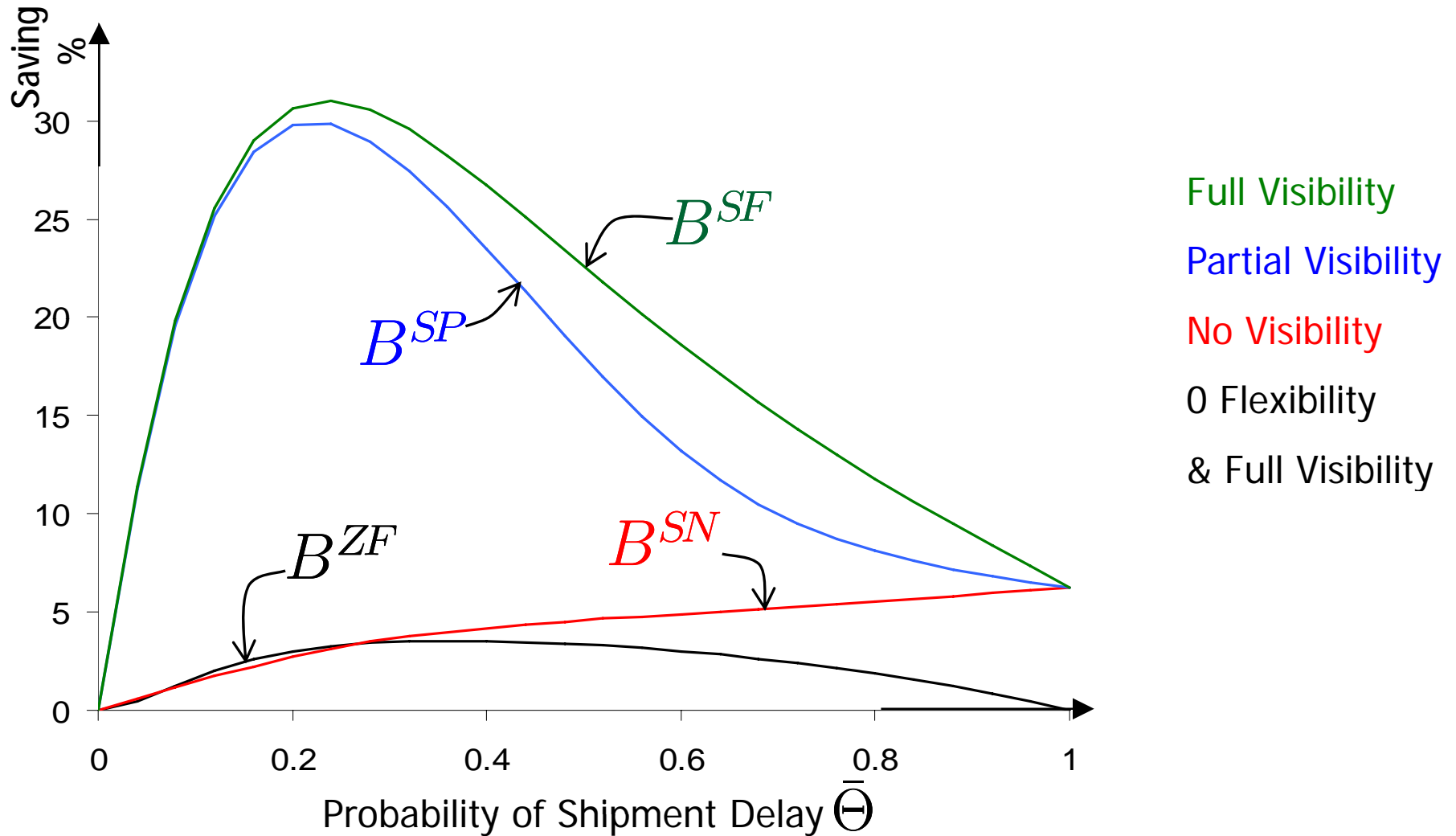$$B^M = \frac{C^{ZN} - C^M}{C^{ZN}}\%$$

Optimal Cost with Base Case ZN

(Zero Flexibility & No Lead-time Visibility)

