Supply Chain Networks with Global Outsourcing and Quick-Response Production under Demand and Cost Uncertainty

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Outline

- Introduction
- Literature review
- Supply chain network with global outsourcing and quick-response production under demand and cost uncertainty
- Analytical results
- Simulation studies
- Managerial insights and conclusions.

Global Outsourcing

- In the past decade, global outsourcing has become increasingly prevalent and has reshaped supply chains in almost all industries.
- A recent study published by PRTM management consultants reported that the average cost reduction was 17% per globalization initiative among the three hundred surveyed international firms (Cohen et al. (2008)).
- Global outsourcing also exposes supply chain firms to various risks including: foreign exchange risk, demand risk, production disruption risk, quality risk, supplier default risk, etc.

Demand Uncertainty

- A survey conducted by The Economist Magazine (The Economist Intelligence Unit (2009)) showed that demand uncertainty is ranked as the top risk factor by 500 global company executives with responsibility for risk management.
- The long lead time in global outsourcing, ranging from three months to nine months (Walker (1999), CNN Tech (2004), Sen (2008)), further amplifies the demand risk.
- Such a decision-making environment is not only relevant to apparel, but also to toys, consumer electronics, personal computers, and seasonal merchandise, including merchandise associated with special events and holidays (see Walker (1999)).

Supply Chain Flexibility and Cost Uncertainty

- Demand risks can be mitigated by increasing the flexibility and the responsiveness of supply chains.
- A well-known case is Zara, the Spanish apparel retailer, which achieves great flexibility by using onshore quick-response production to manufacture 70% to 85% of its products.
- Zara is able to reduce the lead time to only three weeks which helps it to quickly respond to demand and to be able to reduce both markdowns and lost sales.
- The PRTM supply chain trend survey noted that the enhancement of supply chain flexibility is expected to overtake product quality and customer service as the top focus of global supply chain firms (Cohen et al. (2008)).
- The firms which have choices of quick-response production and/or offshore outsourcing have to consider production cost uncertainty.

Literature Review

- Supply chain outsourcing has been the theme of many studies in the literature.
- Huchzermeier and Cohen (1996), Cohen and Huchzermeier (1999), Dasu and Li (1997), Kazaz et al. (2005), Goh et al. (2007). Kouvelis and Milner (2002), Lee et al. (2002), Yang et al. (2007), Liu and Nagurney (2011), Nagurney et al. (2011), Meixell and Gargeya (2005).

Literature Review (Con't)

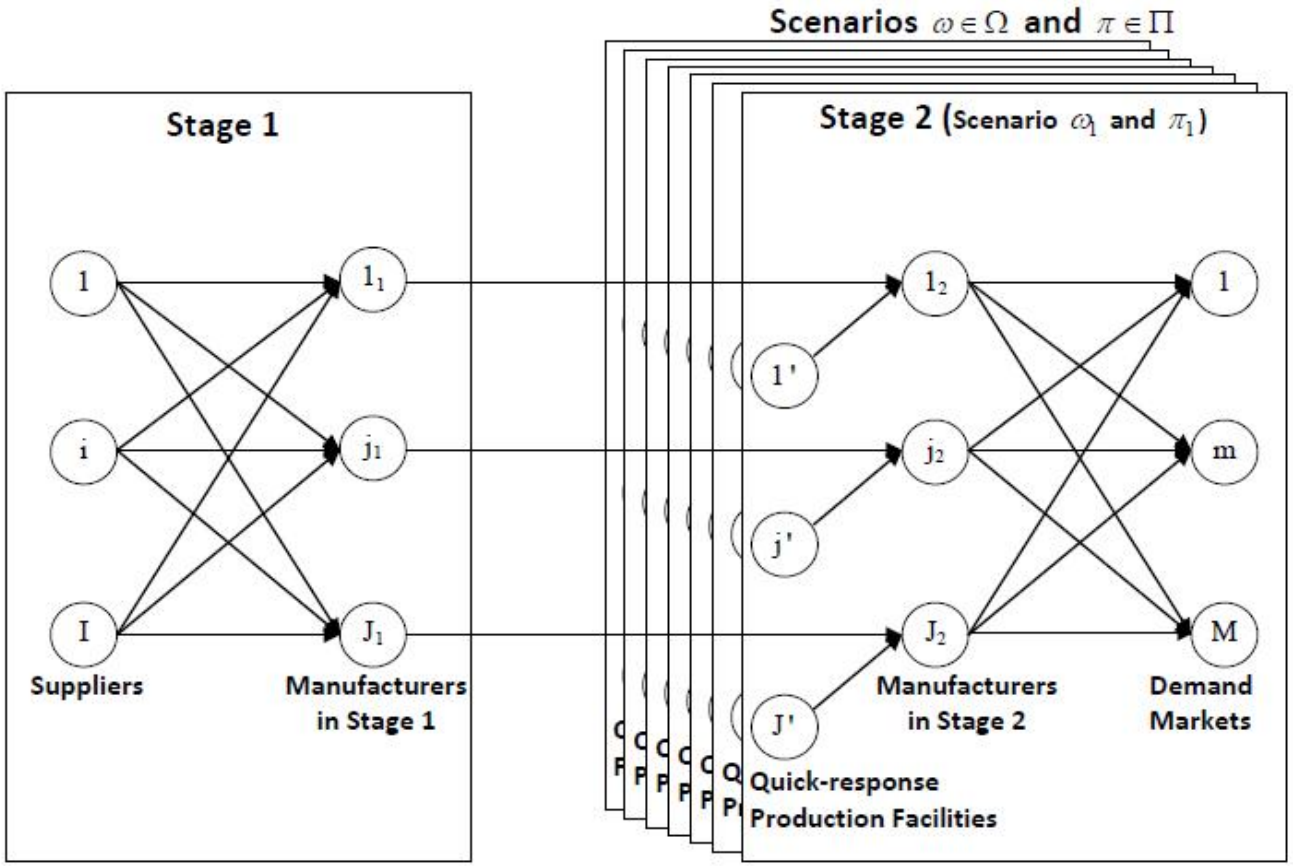
- A number of studies have considered supply chain outsourcing decisions under cost uncertainty from a real option perspective.
  - Datta (2005), Alvarez and Stenbacka (2007), Jiang et al. (2008), Cohen and Mallik (1997).
- Quick-response production has drawn increasing attention from researchers.
  - Upton (1995), Yang and Wee (2001), Barnes-Schuster et al. (2002), Cachon and Swinney (2009), Fisher and Raman (1996), Eppen and Iyer (1997), Iyer and Bergen (1997), Suri (1998), Fisher et al. (2001), Jones et al. (2001), Petruzzi and Dada (2001), Nagurney and Yu (2011a, b), and Cachon and Swinney (2011)).

