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# The investment strategies for a dynamic supply chain under stochastic demands

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ABSTRACT

A successful supply chain management (SCM) should aim to maximize the net present value of joint profits along the supply chain. However, the volatile market conditions cause the future cash flows along the supply chain more difficult to anticipate. To obtain higher supply chain value, the supplier and the retailer should cooperatively determine the optimal entry time. This paper proposes a two-stage dynamic optimization model by using a real option approach and then performs the sensitivity analyses for the option value and the investment threshold. The impacts of some critical factors, including the growth rate and the volatility of demand shock, sunk cost, and relating operational costs (cost rates, fix costs, holding costs of inventory, and shipping costs), are investigated.



## 1. Introduction

In an inflationary world today, the declining demands are seriously hampering the profitability of companies and forcing them to compete for the diminishing profits. However, the proper coordination in the marketing channel could generate more joint profits along the supply chain. The extra profits can be then distributed among the players of the supply chain. Many previous researches have focused on the issues of channel coordination and profits sharing. Giannooccaro and Pontrandolfo (2004) classified the supply chain into two categories: centralized and decentralized. Firstly, the centralized supply chain involves the environment under which a unique decision maker controls the pricing policy due to its dominance and bargaining power along the supply chain. It can be also regarded as a vertical integrated system. Secondly, the decentralized system allows the players in a supply chain to make their own pricing policies separately and independently. However, the local maximization could not necessary be global maximum. Yong-Wu Zhou and Shanlin Yang (2008) demonstrated that the joint profits generated by the players in a supply chain when they make the pricing decisions coordinately are 1.3 and 2.3 times the profits, which are generated when pricing decisions are made independently, in the context of 2-echelon and 3-echelon systems, respectively. Biehl et al. (2006) also examined the effectiveness of joint decision making with buyer–supplier relationships in manufacturing and indicated that cooperative decision making contributes to the efficiency of SCM and to their competitiveness in a market. To facilitate the coordination along the supply chain, some mechanisms can be developed through quantity discount, price discount, and profit-sharing contract, etc. All the mechanisms are used to distribute the extra profits among the players in a supply chain favorably and fairly, and to ensure that all of them will gain more profits when they make decisions jointly than they do separately. Giannooccaro and Pontrandolfo (2004) used the revenue sharing contract in their model to coordinate the supply chain, but they assumed that the market demand is independent of the retailing price, while Zhou and Yang assumed the deterministic price-sensitive demand. Stefano Battiston et al. (2007) investigated the impacts of interactions among firms which are connected by production and credit ties, on the bankruptcy prorogation due to supply failures. All the profit-sharing mechanisms are designed to distribute extra profits among the players in a supply chain favorably and fairly. To measure the effectiveness and desirability of profit sharing mechanism, Giannooccaro and Pontrandolfo (2009) proposed a desirability index by calculating a ratio of profit after coordination relative to profit before coordination for each player in a supply chain. The higher the ratio, the more incremental profit the player gets, and the more the player is satisfied with profit sharing mechanism.

Even though many researches emphasize the coordination issues, but they discussed in different settings. Xiao et al. (2005) proposed a SCM model with one manufacturer and two retailers, and found that the contractual arrangements can enhance the coordination among them, while Sethi et al. (2005) formulated a SCM with two suppliers and a single retailer. Similarly, we aim to explore the cooperative decision making for the joint profits in a single-supplier and single-retailer system. There exist two echelons in the supply chain: the first level belongs to the business

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market with a single supplier, while the second level belongs to the consumer market with a single distributer. The supplier delivers the goods to the distributer, who will then sell the products directly to the final consumers. The optimal delivery rates of the supplier and the distributer are jointly determined through the maximization of the total profits in the supply chain, while the optimal entry time is determined by the rule that the stochastic supply chain value should be higher than the investment threshold (value threshold or demand shock threshold), which can be derived in this framework. According to the definition of Dixit and Pindyck (1994a, 1994b), investment threshold is a cutoff value, greater than which termination of real option (undertaking investment) is optimal, less than which continuation of real option (waiting) is optimal, and at which termination and continuation is equally optimal. Based on the above definition, optimal entry time is defined as the time when undertaking an investment is optimal. In other words, when corporate value is greater than investment threshold, it is the optimal entry time to undertake the investment. As to the investment strategy to be discussed in this framework, it is the strategy of investment timing, defined as a rule to determine the optimal time to invest. Compared with the price trigger in the research of Sigbjorn Sodal (2006) on the entry and exit decisions for the investment projects, the value threshold in this model is similar to the price trigger.

