COORDINATION, MARKET UNCERTAINTY, AND COMPETITIVE RELATIONSHIP IN SUPPLY CHAIN MANAGEMENT

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ABSTRACT

Coordination is one of the most critical factors for successful supply chain management. Thus, it is important to identify environmental conditions conducive to effective coordination between supply chain partners. We consider two such conditions, market uncertainty and competitive nature of the relationship between the partners. We conjecture that the more uncertain the market, the less effective the coordination, and the more competitive the relationship, the less willing are the partners to coordinate. In order to conduct an in-depth analysis of the propositions, we develop a stochastic optimal control model and derive analytical implications.

KEYWORDS

Coordination, Supply Chain Management, Stochastic Optimal Control Model

1. Introduction

Coordination is important for achieving an optimal system-level performance in a supply chain [1, 2]. But, there are different perspectives to define "coordination," e.g., the nature and/or essence of coordinating activities [3, 4]. In this article, we view the coordination as the cooperation between supplier and manufacturer for enhancing certain order-winning characteristics of their final products to the market. For instance, suppliers and manufacturers might work together to reduce the production lead-time so as to increase the market demand for their products. Sometimes they could try to improve the quality of the products through joint effort [5]. We further ask "*Under what circumstances can the coordination be more effective?*" In order to answer the question, we develop a stochastic optimal control model by taking into account two critical factors, i.e., market demand uncertainty and nature of the competitive relationship between supplier and manufacturer.

2. Coordination, Market Uncertainty, and Competitive Nature of a Supply Chain

In this section, we elaborate on the characteristics of market uncertainty and competitive relationship between supply chain partners. First, we assume that the market is 'competitive' in that there are many suppliers and manufacturers as well as buyers in the market, thus the price is essentially given to all of the economic entities. In other words, the supply chain partners as well as individual customers (i.e., buyers) are price-takers.

There is an inherent uncertainty in the marker demand for the final products, produced (or, assembled) and sold by the manufacturer. As shown later, we model the uncertainty with the standard deviation of the market demand.

Regarding the nature of the competitive relationship between supplier and manufacturer, we consider two different situations, *noncompetitive* and *competitive*. With 'noncompetitive supplier-manufacturer relationship,' we mean that there is little conflict of interest between the two partners, i.e., the two economic entities are not competing in the same end market. Figure 1 describes such a context.

Figure 1. A Noncompetitive Supply Chain

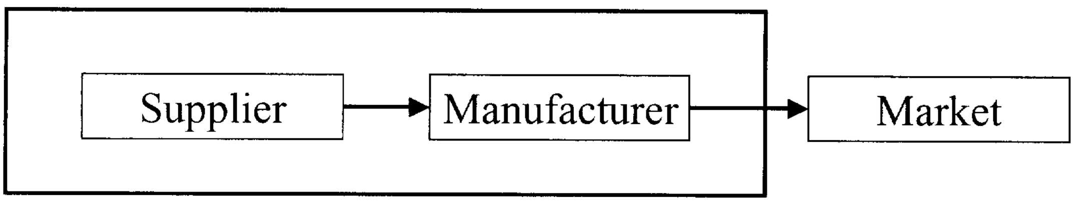
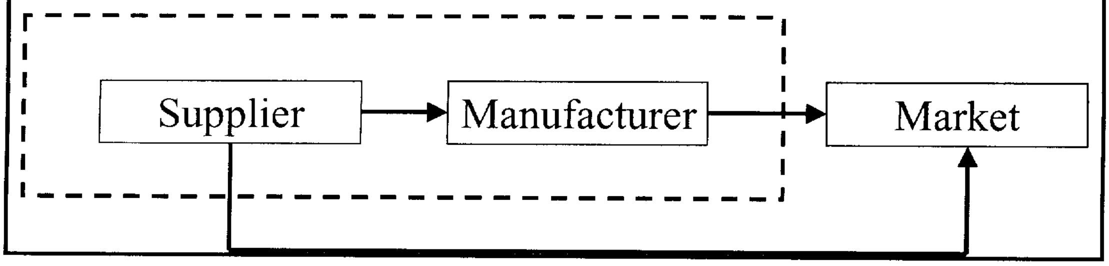