Supply Chain Network with Global Outsourcing and Quick-response Production Under Demand and Cost Uncertainty

We consider multiple suppliers, multiple manufacturers, and multiple demand markets to interact under both demand and cost uncertainty. In particular, we investigate the following questions:

- How does demand uncertainty affect supply chain firms' decisions regarding outsourcing, in-house production, and sales under competition?
- How does demand uncertainty affect supply chain firms' profits and risks under competition?
- How does the prevalence of the quick-response in-house production affect supply chain firms' decisions, profits, and risks under demand uncertainty?
- How does cost uncertainty affect supply chain firms' decisions regarding outsourcing, in-house production, and sales under competition?
- How does cost uncertainty affect supply chain firms' profits and risks under competition?

Supply Chain Network and Decision Timeline



The Behavior of the Manufacturers

Each manufacturer maximizes its expected profit as follows:

$$MAX\ E(\text{Profit}_j) = -\sum_{i=1}^{I} \rho_j^{i*} v_j^i - \sum_{i=1}^{I} h_j^i v_j^i + E[Q_{\omega\pi}^j(v_j, \Theta_\omega, \Phi_\pi)] \qquad (1)$$

The third term is the expected value of manufacturer j's net revenue in Stage 2. In particular, $Q_{\omega\pi}^j(v_j, \Theta_\omega, \Phi_\pi)$ is the optimal value of the following problem:

$$MAX\ \text{NetRevenue}_{j\omega\pi} = \sum_{m=1}^{M} \rho_m^j(\theta_{m\omega}, Y_{\omega\pi}^m) y_{\omega\pi}^{jm} - c_j(\phi_\pi, u_{\omega\pi}^j) \qquad (2)$$

subject to

$$\sum_{m=1}^{M} y_{\omega\pi}^{jm} \leq \sum_{i=1}^{I} v_j^i + u_{\omega\pi}^j, \qquad (3)$$

$$u_{\omega\pi}^j \leq CAP_j. \qquad (4)$$

The Behavior of the Offshore Suppliers

The offshore suppliers only transact with the manufacturers in the first stage, and do not need to consider the scenarios in the second stage. The optimization problem faced by Supplier i; $i = 1, ..., I$, can be expressed as follows:

$$MAX \text{ Profit}_i = \sum_{j=1}^{J} \rho_j^{i*} v_j^i - c_i(V^i) \tag{5}$$

subject to

$$\sum_{j=1}^{J} v_j^i \leq CAP_i, \tag{6}$$

$$v_j^i \geq 0, \quad \forall j.$$

Theorem: Variational Inequality Formulation of the Supply Chain Network Equilibrium

