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Price and Service Decisions in a Joint Product Network under Demand Uncertainty

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1. INTRODUCTION

The classical newsvendor model assumes unmet demand is lost (Petruzzi & Dada, 1999). Its assumption implies that customers are stockout neutral. In practice, it is usually unacceptable for firms to thoroughly lose the unmet demand, because those unsatisfied customers will attempt to purchase from their competitors (Feng & Zhang, 2017), even will not be back anymore. This study devotes to the inter supply chain competition, in which each firm in a supply chain maximizes the profits (or expected profits) and optimizes the probability of customers choosing a joint product, which depends on selling price and service level. The customers are assumed to be stockout aversion. We design a two-echelon supply chain network of joint products, including raw material suppliers and joint product producers. Our results attempt to answer the following questions based on that customers are stockout aversion. "How are the firms' equilibria under affected by joint production under demand uncertainty?" and "How is the effect of the variance of demand fluctuation and customers service preference on the equilibria."

2. THEORY AND RESEARCH FRAMEWORK

We develop a network equilibrium model for joint products under customer stockout aversion. The risk of demand is captured through the variance of demand fluctuation. We design a two-echelon joint product network constituted with suppliers and producers. Consider I joint products being produced by producer m, $m \in \{1, \cdots, M\}$ in a joint product network. Each producer purchases materials from supplier n, $n \in \{1, \cdots, N\}$ and sells end joint products to demand markets k, $k \in \{1, \cdots, K\}$. The market demands are uncertain, which is affected by many factors, including such things as weather, transportation, politics, and traffic accidents. The suppliers and producers are set to compete in a noncooperative fashion. In our model, we consider a fixed production ratio, and the range of the ratio fluctuation can be treated as a measure of producer m's technology, for example production line flexibility. Let γ_m^i denote the ratio of producer m producing joint product i.

Each supplier makes decisions by controlling wholesale price p_{nm} and output q_{nm} to go for profit maximization, $(p_{nm}, q_{nm}) \coloneqq argmax\, \pi_n(p_{nm}, q_{nm})$, where π_n is the profit function of supplier n. The output of supplier n is equal to the flows that supplier n delivers to all producers. Here, producer m makes its production decision and pricing of joint products, which is denoted by q_{mk}^i and p_{mk}^i. In the model, two decision variables are adopted by the producer to optimize its expected profit: (i) via retail price to match supply and demand and (ii) via its output (q_{mk}^i) to satisfy the uncertainty demand and influence the service level. The unsold products may bring back additional overage costs. Note that γ_m^i quantifies the ratios of the raw material is produced into joint products in the joint-production process. We assume that every producer goes for expected profit maximization by controlling retail price and output, $(p_{mk}^i, q_{mk}^i) \coloneqq argmax\, \pi_m(p_{mk}^i, q_{mk}^i)$, where π_m is the expected profit function of producer m. If market demands are elastic price functions, and $I = 1$ (assembly supply chains), this model will become a classical network equilibrium model provided by Nagurney, Dong, et al. (2002)

3. RESULTS AND MAJOR FINDINGS

To our knowledge, our study first bridges joint product supply chains with a network equilibrium model under demand uncertainty. Special attention is given to the scenario where the producers' products are joint. On the one hand, the supply and demand of one of joint products jointly affect the supplies and demands of other joint products. On the other hand, the demand fluctuation of one of joint products brings additional surplus (inventory) risk for other joint products because of joint production. The interaction effect of supply-demand of joint products can offset the impact of commodity demands' augment by customers. Consequently, the profits of joint products in producers or retailers cannot be maximized in isolation. This also requires new methods because of the interaction effect of the supply-demand of joint products. In this study, a network equilibrium model incorporated with customer choice behavior is applied to optimize firms' decisions under inter supply chain competition of joint product setting. Integrating network equilibrium models with discrete choice models is a challenge with dimensionality augment. If customers consider more than two dimensions in their purchasing behavior in the model, the equilibrium conditions will be complicated, and computational speed will decrease exponentially. Therefore, customers are assumed to consider retail price and service level in their purchasing decision in the proposed model. Based on the equilibrium solutions, we can understand how various factors, such as competition, technology, and other joint products' supply-demand, influence the joint product flows among the supply chains, retail pricing, and surplus. Some valuable insights have been obtained from our proposed model. These results could potentially provide implications for governments and companies in making strategic decisions and policies, specifically for some industries that their demand is uncertain and the service level is a crucial factor on customer purchase behavior.

4. CONTRIBUTIONS

Stockout aversion customer behavior has overly been ignored in newsvendor problems. This paper fills the gap from several perspectives in the risk management of the joint product network: (1) In our model, the producer's products are joint. The proposed model and computational framework are widely applicable in joint product network management. The model can be used to deal with competition between joint product supply chains and optimize the profit of joint products' producers and providers, for example, petroleum refining firms in petroleum supply chains, coal producers in coal supply chains, and dairy producers in dairy supply chains. (2) An assumption is generalized and relaxed by incorporating customer choice behavior into the joint product network. The assumption that customers are stockout aversion is adopted in our model. Service level (α-type service level) is a key influence factor on customers purchasing behavior.

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