This paper extends the "Capacity Choice" model by Pindyck (1988), who employs the contingent claim approach to propose that the market value of a firm can be maximized through the optimal choice of the production capacity, which depends deeply on how the stochastic demand evolves. Instead, we intend to propose an optimization model by using the stochastic dynamic programming approach to valuate a dynamic supply chain. Moreover, Pindyck (1991) indicated in the framework of "Investment Timing" that the value threshold is chosen to maximize the net payoff of an investment, which once undertaken incurs the irreversible sunk cost. The common decision rule for those papers focusing on the entry strategies is that the investment will not be undertaken until the project value stochastically evolves higher than the value threshold. The first passage time when the value of the underlying real asset is above the threshold is referred to as the optimal entry time.

Under the assumption that the uncertainty of market demands follows a geometric Brownian motion (GBM), the delivery rates for the supplier and the retailer can be simultaneously determined in maximizing the supply chain value by a real option approach. Many discussions on the real option model in continuous time could be found in the researches by Brennan and Schwartz (1985), McDonald and Siegel (1986), Pindyck (1988, 1991), Dixit (1989) while the lattice method in discrete time is used to valuate the real option by Brandao and Dyer (2005), who derive the numerical solutions by a decision tree tool. Most of them focus on the revenue-related uncertainty, while some others focus on the technological uncertainty, e.g. Grenadier and Weiss (1977), Farzin et al. (1998), Doraszelski (2004). Moreover, Pauli Murto (2007) investigates the interactions between the technological and the revenue-related uncertainties. The main reason why the scholars valuate a real asset (a project or firm value) by the real option approach is that the traditional NPV method underestimates the value of the real asset because of the neglect of the uncertainty and the manufacturing flexibility (Pindyck, 1991; Triantis and Hodder, 1990). They focused on the effects of the price volatility on the output rate and found that the increase of the price volatility induces the increase of the output rate. The other effects of the price volatility could be found in the works of Van Wijnbergen (1985), Ingersoll and Ross (1992). In this model, the demand uncertainty, instead of the price uncertainty, is introduced. The price elasticity of demand and the discount rate are also considered in the derivation of the value threshold for the supply chain investment. Sensitivity analyses of the value threshold and the option value to the demand uncertainty and elasticity are also performed to provide readers with more insights into this framework.

This paper is organized as follows: Section 1 addresses the necessity and benefits of implementing a coordinated supply chain and introduces the recent researches on the maximization of joint profits. A real option approach is also introduced to explore and the effects of the price (demand) uncertainty and the interest rate on the output rate for a manufacturing company. Section 2 presents a two-echelon supply chain model under the assumption of the stochastically evolved demand uncertainty in a single-supplier/single-retailer system. The dynamic maximization in joint profits generated from the supplier and the retailer is proposed and the analytical solutions are obtained. In Section 3, we use the empirical data to test the fit of a GBM process for several different products and then estimate the parameters used in this framework. Section 4 performs sensitivity analyses of value thresholds and option values. The analytical results are also depicted in figures and the implications are discussed. Section 5 concludes this paper and recommends the possible further studies.

## 2. The model

In this model, we intend to optimize the value of a two-echelon supply chain by using the stochastic dynamic programming approach (Dreyfus, 1965). We assume that there are two major players in the supply chain: a single supplier, which manufactures and delivers the goods to a single retailer, who will instantly forward the products to the final customers in the consumer market. We assume that the supplier and the retailer own enough production and shipping capacity to instantly meet their customers' demands. In order to clearly demonstrate inputs, variables, parameters and outputs in this framework, the following symbols are defined:

(1) Inputs

| | |
|---|---|
| $P_{it}$ | denotes unit price of products at time $t$ for supplier ($i=1$) or retailer ($i=2$) |
| $C_{it}$ | denotes marginal cost of products for supplier or retailer |
| $Q_{it}$ | denotes demanded and delivered quantity for supplier or retailer |
| $R_{it}$ | denotes revenue at time $t$ for supplier or retailer |
| $\phi_t$ | denotes demand shock |

(2) Variables

| | |
|---|---|
| $s_i$ | denotes shipping cost for supplier or retailer |
| $h$ | denotes holding cost of inventory |
| $\gamma_i$ | denotes cost rate for supplier or retailer |
| $C_{i0}$ | denotes fix cost for supplier or retailer |
| $I$ | denotes sunk cost of investment |

(3) Parameters

| | |
|---|---|
| $\rho$ | denotes constant risk-adjusted discount rate |
| $\varepsilon$ | denotes price elasticity of demand |
| $\alpha$ | denotes the growth rate of demand shock |
| $\sigma$ | denotes the volatility of demand shock |
| $dz_i$ | denotes a standard-distributed Brownian motion |

(4) Outputs

| | |
|---|---|
| $V_t$ | denotes supply chain value at time $t$ |