The equilibrium conditions governing the two-stage supply chain under demand and cost uncertainty coincide with the solution of the variational inequality given by: Determine $(V^*, U^*, Y^*) \in \mathcal{K}^3$ *satisfying:*

$$\sum_{i=1}^{I}\sum_{j=1}^{J}[\frac{\partial c_i(V^{i*})}{\partial v_j^i}+h_j^i]\times\left[v_j^i - v_j^{i*}\right]+\sum_{\omega\in\Omega}\sum_{\pi\in\Pi}\sum_{j=1}^{J} f(\omega,\pi)\frac{\partial c_j(\phi_\pi, u_{\omega\pi}^j)}{\partial u_{\omega\pi}^j}\times\left[u_{\omega\pi}^j - u_{\omega\pi}^{j*}\right]$$

$$-\sum_{\omega\in\Omega}\sum_{\pi\in\Pi}\sum_{j=1}^{J}\sum_{m=1}^{M} f(\omega,\pi)[\rho_m^j(\theta_{m\omega}, Y_{\omega\pi}^{m*})+\frac{\partial\rho_m^j(\theta_{m\omega}, Y_{\omega\pi}^{m*})}{\partial Y_{\omega\pi}^m}y_{\omega\pi}^{jm*}]\times\left[y_{\omega\pi}^{jm} - y_{\omega\pi}^{jm*}\right]\geq 0,$$

$$\forall (V, U, Y) \in \mathcal{K}^3, \qquad (7)$$

where

$\mathcal{K}^3 \equiv ((V, U, Y)|(V, U, Y) \in R_+^{IJ+|\Omega||\Pi|(J+JM)}$ *and* (3), (4), *and* (6) *hold).*

Qualitative Properties

Theorem 2: Existence *If all the cost functions are continuously differentiable and the inverse demand functions are continuous and continuously differentiable then there exists a solution to variational inequality (7).*

Theorem 3: Monotonicity
Suppose that all the cost functions in the model are continuously differentiable and convex. Also, suppose that all inverse demand functions are continuously differentiable, decreasing, and concave (hence, it could be linear). Then the vector F that enters the variational inequality (7) as expressed in (8) is monotone, that is,

$$\left\langle (F(X') - F(X''))^T, X' - X'' \right\rangle \geq 0, \quad \forall X', X'' \in \mathcal{K}, X' \neq X''. \tag{8}$$

Analytical Results

Propositions 1 and 2 establish connections between the value of outsourcing and real call and put options.

- A call option gives the option holder the right, but not the obligation, to purchase the underlying asset (e.g., a stock) at a pre-determined price (strike price) before/on a future expiration day. The payoff function of a call option on the expiration day is as follows:

$$\text{payoff} = MAX(0, S - K), \tag{9}$$

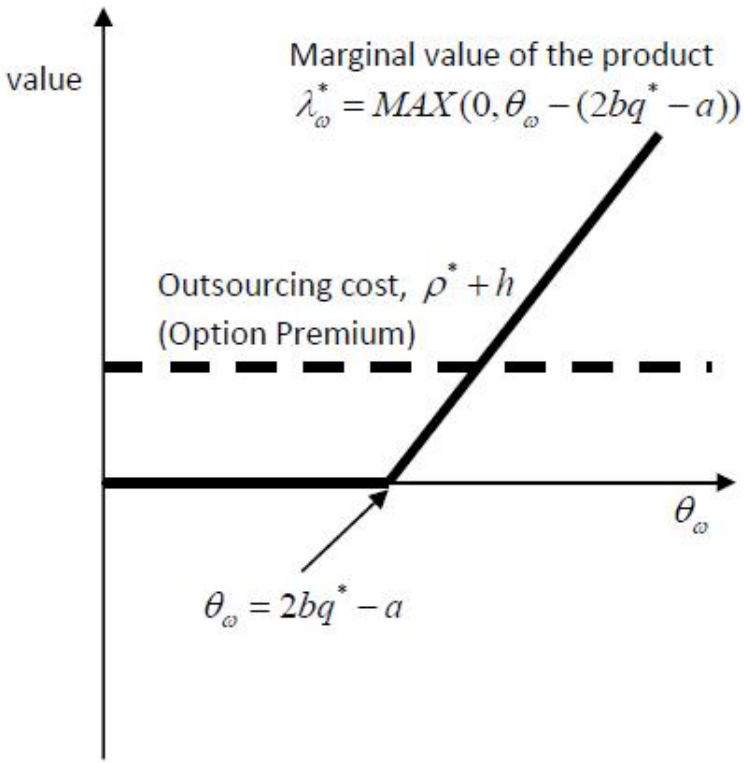
- A put option, on the other hand, gives the option holder the right but not the obligation to sell the underlying asset at a pre-determined price (strike price, K) before/on a future expiration day. The payoff function of a put option on the expiration day is as follows:

