TSINGHUA SCIENCE AND TECHNOLOGY
ISSN 1007-0214 11/18 pp218-224
Volume 14, Number 2, April 2009

Supply Chain Coordination by Single-Period and Long-Term Contracts with Fuzzy Market Demand*

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Abstract: Due to the uncertainty of the market demand in the supply chain, this paper characterized market demand as a fuzzy variable and proposed single-period and long-term contracts to coordinate the two members (supplier and buyer) in the supply chain. Comparison of the effectiveness of the two contracts indicates that a long-term contract is more effective than a single-period contract in improving the profit potential of both the total supply chain and each member in the supply chain. This conclusion is useful to the decision-maker in supply chains with fuzzy market demand.

Key words: supply chain; long-term contract; game theory; fuzzy variable

Introduction

Supply chain contracts are tools adopted to achieve channel coordination in supply chain management. Various contract models have been presented in the literature, which differ based on the contractual clauses between the buyers (retailers or manufacturers) and the sellers (suppliers). For example, Tsay[1] and Tsay and Lovejoy[2] considered a supply chain consisting of two independent agents: the supplier and the buyer. Then they characterized the implications of quantity flexibility contracts on the behavior and performance of both parties, and on the supply chain as a whole. Eppen and Iyer[3] focused on the effect of a backup agreement between a catalog company and manufacturers in a scheme to provide upstream sourcing flexibility for fashion merchandise. Previous research has applied game theory to show that such opportunistic behavior results in supply chain inefficiencies[4-8]. A recent empirical study of the semiconductor equipment industry confirmed these results by demonstrating that if forecasts are not credible, they will be ignored and supply chain performance suffers[9]. This study also concludes that information sharing among supply chain members by itself is not sufficient to improve supply chain performance.

If the demand is known before the order is placed to the supplier by the manufacturer, the contracts above may be effective in some industries. In the real world, demand changes from one period to another. Thus, there is a high degree of uncertainty in a data set but it is difficult to estimate its probability of distribution due to the lack of historic data. Fuzzy set theory was originally introduced by Zadeh[10] to provide a framework for handling this type of problem in fuzzy environments. Since then, many researchers such as Yager[11] and Zimmermann[12] have successfully applied the theory to optimization problems. Recently, Liu[13] laid a foundation for optimization theory in uncertain environments with numerous models proposed to deal with the optimization problems. In this paper, the uncertainty of market demand is characterized by a fuzzy variable to contribute new insight into decision making in engineering management.

Received: 2008-03-07; revised: 2008-07-02

* Supported by the National Natural Science Foundation of China (No. 70801042) and the Scientific Research Launching Foundation for Introduced Talents in Tianjin University of Science and Technology (No. 20080430)

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1 Preliminaries

Let Θ be a nonempty set and $P(\Theta)$ the power set of Θ. For any $A \in P(\Theta)$, a credibility measure $\mathrm{Cr}\{A\}$ is used to express the chance that a fuzzy event A occurs[14]. Li and Liu[15] proved that a set function $\mathrm{Cr}\{\cdot\}$ is a credibility measure if and only if

(1) $\mathrm{Cr}\{\Theta\} = 1$;

(2) Cr is increasing, i.e., $\mathrm{Cr}\{A\} \leqslant \mathrm{Cr}\{B\}$ whenever $A \subset B$;

(3) Cr is self-dual, i.e., $\mathrm{Cr}\{A\} + \mathrm{Cr}\{A^c\} = 1$ for any $A \in P(\Theta)$;

(4) $\mathrm{Cr}\{\cup_i A_i\} \wedge 0.5 = \sup_i \mathrm{Cr}\{A_i\}$ for any A_i with $\mathrm{Cr}\{A_i\} \leqslant 0.5$.

The triplet $(\Theta, P(\Theta), \mathrm{Cr})$ is called a credibility space and a fuzzy variable is defined as a function from this space to the set of real numbers[16].