$$M \in \{ZF, LN, LP, LF, SN, SP, SF\}$$

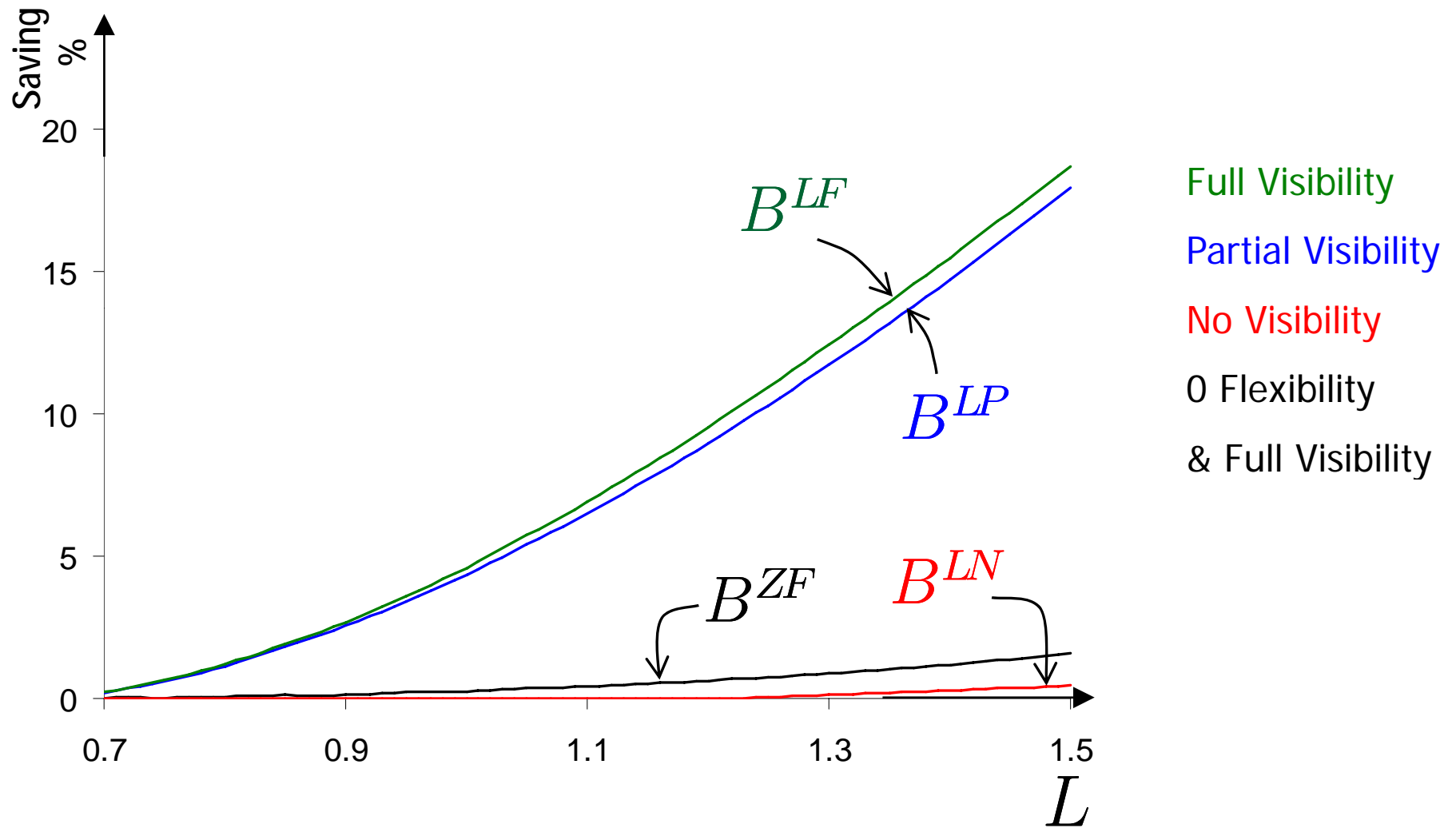