$$\text{payoff} = MAX(0, K - S). \tag{10}$$

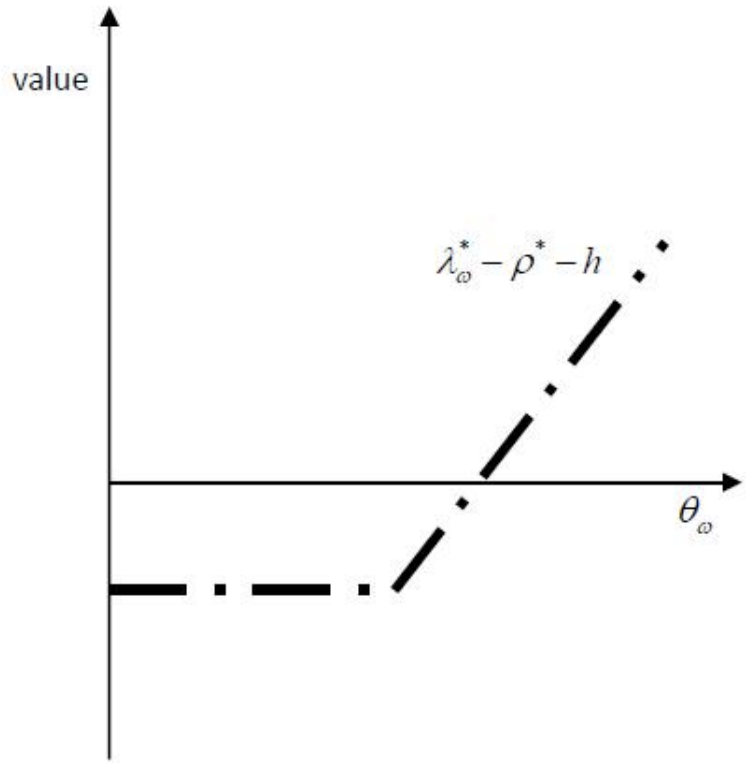
Proposition 1

Suppose that the manufacturer's capacity for fast-response in-house production is zero and that the manufacturer's outsourcing activity is positive ($v^* > 0$). The marginal value of the product in the second stage resembles the payoff of a real call option on the random demand factor, θ_ω, with strike price $K = 2bv^* - a$, that is, $\lambda^*_\omega = MAX(0, \theta_\omega - (2bv^* - a))$. Moreover, in the first stage the outsourcing cost the manufacturer is willing to pay, $\rho^* + h$, is equal to the expected value of this real call option, $\sum_{\omega \in \Omega} f(\omega)\lambda^*_\omega$.