Definition 1[13] The credibility distribution Φ: $\mathbf{R} \to [0,1]$ of a fuzzy variable ξ is defined by

$$\Phi(x) = \mathrm{Cr}\{\theta \in \Theta \mid \xi(\theta) \leqslant x\} \tag{1}$$

then $\Phi(\cdot)$ is called the credibility distribution of the fuzzy variable ξ.

Definition 2[13] Suppose that ξ is a fuzzy variable and Φ is the credibility distribution of ξ. If the function $\phi: \mathbf{R} \to [0, +\infty)$ satisfies the following equation:

$$\Phi(x) = \int_{-\infty}^{x} \phi(y)\mathrm{d}y, \ \forall x \in \mathbf{R} \tag{2}$$

then ϕ is called the credibility density function of the fuzzy variable ξ.

Definition 3[14] Let ξ be a fuzzy variable defined on the credibility space $(\Theta, P(\Theta), \mathrm{Cr})$. The expected value is defined as

$$E[\xi] = \int_0^{+\infty} \mathrm{Cr}\{\xi \geqslant x\}\mathrm{d}r - \int_{-\infty}^{0} \mathrm{Cr}\{\xi \leqslant x\}\mathrm{d}r \tag{3}$$

provided that at least one of the two integrals is finite.

Remark 1[14] Let f be a function on $\mathbf{R} \to \mathbf{R}$ and ξ be a fuzzy variable defined on the credibility space $(\Theta, P(\Theta), \mathrm{Cr})$. Then, the expected value $E[f(\xi)]$ is defined as

$$E[f(\xi)] = \int_0^{+\infty} \mathrm{Cr}\{f(\xi) \geqslant x\}\mathrm{d}r - \int_{-\infty}^{0} \mathrm{Cr}\{f(\xi) \geqslant x\}\mathrm{d}r \tag{4}$$

Definition 4[17] The fuzzy variables $\xi_1, \xi_2, \dots, \xi_m$ are independent if and only if

$$\mathrm{Cr}\{\bigcap_{i=1}^{m}\{\xi_i \in B_i\}\} = \min_{1 \leqslant i \leqslant m} \mathrm{Cr}\{\xi \in B_i\} \tag{5}$$

for any sets B_1, B_2, …, B_m of $\mathbf{R}$.

Lemma 1[17] The fuzzy variables ξ_1, ξ_2, …, ξ_m are independent if and only if

$$\mathrm{Cr}\{\bigcup_{i=1}^{m}\{\xi_i \in B_i\}\} = \max_{1 \leqslant i \leqslant m} \mathrm{Cr}\{\xi \in B_i\} \tag{6}$$

for any sets B_1, B_2, ..., B_m of $\mathbf{R}$.

Lemma 2[18] Let ξ be a fuzzy variable with the credibility distribution function $\Phi(\cdot)$ and the credibility density function $\phi(\cdot)$. Assume that the support of ξ is denoted by $\Theta = [u, v]$, then

$$E[\min(z, \xi)] = z - \int_u^z (z - x)\phi(x)\mathrm{d}x \tag{7}$$

where $0 \leqslant u \leqslant z \leqslant v$.

2 Problem Formulation

Consider a supply chain with two successive links: a manufacturer and its supplier. After forecasting the market demand, the manufacturer places an order to the supplier who will agree to any transaction with the manufacturer that yields a non-negative economic profit. Then, the supplier decides his production quantity. The transaction between the supplier and the manufacturer is made either with a single-period or a long-term contract.

The parameters and assumptions used in this paper are listed below.

Parameters

p : product's selling price per unit;

q : supplier's production quantity;

Q : manufacturer's order quantity to the supplier;

c_s : supplier's production cost per unit;

c_m : manufacturer's production cost per unit;

w: wholesale price that the manufacturer pays to the supplier per unit;

D: market demand;

π_s: supplier's profit for the single-period contract;

π_m : manufacturer's profit for the single-period contract;

Π: total supply chain's profit for the single-period contract;

π_s^L: supplier's profit for the long-term contract;

π_m^L: manufacturer's profit for the long-term contract;

Π^L: total supply chain's profit for the long-term