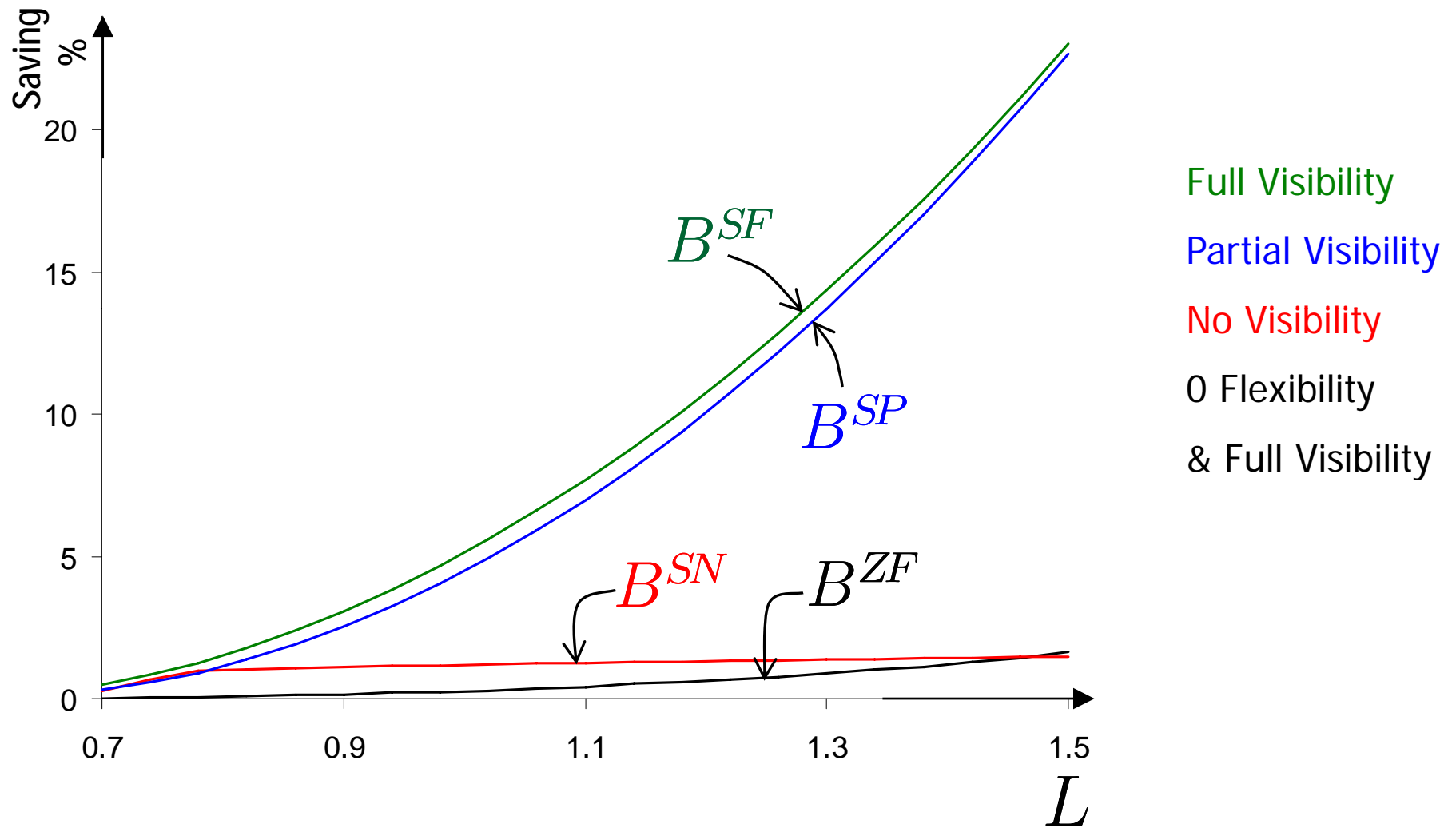# Effect of Delay Probability (Logistics Flexibility)