Marginal Value of the Product in Stage 2 with Uncertain Demand



A. Marginal Value of the Product in Stage 2

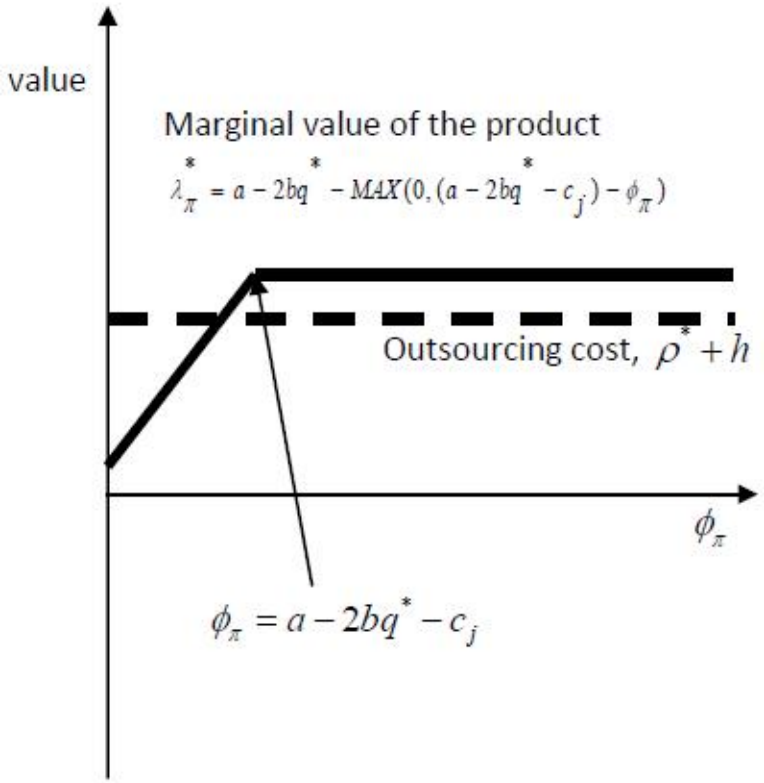


B. Net Marginal Value of the Product in Stage 2

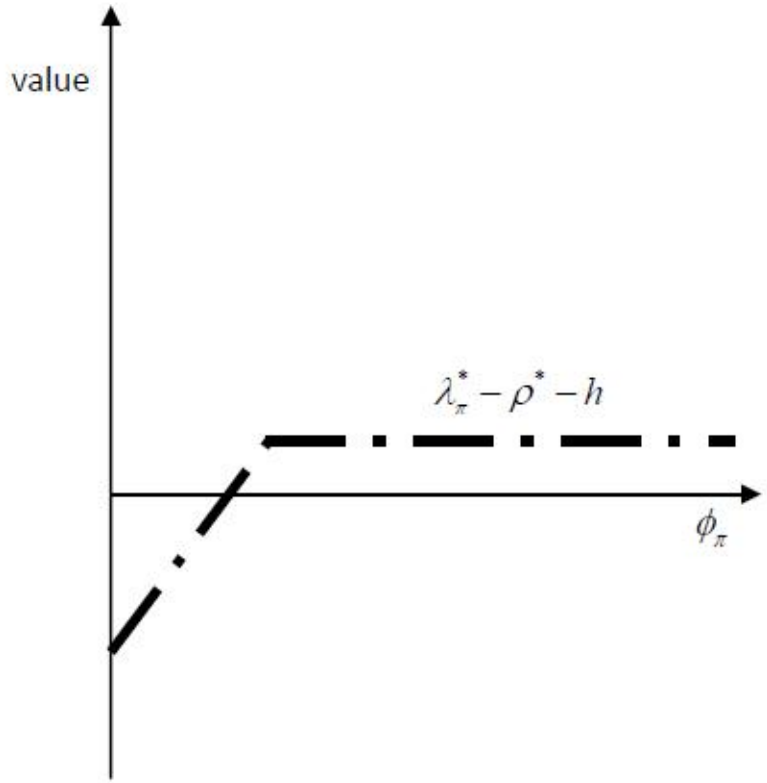
Proposition 2

Suppose that the manufacturer's capacity for fast-response in-house production is sufficiently large and that the manufacturer's outsourcing activity is positive ($v^* > 0$). The marginal value of the outsourced product in the second stage resembles the payoff of the short position of a real put option on the random cost factor, ϕ_π, with strike price $K = a - 2bv^* - c_j$, plus a constant, that is, $\lambda_\pi^* = (a - 2bv^*) - MAX(0, (a - 2bv^* - c_j) - \phi_\pi)$. Moreover, in the first stage, the outsourcing cost the manufacturer is willing to pay is equal to the expected payoff of such position, $\sum_{\pi \in \Pi} f(\pi)\lambda_\pi^*$.

Marginal Value of the Product in Stage 2 with Uncertain In-House Production Cost



A. Marginal Value of the Product in Stage 2



B. Net Marginal Value of the Product in Stage 2

Real Option Interpretations

- The value of an option increases as the volatility of the underlying asset increases.
- The outsourcing cost that the manufacturers without quick-response capability are willing to pay will *increase* as the uncertainty of demand gets *higher*.
- The outsourcing cost the manufacturers with quick-response capability are willing to pay will *decrease* as the uncertainty of the quick-response production cost gets *higher*.

