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RESEARCH PAPER

Fresh Product Supply Chain Coordination under CIF Business Model with Long Distance Transportation

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Abstract: This article focuses on the optimization and coordination of a fresh product supply chain under the CIF (Cost Insurance and Freight) business model with an uncertain long distance transportation. The following system is considered: A producer transports a certain amount of fresh products to a distant wholesale market, at which he sells them to a distributor. Because of the uncertain transportation delays, he faces the risk that the product might decay or deteriorate during the transportation process. The distributor procures the products at the wholesale market and sells them to a consumer-market that is sensitive to both the price and the freshness level of the product. The optimal initial quantity, the optimal wholesale price, and the optimal retailing price are studied under the assumption that both the decision makers are risk-neutral. On basis of the optimal solutions for the centralized system as a benchmark, a simple cost sharing mechanism is developed to coordinate the supply chain under consideration.

Key Words: supply chain coordination; long distance transportation; fresh product; cost insurance and freight.

1 Introduction

The production of fresh products, such as live seafood, fresh fruit, fresh vegetables, fresh flowers, etc., is highly characterized by geographical location. As such, it is quite common that a product that is produced in one region is sold to another distant market, in which the product is consumed. For example, fresh fruit is imported into China from California, whereas fresh vegetables are exported from China to other countries such as Europe and Japan. The so-called "South-Vegetable North-Transportation" project is also an example of long-distance transportation of fresh products. The highly perishable nature of the products, however, makes it a big challenge to keep them fresh during the long distance transportation. The product will continue to decay or deteriorate and therefore incurs great economical loss even under the optimal handling and transportation conditions[1]. Some uncontrollable factors like bad weather condition, machine breakdown, schedule adjustment, etc., will further enlarge the magnitude of product loss. As a recent Accenture report shows, the product loss in China Cold Chain is rather severe, with an annual loss of $8.9 billion for vegetables and fruits, which accounts for 30% of the total output[2]. Other statistics show that the decay/deteriorate rate in transportation of China fruits is as high as 15–30%[3].

The highly perishable nature of the product has made it a great challenge for the producer and the distributor during the supply chain management. This is because, the decay/deterioration risk creates huge uncertainties for the effective supply of the products; as a result, the producer and the distributor involved in the supply chain face the problem of how to match the unreliable supply with the market demand so as to improve the profit. Let's consider the CIF (Cost Insurance and Freight) business model as an example, where the producer transships the products to a distant wholesale market and sells them to a distributor. Considering the possible product decay/deterioration, the producer needs to determine the quantity to be transported; after the products arrive at the target market, he needs to choose a suitable wholesale price, on basis of the freshness level and effective inventory status. In contrast, the distributor needs to decide on her optimal procurement quantity and retail price to maximize her own profit, in response to the upstream producer's selling price and the freshness level of the product. Two interesting issues occur in the above CIF business model: what are the best decisions for the producer and the distributor who seek to maximize their respective profit? Could one develop an effective mechanism under which both parties can be better off? This article seeks to give answers to the questions.

As a special category of the perishable products, the fresh product has its own particularity. That is, the decay/deterioration decreases not only the effective supply, but also the freshness level that might impact the market demand (i.e., the market demand depends on the freshness level). In traditional publications that study the inventory management and pricing strategies of perishable products[4−5], only the quantity loss of products is considered; therefore they belong to the "Random Yield" stream of publications[6−8]. In

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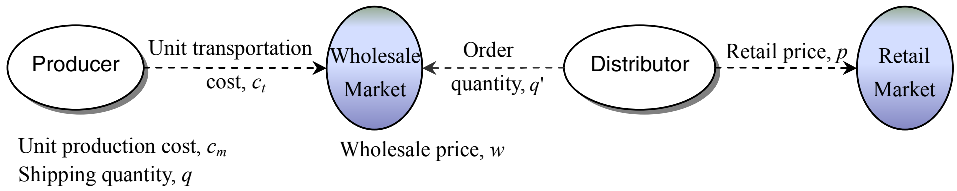

Figure 1. Model under investigation

the fresh product supply chain under consideration, the decay/deterioration of the products might impact both the effective supply and market demand; this increases the difficulty in matching the supply with demand by using price adjustment. To the best of our knowledge, Rajan et al. study both value drop and quantity decrease[9]. They focus, however, on a model with deterministic demand, in which the decision maker tries to optimize the price $p(t)$ and the order cycle length of inventory replenishment to maximize the average profit per unit time (the optimal price is assumed to be a deterministic function of t). Whereas our model considers the uncertainties associated with both the market demand and product decay/deterioration, and focuses on the impact of the loss in quantity and quality of products simultaneously.