Full Visibility

Partial Visibility

No Visibility

0 Flexibility

& Full Visibility

Saving %

B^{LF}

B^{LP}

B^{ZF}

B^{LN}

Probability of Shipment Delay $\bar{\Theta}$

Effect of Delay Probability (Sourcing Flexibility)

Full Visibility
Partial Visibility
No Visibility
0 Flexibility
& Full Visibility

B^{SF}

B^{SP}

B^{ZF}

B^{SN}
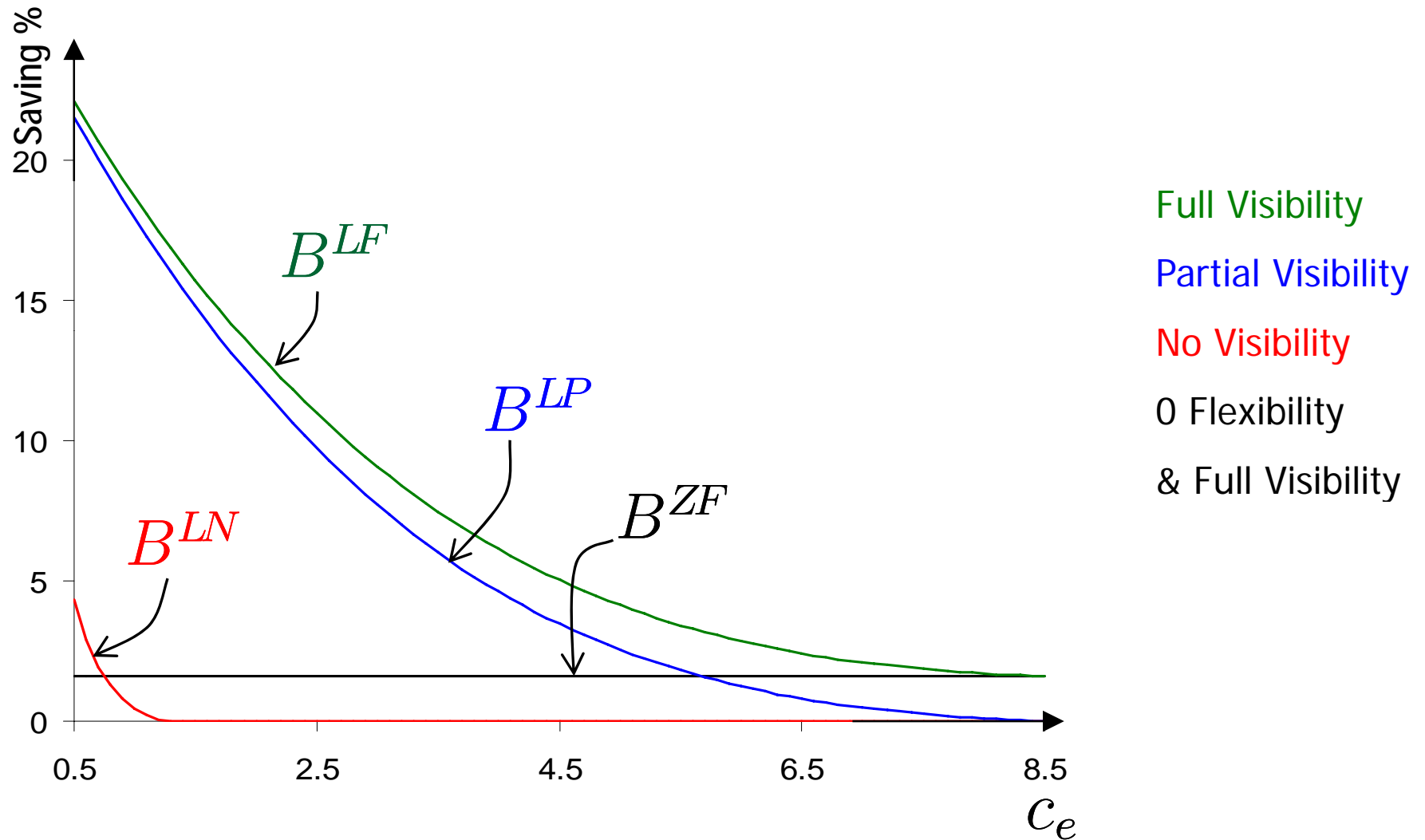
Saving %

Probability of Shipment Delay $\bar{\Theta}$

Effect of Delay Time (Logistics Flexibility)

Effect of Delay Time (Sourcing Flexibility)

Effect of Expediting Cost (Logistics Flexibility)