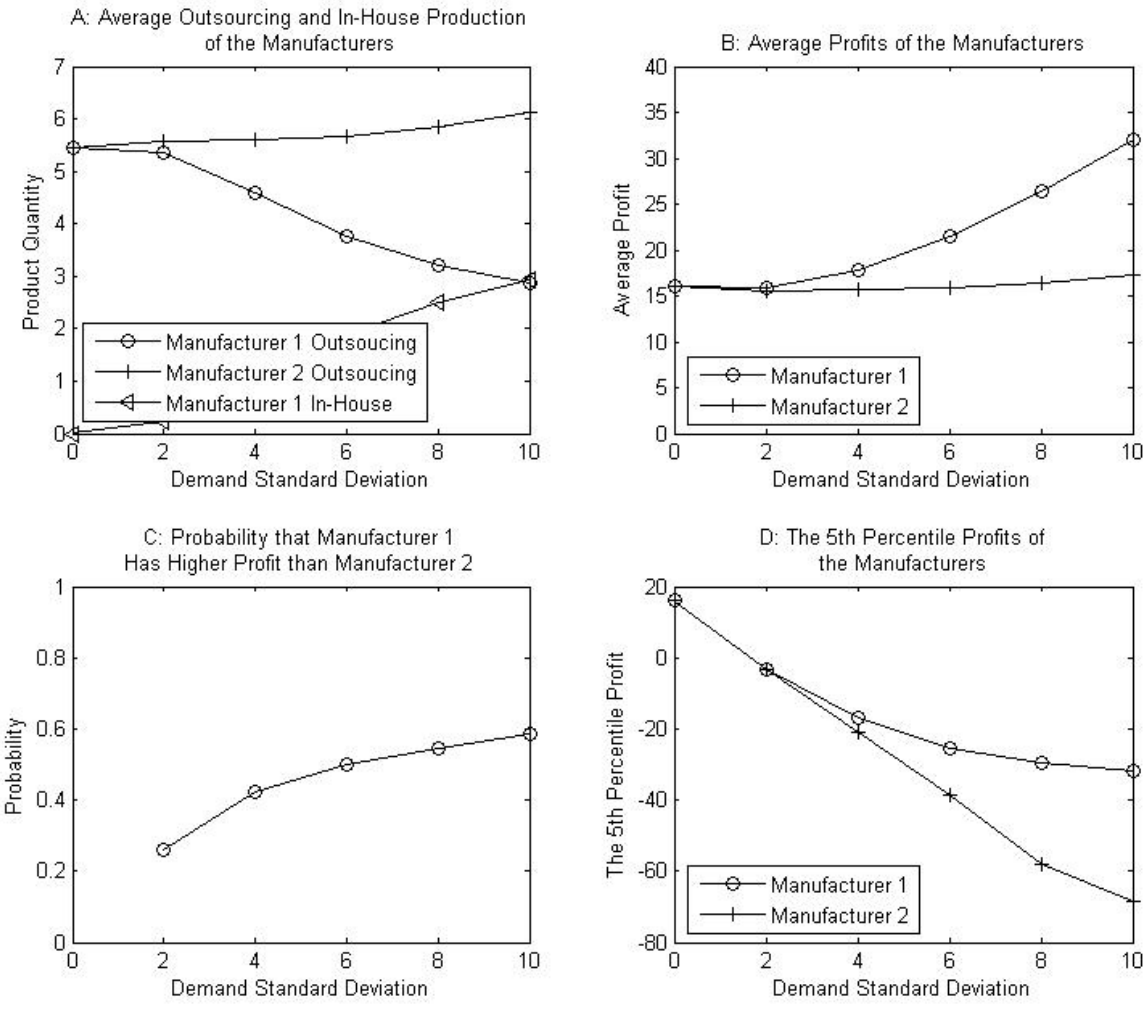
Simulation Studies

- Three simulation case studies
- Two hundred scenarios generated based on normal distribution

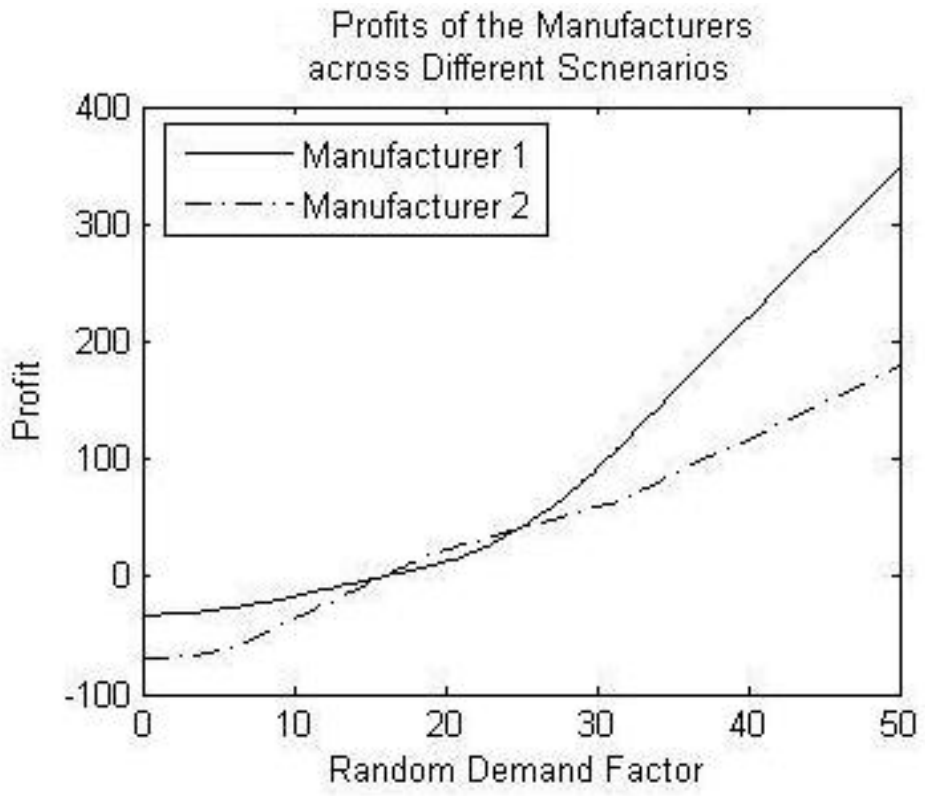
Simulation Study 1: Demand Uncertainty

- Two manufacturers: Manufacturer 1 has quick-response capability; Manufacturer 2 does not have such capability.
- How does demand uncertainty affect supply chain firms' decisions regarding outsourcing, in-house production, and sales under competition?
- How does demand uncertainty affect supply chain firms' profits and risks under competition?

Manufacturers' Decisions, Profits, and Risks at Different Levels of Demand Uncertainty



