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A multi-period supply chain network equilibrium model considering retailers' uncertain demands and dynamic loss-averse behaviors

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ABSTRACT

This study constructs an equilibrium model of a multi-period supply chain network with uncertain demand. In the multi-period equilibrium model, we consider not only retailers' static loss-averse behaviors, but also their dynamic loss-averse behaviors, in which retailers dynamically adjust their loss-averse parameters according to their gains or losses over the production periods. The equilibrium conditions of the various decision makers and the network are established by the finite-dimensional variational inequality. Finally, numerical examples are solved to show how retailers' loss-averse behaviors would affect decisions, profits of manufacturers and utilities of retailers at equilibrium when compared with their loss-neutral behaviors.

1. Introduction

Supply chain network (SCN) equilibrium models have been widely studied by using a variational inequality (VI) formulation. For instance, by considering the noncooperative competition of multi-manufacturers and multi-retailers, Nagurney et al. (2002) and Dong et al. (2004) established the SCN equilibrium models involving a lot of decision makers for deterministic demands and uncertain demands, respectively. Nagurney et al. (2015) constructed the SCN equilibrium model with multiple manufacturers and multiple freight service providers. Nagurney et al. (2016) established a generalized network equilibrium model considering the post-disaster humanitarian relief. Li et al. (2018) studied a spatial price equilibrium model of the network with multiple supply markets and multiple demand markets under quality information asymmetry. By considering the noncooperative competition of multi-recyclers and multi-processors, Nagurney and Toyasaki (2005) and Toyasaki et al. (2014) established the reverse logistics network equilibrium models for electronic waste and end-of-life products, respectively. By considering the optimal management of new products and recyclable products, Hammond and Beullens (2007) established a closed-loop SCN equilibrium model for the electric and electronic equipment, Yang et al. (2009) established a closed-loop SCN equilibrium model including multiple suppliers, manufacturers, retailers, and recovery centers, and Qiang et al. (2013) established a closed-loop SCN equilibrium model involving the uncertain demand. By considering the oligopoly competition of multi-firms, Masoumi et al. (2012), Nagurney and Yu (2012) and Yu and Nagurney (2013) constructed the oligopoly competition equilibrium models for a pharmaceutical SCN, a fresh food SCN, and a fashion SCN, respectively. Nagurney et al. (2014) focused on a SCN oligopolistic competition problem in which firms produce timely deliveries of products. Zhou et al. (2014) investigated a closed-loop SCN oligopoly competition equilibrium model with uncertain demand and return products. Li and Nagurney (2015) constructed an oligopoly competition equilibrium model for both firms and

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suppliers. Nagurney and Shukla (2017) constructed the multi-firm network equilibrium models for a cybersecurity investment problem. All the above models analyzed the single-period SCN equilibrium problem, in which the decision makers choose their equilibrium decisions considering only single-period production plan.

For multi-period SCN equilibrium models considering the production capacity, the effect of the disruption and opportunism risks and a transportation network were established by Hamdouch (2011), Cruz and Liu (2011) and Liu and Nagurney (2012), respectively. Feng et al. (2014) focused on a closed-loop SCN competition problem with time-parameter. Possamai et al. (2015) constructed a multi-period spatial equilibrium model considering the seasonal commodity price problem. Miralinaghi and Peeta (2016) considered a multi-period equilibrium model for the tradable credit schemes. Saberi et al. (2018) constructed a multi-period SCN equilibrium model involving freight carriers and green technology investment option. All the above multi-period SCN equilibrium models involved only certain demands.