Saving %

- Full Visibility
- Partial Visibility
- No Visibility
- 0 Flexibility
- & Full Visibility
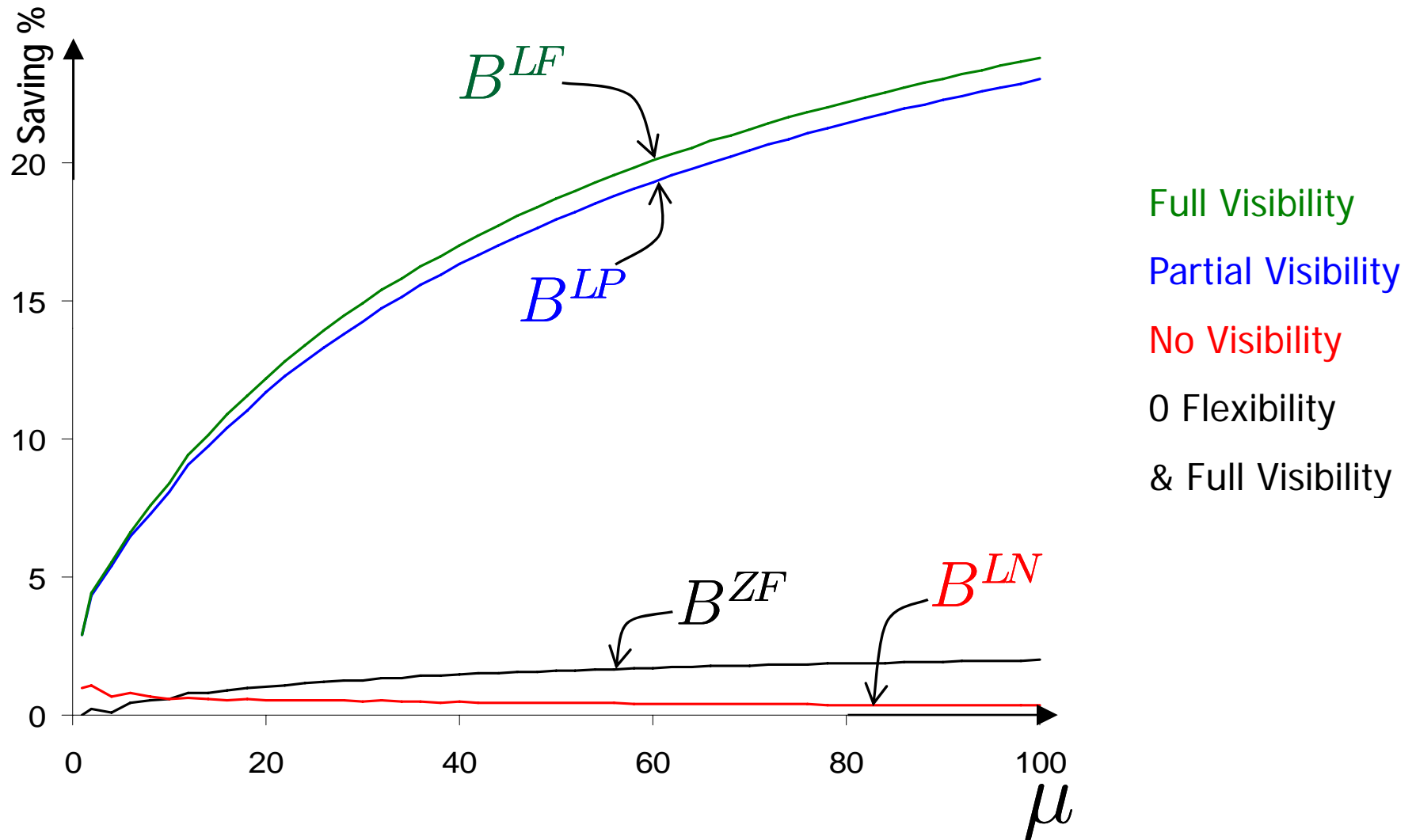
B^{LF}