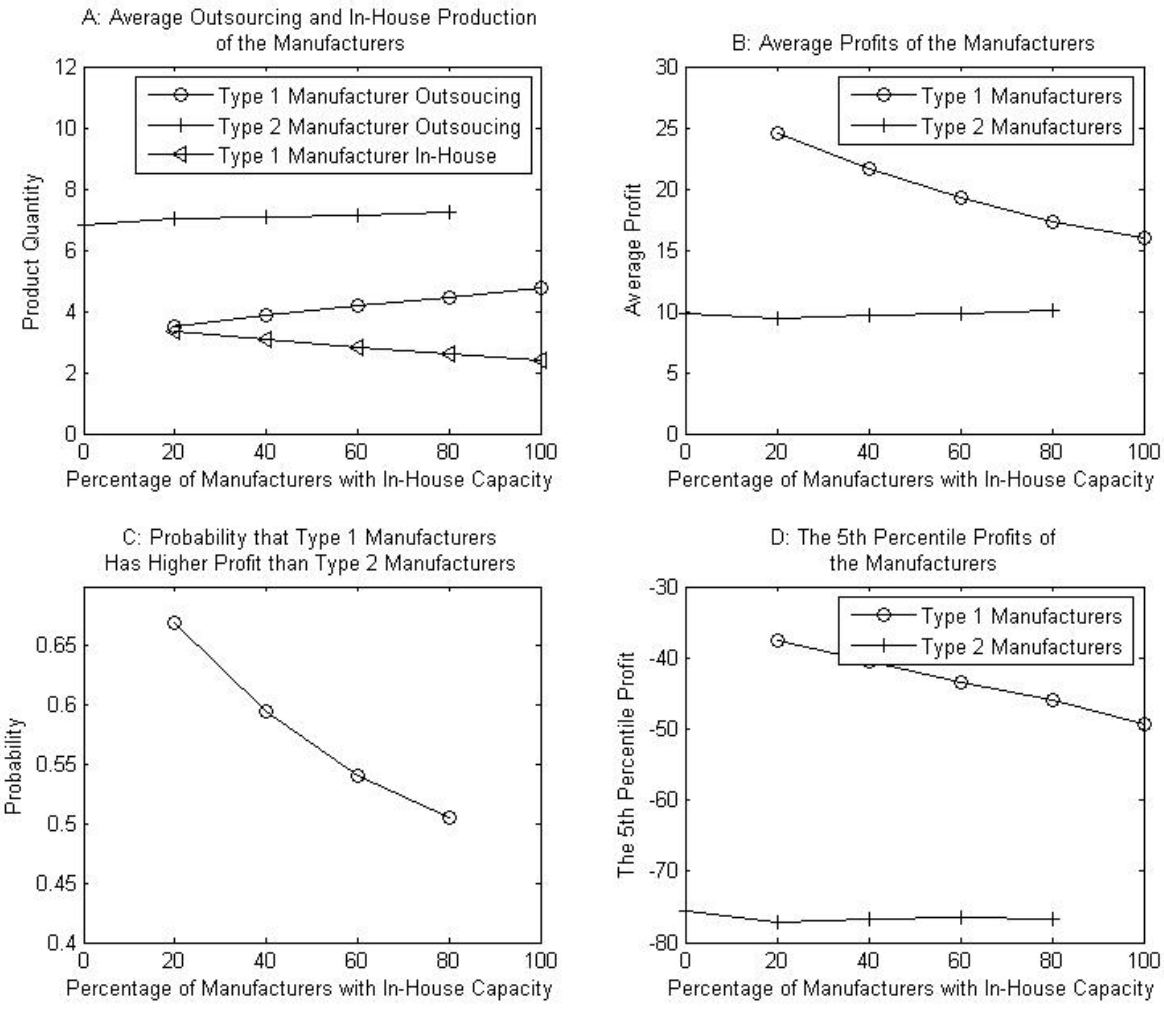
Manufacturers' Profits in Different Demand Scenarios



Simulation Study 2

- Five manufacturers: Type 1 manufacturers have quick-response capability; Type 2 manufacturers do not have such capability.
- We change the proportion of Type 1 manufacturers from 0% to 100%.
- How does the prevalence of the quick-response in-house production affect supply chain firms' decisions, profits, and risks under demand uncertainty?

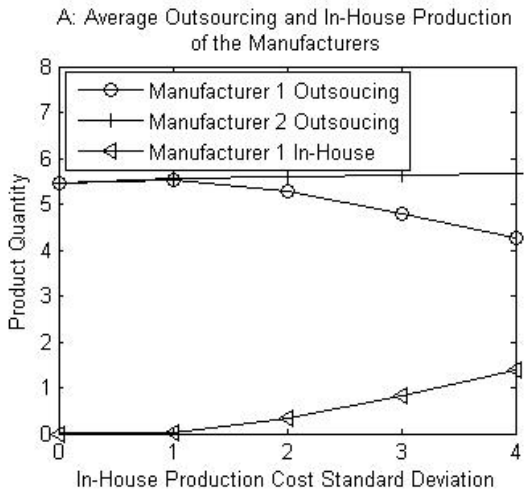
Manufacturers' Decisions, Profits, and Risks at Different Levels of Prevalence of Quick-response Production