Figure 2. A Competitive Supply Chain



In a competitive supply chain as defined in this article, the supplier competes *both directly and indirectly* against the manufacturer. For instance, consider the PC industry. Distribution channels in the PC industry are characterized with a two-tiered system. Computer network and equipment manufacturers sell their products to full-line distributors including value-added resellers that in turn sell the final products to the end customers, and at the same time directly to the final customers, e.g., small and medium sized businesses and work-at-home consumers [6]. In this case, the supplier supplies its products to the manufacturer as intermediate goods, and at the same time sells them as finished ones after processing them fully. Figure 2 depicts such a situation.

In this article, we are asking '*whether the nature of competitive relationship along with the market uncertainty affects the coordination between supplier and manufacturer*' and '*how much, if any?*' In the next section, we develop a simple stochastic optimal control model to answer the questions. We incorporate the two critical factors, market uncertainty and competitive relationship between the two supply chain partners.

3. A Stochastic Optimal Control Model

Based on the model specifications in the previous section, we develop a stochastic optimal control model as follows. First, we consider the simpler case, i.e., the noncompetitive supply chain. Here we assume the primary objective of coordination is to enhance the quality of the products. Thus, hereafter we regard the goal of coordination as quality improvement.

The Noncompetitive Supply Chain

For the following development, we summarize the definitions of variables and parameters in Appendix 1.

- Quality improvement dynamics: $q' = \alpha_s e_s + \alpha_m e_m - \delta q$ ...(1)
- Market demand dynamics: $dx = qxdt + \sigma xdz$ ...(2)

As mentioned before, we consider an uncertain market demand and model it with a stochastic optimal dynamics as in (2). Equation (2) implies that over a short period of time, the proportionate change of the market demand is normally distributed with mean qdt and variance $\sigma^2 dt$: note $dx/x = qdt + \sigma dz$ [7].

Referring to the definitions in Appendix 1 and the constraints defined above, we can derive the supplier's expected profit as follows:

$$\Pi^s = E\left[\int_0^T \{(\phi p - c_s)x - \gamma_s(e_s - \bar{e}_s)^2\} dt + \psi_s(x(T), q(T), T)\right]. \qquad \ldots(3)$$

Similarly the manufacturer's expected profit is

$$\Pi^m = E\left[\int_0^T \{((1-\phi)p - c_m)x - \gamma_m(e_m - \bar{e}_m)^2\} dt + \psi_m(x(T), q(T), T)\right]. \qquad \ldots(4)$$

Thus, the supplier has the following *stochastic* optimal control problem:

Max $\quad \Pi^s = E\left[\int_0^T \{(\phi p - c_s)x - \gamma_s(e_s - \bar{e}_s)^2\} dt + \psi_s(x(T), q(T), T)\right]$

Subject to $\quad q' = \alpha_s e_s + \alpha_m e_m - \delta q$

$dx = qxdt + \sigma xdz$

with appropriate nonnegativity and other resource constraints.

Likewise, the manufacturer's decision problem is:

Max $\quad \Pi^m = E\left[\int_0^T \{((1-\phi)p - c_m)x - \gamma_m(e_m - \bar{e}_m)^2\} dt + \psi_m(x(T), q(T), T)\right]$

Subject to $\quad q' = \alpha_s e_s + \alpha_m e_m - \delta q$

$dx = qxdt + \sigma xdz$

with appropriate nonnegativity and other resource constraints.

The Competitive Supply Chain

Now let's consider the competitive supply chain, where the supplier has a conflicting relationship with the manufacturer. In defining the model, we use the same notations employed in the previous section with an exception for an additional notation: variables and parameters applicable only for the competitive supply chain have an additional subscript, v.