For the uncertain demand, the equilibrium models of Dong et al. (2004), Qiang et al. (2013) and Zhou et al. (2014) are based on the completely rational behavior assumption such that the retailers who maximize their expected profit in an uncertain situation are loss-neutral. Many experimental studies and managerial decision-making practices under uncertainty (Fisher and Raman, 1996; Schweitzer and Cachon, 2000; Ho and Zhang, 2008) have asserted that obvious deviations between actual decision-making and predictable values of expected utility theory (EUT) (Von Neumann and Morgenstern, 1994) exist. To keep risk or loss within a certain level, retailers would rather maintain a low inventory, even when they are aware that increasing their inventory level might result in greater profit at times. This type of decision-making behavior is identified as loss-averse behavior, one of the key features in prospect theory (PT) (Kahneman and Tversky, 1979). Loss aversion refers to the behavior that people are more averse to losses than they are attracted by gains of equal size. Under uncertainty, many decision makers are willing to trade off lower expected utility for downside protection against possible losses (Xu et al., 2018). A lot of researches have been conducted to study the impact of the loss-averse behavior on the decision-making of supply chains. Schweitzer and Cachon (2000), Wang and Webster (2009), Zhang et al. (2016) and Vipin and Amit (2017) studied the impact of the loss aversion on the optimal decisions in a newsvendor problem. Schweitzer and Cachon (2000) found that the optimal order quantity of a loss-averse newsvendor is smaller than that of a loss-neutral newsvendor. Wang and Webster (2009) showed that if shortage cost is relatively high, a loss-averse newsvendor's optimal order quantity will be higher than that of a loss-neutral newsvendor. The authors also found that, unlike the loss-neutral newsvendor model, the optimal order quantity of a loss-averse newsvendor may increase in wholesale price and decrease in retail price. Zhang et al. (2016) showed that if retailer's loss aversion increases, the required initial capital will decrease. Vipin and Amit (2017) showed that loss aversion can improve the performance of the utility function based model of the newsvendor. Hu et al. (2016) and Zhang et al. (2016) studied the coordination of a supply chain with a loss-averse retailer and a loss-averse supplier, respectively. Hu et al. (2016) found that a loss-averse retailer gains less profits and lower utility, when compared with a loss-neutral retailer. Zhang et al. (2016) showed that a loss-averse supplier should not be indifferent between buyback and revenue-sharing contracts. He should use different contracts according to high or low critical ratio. Fulga (2016) found that a loss-averse investor should use the Mean-Risk framework in a portfolio optimization problem, compared with the classical frameworks. Chen and Sheu (2017) found that consumer's loss-averse behavior affects green product strategy. Hence, it is essential to study the impacts of loss aversion on the decisions and performance of a supply chain. However, the above researches focused on the loss-averse behavior for one period production plan only.

As mentioned in Kahneman and Tversky (1979), PT has the following important assumptions: (1) The instantaneous profit of decision maker is identified as 'gain' when the profit is above a current reference value, and is identified as 'loss', otherwise. (2) Decision maker is more sensitive to losses than gains of equal-sized. This is referred to as loss-averse behavior. Notwithstanding the usefulness of PT, Nagarajan and Shechter (2014) showed that PT still have shortcomings, which can be explained as follows: One of the main features of PT is based on the assumption that decision maker is risk-seeking when he is losing. Thus, it can depict the risk-seeking behavior of the decision maker only when both positive profit and negative profit exist in their business; it cannot depict this behavior if only positive profit exists. In our model, we assume that there exists both positive profit and negative profit for each retailer of the SCN. On the other hand, in reality, smaller supply chain members, such as retailers, not only are more sensitive to losses than gains with the same size, but also adjust their loss-averse degrees (i.e. the ratios of the retailers' sensitivities to losses to their sensitivities to gains) according to the market status and the relative profits of themselves. This is the basic assumptions of applying PT in multi-period setting, in which the decision maker's loss-averse behavior is dynamically adjusted in multi-period setting. Thaler and Johnson (1990) showed that the loss-averse decision maker's decision under risk is affected by his gains and losses in the prior period, which is called the 'house-money' effect. Barberis et al. (2001) showed that the utilities of the loss-averse decision makers involving gains and losses depend on the result of their prior outcomes. The decision makers become more loss-averse when they are losing over a certain period. Zhang andSemmler (2009) explored empirical evidence on the prospect theory for stock markets with time-series data. Hsieh and Dye (2017) discussed the dynamic pricing problem, in which the decision makers adjust their current price on the basis of the past prices. If the current price is lower than the past prices, it will result in a gain and more purchase for the customer. The opposite situation will result in a loss and less purchase. Hence, a general conclusion of the above researches is that loss-averse behavior is dynamic in a multi-period setting. In practice, the negative effect brought by loss not only depends on the loss in the current period, but also depends on the loss in the prior period. If a retailer obtains more positive profit in the current period than that of the prior period, then his positive profit will give a buffer to the negative effect of loss encountered in the prior period. If a retailer suffers more loss in the prior period, he is more sensitive to the negative effect of loss encountered in the current period than the same amount of loss in the prior period. In this paper, we also incorporate this dynamic loss-averse behavior into an uncertain multi-period SCN equilibrium model. In our model, we not only consider retailers' loss-averse behaviors in a multi-period setting, in which their loss-averse parameters are either static or dynamically adjusted according to their gains or losses over the production periods, but also combine retailers' non-cooperative competition with their loss-averse behaviors in the multi-period SCN.