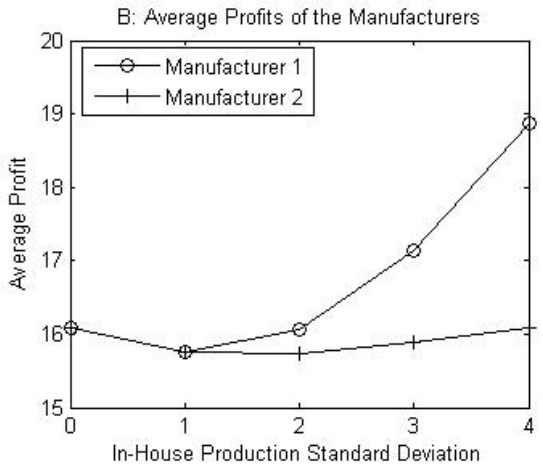


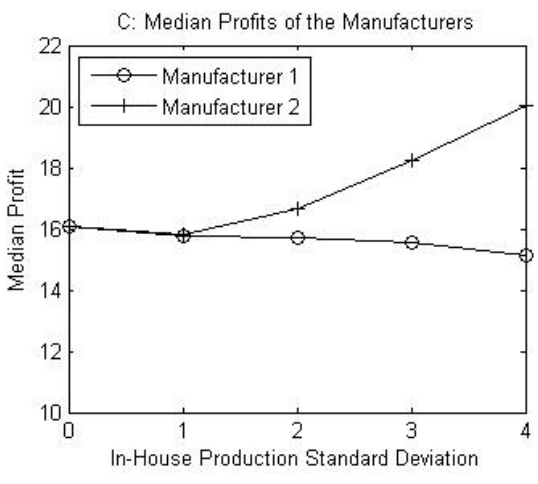
Simulation Study 3: Cost Uncertainty

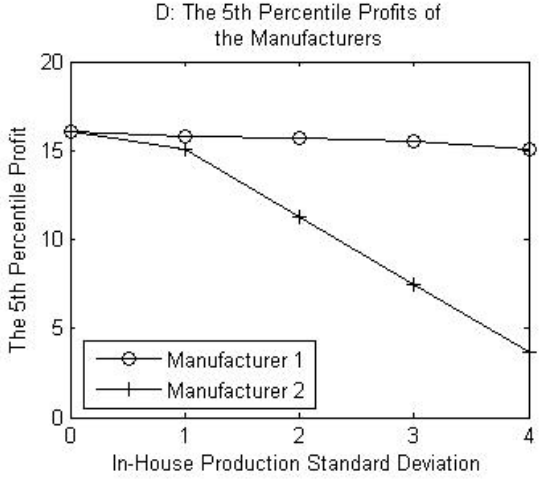
- Two manufacturers: Manufacturer 1 has quick-response capability; Manufacturer 2 does not have such capability.
- How does cost uncertainty affect supply chain firms' decisions regarding outsourcing, in-house production, and sales under competition?
- How does cost uncertainty affect supply chain firms' profits and risks under competition?

Manufacturers' Decisions, Profits, and Risks at Different Levels of Uncertainty of Quick-response Production Cost

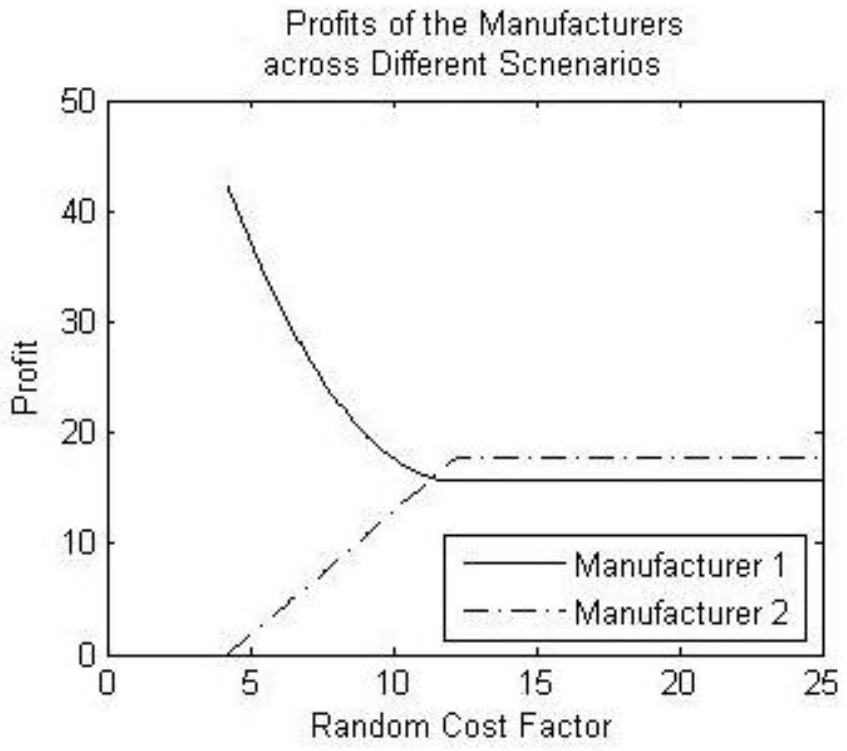








Manufacturers' Profits in Different Cost Scenarios



Managerial Insights and Conclusions

- The real option interpretations indicate that for manufacturers who do not have quick-response production capability, rising demand uncertainty will increase the value of outsourcing; and that for risk-neutral decision makers who have quick-response production capability, rising cost uncertainty will reduce the value of outsourcing.
- Manufacturers with quick-response production can expect higher average profit and lower risk than their competitors who do not have such capability. However, these manufacturers may not have a higher chance to beat their competitors in terms of profit when the demand uncertainty is low.
- Manufacturers without quick-response production are more profitable when the demand turns out to be at normal levels while manufacturers with such capability are more profitable when the demand is unexpectedly high or low.
- The prevalence of quick-response production will reduce the benefit.
- Manufacturers without quick-response capability should understand that they can still be indirectly and negatively affected by the cost variations of quick-response production through market competition.