B^{LP}

B^{ZF}

B^{LN}

c_e

Effect of Alternative Sourcing Cost (Sourcing Flexibility)
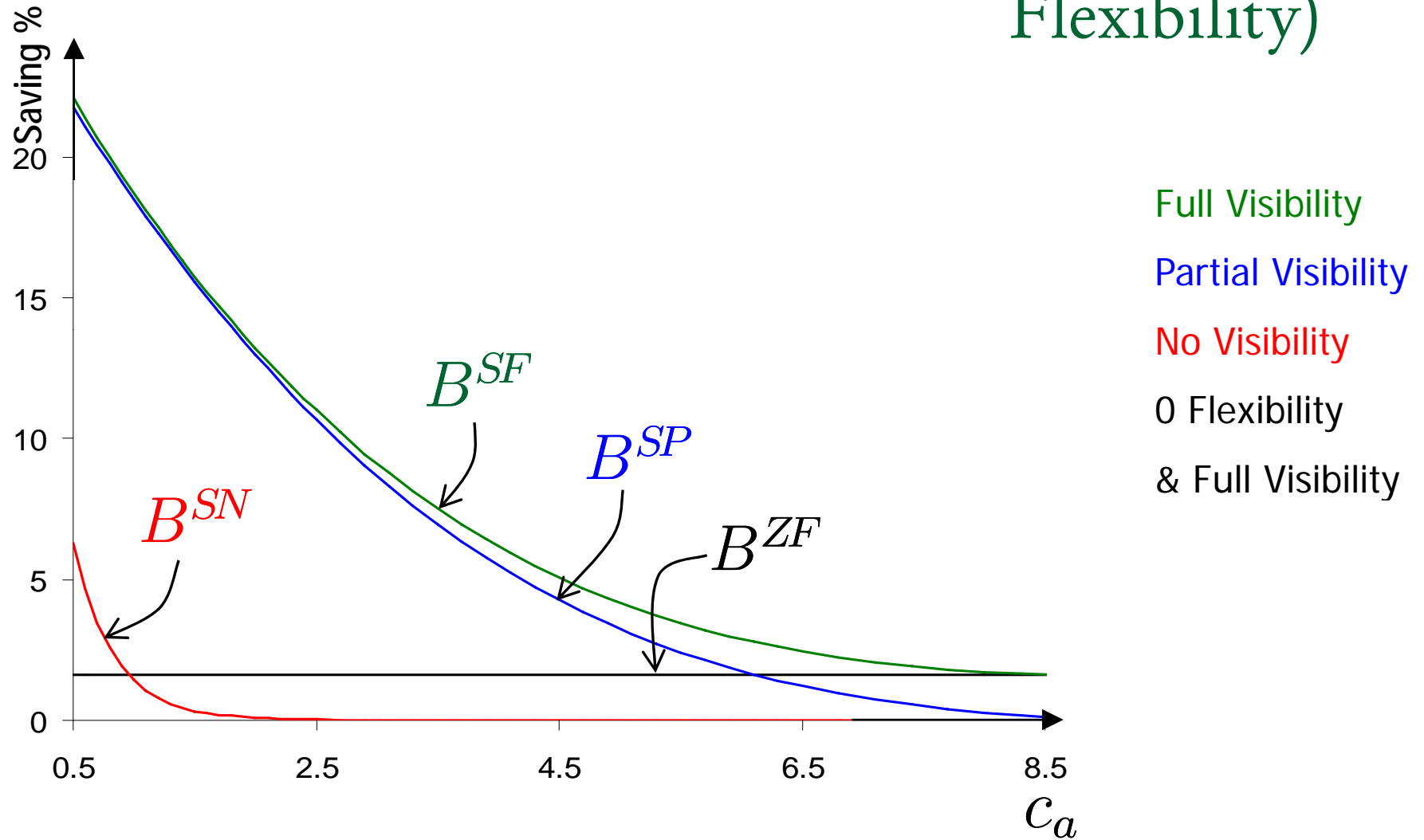
Effect of Demand Rate (Logistics Flexibility)

Effect of Demand Rate (Sourcing Flexibility)