Moreover, we will investigate the feasible mechanism(s) that might induce the producer and the distributor to act in a coordinated way. In the wide stream of publishing on supply chain coordination[10−11], the starting point of the mechanisms is to share the market risk between the upstream and downstream firms, so that the decentralized supply chain can achieve a same performance as that of the centralized supply chain. Our model, however, also incorporates the product decay/deteriation risk, which might increase the complexities of the feasible coordination mechanism. Our research shows that, a simple "cost sharing" mechanism can coordinate the supply chain efficiently.

In a previous work, we have studied the coordination between the producer and distributor under the FOB (Free on Board) business model[12], where the distributor procures from the producer and then transports the products to a distant market. In the FOB business model, both the market risk and product loss risk are born by the downstream distributor, whereas in the business model considered in this article, the market risk and the transportation risk are born by the distributor and the producer, respectively. Our research shows that different business models might have great impact on the optimal decisions and feasible coordination mechanisms. Comparison between the two business models might provide some interesting managerial insights for the management of fresh product supply chains.

2 Notations and assumptions

We study a single-period supply chain that comprises of one producer and one distributor. At the beginning of the period, the producer produces a certain amount, denoted by q, of some fresh product at unit production cost c_m.Because of its own character, the product has a fresh duration, say τ, exceeding which, the product begins to deteriorate. After the production, the producer transports the products to a distant wholesale market by some vehicle, who in turn undertakes both the transportation fee and risk. Denote the unit transportation fee by c_t. Without loss of generality, we assume a zero fixed transportation cost. Because of uncontrollable factors like bad weather condition, facility malfunction, schedule adjustment, etc., the transportation time T is uncertain, with known distribution based on past experiences. For ease of exposition, we assume T is a random variable in $[a, b]$ ($a < \tau < b$) with CDF $G(t)$ and PDF $g(t)$ respectively. The transportation process will take effects on the fresh product in the following two aspects:

(1) On the "quantity" side: it is inevitable that a portion of the products will be spoiled during the transportation process. The longer the transportation time, the more the products will be wasted. We define a transportation time related spoilage factor $\phi(t) \in [0, 1]$, which means $q\phi(t)$ products will be lost given the transportation time being t. As a result, the efficient supply of the product is $q(1 - \phi(t)) := qm(t)$.

(2) On the "quality" side: The longer the transportation time, the less fresher the product becomes. Denote by $\theta(t)$ the freshness factor ($0 \le \theta(t) \le 1$), a piece-wise continuous decrease function. For a given wholesale price, the higher the freshness level, the larger the market demand.

After the products arrive at the wholesale market, the producer decides the selling price, denoted as w, on basis of the product's status (the available supply and the freshness level). As a consequence, the distributor then decides his order quantity q' and set a wholesale price p accordingly. An illustration of the model under consideration is given by Figure 1.

Following Petruzzi and Dada, and Wang et al.[13,14], we used the following demand function with multiplicative format:

$$D(p, t) = y_0 p^{-k} \theta(t) \cdot \varepsilon, \quad k > 1$$

where ε is a stochastic variable with PDF $f(x)$ and CDF $F(x)$, y_0 is a measurement of market scale, and k represents the price elasticity of market demand. Without loss of generality, we assume $\mathbb{E}[\varepsilon] = 1$. As our research focus is on the price-sensitive product, we assume $k > 1$. The above demand function is actually an extension of classical multiplicative demand format by taking into account the effect of the product's freshness level.

To simplify our analysis, we assume that the salvage value of any unsold product is zero. We don't consider the loss of goodwill either. We assume that all the information (e.g., production cost, market demand) are common knowledge to both parties. The sequence of events is as follows: the producer determines his optimal shipping quantity q first, and then the selling price w upon the products' arriving at the wholesale market;and the producer decides on his purchasing quantity q' and wholesale price based on the producer's