For the competitive supply chain, the supplier's expected profit is

$$\Pi^{v} = E\left[\int_{0}^{T}\left\{\left[(\phi p - c_s)x - \gamma_s(e_s - \bar{e}_s)^2\right] + \left[(p - c_v)x_v - \gamma_v(e_v - \bar{e}_v)^2\right]\right\}dt + \psi_v(x, x_v, q, q_v, T)\right]$$

...(5)

In addition to the dynamic constraints in the previous section, the present model needs to take into account two more dynamic constraints due to the competitive nature between the supplier and the manufacturer. The additional constraints are:

$$q_v' = \alpha_v e_v - \delta_v q_v \qquad ...(6)$$
$$dx_v = q_v x_v dt + \sigma_v x_v dz \qquad ...(7)$$

Now the supplier's stochastic optimal control problem can be defined as follows:

Max

$$\Pi^{v} = E\left[\int_{0}^{T}\left\{\left[(\phi p - c_s)x - \gamma_s(e_s - \bar{e}_s)^2\right] + \left[(p - c_v)x_v - \gamma_v(e_v - \bar{e}_v)^2\right]\right\}dt + \psi_v(x, x_v, q, q_v, T)\right]$$

Subject to

$$q' = \alpha_s e_s + \alpha_m e_m - \delta q$$
$$q_v' = \alpha_v e_v - \delta_v q_v$$
$$dx = qxdt + \sigma xdz$$
$$dx_v = q_v x_v dt + \sigma_v x_v dz$$

with appropriate nonnegativity and other resource constraints.

Since the competitive relationship affects only the supplier's profit function, the manufacturer has the same stochastic optimal control problem as in the previous setting.

Analytically solving the three models developed above is not straightforward. We try to sketch the problem solving procedure for the first model, i.e., the supplier's stochastic optimal control problem in the noncompetitive supply chain, in Appendix 2.

4. Discussion

The primary objective of this article is to explore a research issue in supply chain management. Recall the research question: "*How does the nature of the competitive relationship between supplier and manufacturer affect each player's decision on coordination when there is market demand uncertainty?*"

Consistent with the objective of this article, we suggest two propositions and peruse their managerial implications rather than solve the mathematical problems analytically. Our propositions are depicted in Figure 3 and 4.

Figure 3 shows the possible interaction among market uncertainty, competitive relationship, and supplier's coordination effort: although the dynamics of the manufacturer's coordination effort should be also interesting, we focus on the supplier's since the supplier's strategic reaction to market uncertainty and competitive relationship is more complicated. In Figure 3, the x-axis shows the relative level of uncertainty: since σ_v represents the market uncertainty for the competitive supply chain and σ for the noncompetitive supply chain, $\frac{\sigma_v}{\sigma}$ measures the relative level of uncertainty for the competitive supply chain vis-à-vis that of noncompetitive supply chain. On the other hands, the $y-axis$ represents the relative effort level of the supplier in the competitive supply chain to that in the noncompetitive supply chain, i.e., $\frac{e_v}{e_s}$. In the context of Figure 3, we can think of two different situations: as the market uncertainty of the competitive supply chain increases in relation to that of the noncompetitive supply chain, (a) the supplier relatively increases its effort for the coordination, or (b) decreases it. The exact shape of the relationship between the relative market uncertainty and the supplier's effort level will be determined by specific values taken by the parameters in the model. Of course, we are not excluding a possibility to see a relationship which is nonlinear, encompassing parts of (a) and (b) at the same time.

Figure 3. Proposition 1 – Market Uncertainty, Competitive Nature, and Supplier's Coordination Effort