Full Visibility

Partial Visibility

No Visibility

0 Flexibility
& Full Visibility
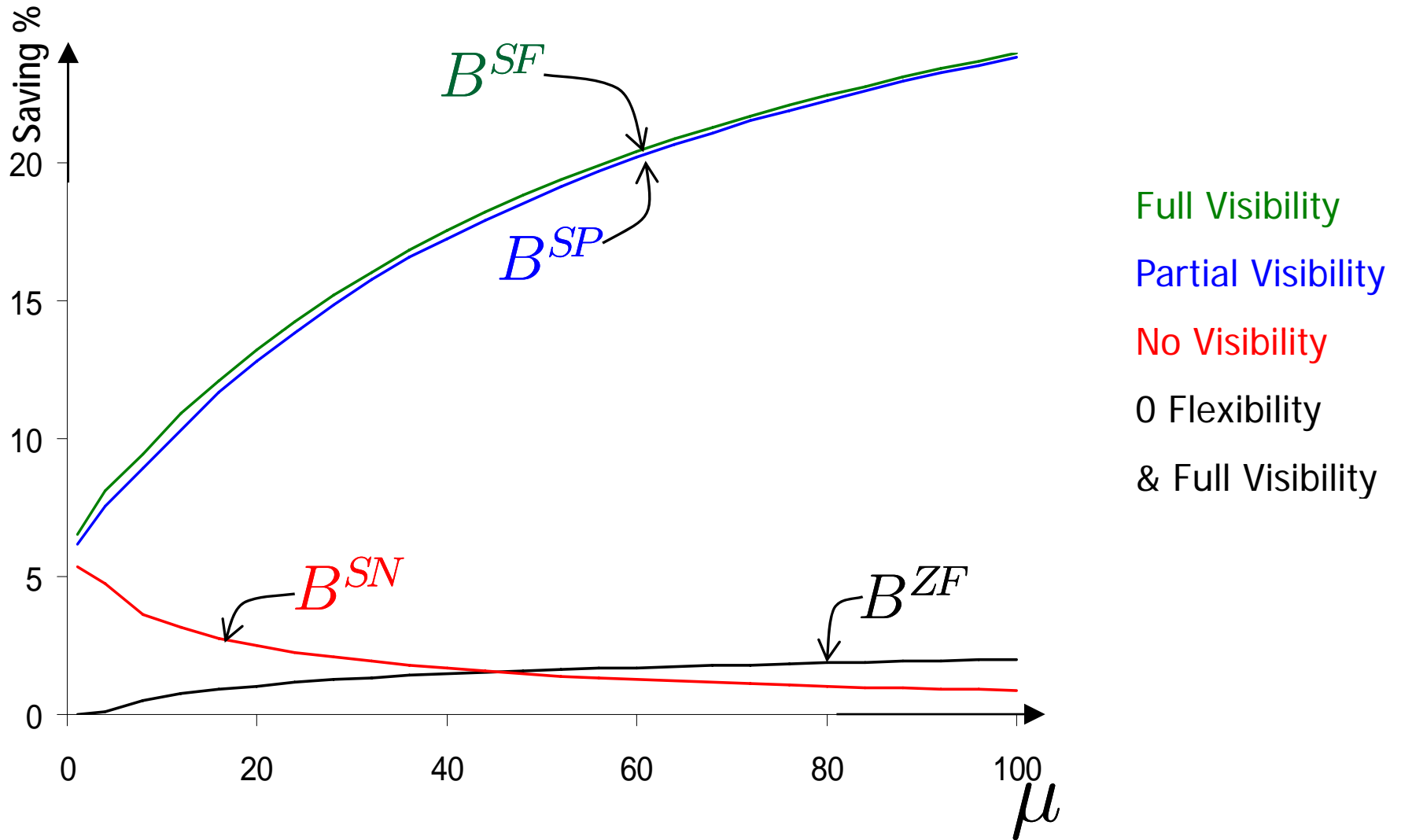
Observations

- Flexibility protects from long lead-times

- Lead-time visibility protects from uncertainty in lead-times

- Operational flexibility and lead-time visibility are complementary

- Partial lead-time visibility captures most of the gains with full visibility

Impact of Other Factors

- **More general delays**
  - Complex optimal ordering policies
  - Robust heuristics

- **Fixed costs of Ordering/Freight Mode**
  - Reduced Flexibility (Jain, Groenevelt and Rudi)
  - Scope for negotiation on Fixed vs Variable costs

Impact of other factors

- Capacity constraints on freight modes
  - Real options.. How to value it?
  - Market for freight modes

- Information availability
  - Cost of providing information
  - Incentive to share timely information on delays

Contribution

- Model to identify impact of operational flexibility and lead-time visibility on
  - Optimal policies
  - Costs

- Justification for investments in
  - Logistics and sourcing flexibility
  - Information system