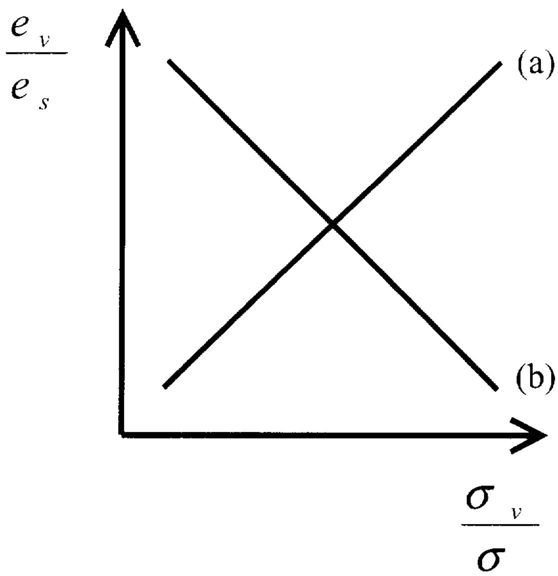
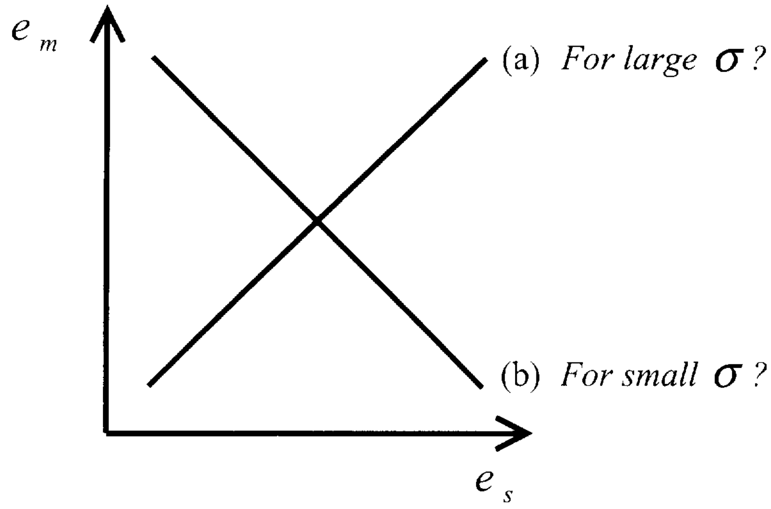


Figure 4. Proposition 2 – Supplier's Effort *versus* Manufacturer's Effort



In Figure 4, we compare the supplier's effort for the coordination with the manufacturer's, when the market uncertainty is large or small: here we are concerned with the noncompetitive supply chain only. Depending on the specific values of the market demand uncertainty, we will observe a positive relationship between the supplier's effort and the manufacturer's, or a negative relationship. We are again not excluding a possibility to observe a nonlinear (or any other) relationship for a particular set of parameter values.

The next step of this research is to either numerically or analytically solve the stochastic optimal control problems and to confirm or disconfirm the propositions suggested above. In doing so, we will be able to gain more (possibly new) insights into the dynamic interplay among market uncertainty, competitive relationship, and coordination effort in the supply chain management.

Future research needs to remedy some of the limitations this article has not been able to address fully. For instance, any game-theoretic situations are ignored here, nor information delay/distortion is discussed. It will be also interesting to see how the salvage value terms affect the final dynamics. In effect, this article is an exploratory piece that sets out a research agenda worthy to pursue.

5. Appendix

Appendix 1: Summary of Variables and Parameters

x : Market demand
q : Joint quality
e_s : Supplier's effort for improving the joint quality
$\bar{e}_s$: Most ideal level of the supplier's effort
e_m : Manufacturer's effort for improving the joint quality
$\bar{e}_m$: Most ideal level of the manufacturer's effort
c_s : Supplier's unit production cost
c_m : Manufacturer's unit production cost
γ_s : Unit cost of the supplier's effort
γ_m : Unit cost of the manufacturer's effort
α_s : Effectiveness measure of the supplier's effort
α_m : Effectiveness measure of the manufacturer's effort
δ : Decay rate of the joint quality
σ : Constant
z : Random variable following Wiener process
p : Given market unit price
ϕ : Proportion of the market price paid to the supplier
$\psi_s(x(T), q(T), T)$: Salvage value for the supplier
$\psi_m(x(T), q(T), T)$: Salvage value for the manufacturer

Appendix 2: Solution Procedure for the First Model

First, we try to solve the supplier's stochastic optimal control problem when the supplier-manufacturer relationship is not competitive. That is,

$$Max \qquad \Pi^s = E\left[\int_0^T \{(\phi p - c_s)x - \gamma_s(e_s - \bar{e}_s)^2\}dt + \psi_s(x(T), q(T), T)\right]$$

$$Subject\ to \qquad \begin{aligned} q' &= \alpha_s e_s + \alpha_m e_m - \delta q \\ dx &= qxdt + \sigma x dz. \end{aligned}$$

Define $J^s(x_0, q_0, t_0) = \max_{e_s} E\left[\int_{t_0}^T \{(\phi p - c_s)x - \gamma_s(e_s - \bar{e}_s)^2\}dt + \psi_s(x(T), q(T), T)\right]$

subject to $q' = \alpha_s e_s + \alpha_m e_m - \delta q$, $dx = qxdt + \sigma x dz$, $x(t_0) = x_0$, $q(t_0) = q_0$.

Now, $J^s(x, q, t) \cong \max_{e_s} E\left[\{(\phi p - c_s)x - \gamma_s(e_s - \bar{e}_s)^2\}\Delta t + J^s(x + \Delta x, q + \Delta q, t + \Delta t)\right]$

$$\begin{aligned} J^s(x + \Delta x, q + \Delta q, t + \Delta t) &= J^s + J_t^s \Delta t + J_x^s \Delta x + J_q^s \Delta q + \frac{1}{2} J_{tt}^s (\Delta t)^2 \\ &+ \frac{1}{2} J_{xx}^s (\Delta x)^2 + \frac{1}{2} J_{qq}^s (\Delta q)^2 + J_{tx}^s (\Delta t)(\Delta x) + J_{tq}^s (\Delta t)(\Delta q) + J_{xq}^s (\Delta x)(\Delta q) \end{aligned}$$

$$\therefore J^s(x + \Delta x, q + \Delta q, t + \Delta t) = J^s + J_t^s \Delta t + J_x^s \Delta x + J_q^s \Delta q + \frac{1}{2} J_{xx}^s (\Delta x)^2,$$

where we used $\Delta x = qx\Delta t + \sigma x \Delta z$, $\Delta q = (\alpha_s e_s + \alpha_m e_m - \delta q)\Delta t$, and Ito's lemma.

$$(\Delta x)^2 = (qx\Delta t + \sigma x \Delta z)(qx\Delta t + \sigma x \Delta z) = \sigma^2 x^2 \Delta t + h.o.t.$$

$$\therefore J^s(x + \Delta x, q + \Delta q, t + \Delta t) = J^s + J_t^s \Delta t + J_x^s \Delta x + J_q^s \Delta q + \frac{1}{2} J_{xx}^s (\Delta x)^2$$

$\therefore J^s = \max_{e_s} \Gamma$, where

$$\Gamma = E\left[\left\{(\phi p - c_s)x - \gamma_s(e_s - \bar{e}_s)^2\right\}\Delta t + J^s + J_t^s\Delta t + J_x^s\Delta x + J_q^s\Delta q + \frac{1}{2}J_{xx}^s\sigma^2 x^2\Delta t + h.o.t.\right]$$

Note that $E(\Delta z) = 0$. By rearranging terms, dividing both sides by Δt, and letting $\Delta t \to 0$, we have the following,

$$-J_t^s = \max_{e_s}\left[\left\{(\phi p - c_s)x - \gamma_s(e_s - \bar{e}_s)^2\right\} + J_x^s qx + J_q^s(\alpha_s e_s + \alpha_m e_m - \delta q) + \frac{1}{2}\sigma^2 x^2 J_{xx}^s\right]$$

$\therefore e_s^* = \bar{e}_s + \left(\frac{\alpha_s}{2\gamma_s}\right)J_q^s$, given e_m.

It is also easy to derive $x(t)^* = x_0 e^{(q-\sigma^2/2)t+\sigma z}$, $x(t)^* = x_0\exp\left(\left(q - \frac{\sigma^2}{2}\right)t + \sigma z\right)$

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