The loss-averse newsvendor game

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ABSTRACT

This paper extends the standard newsvendor problem based upon risk neutrality to a game setting where multiple newsvendors with loss aversion preferences are competing for inventory from a risk-neutral supplier. We show that if the supplier allocates the total demand among the newsvendors proportional to their order quantities, then there exists a unique Nash equilibrium order quantity in this newsvendor game. We also find that while the demand-stealing effect increases the total order quantity of the newsvendors, the loss aversion effect decreases the newsvendors' total order quantity and if strong enough, may lead to a lower total inventory level of the decentralized supply chain than that of an integrated supply chain.

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1. Introduction

The newsvendor problem is one of the fundamental problems in operations and supply chain management. The standard newsvendor model is based upon risk neutrality with an objective of maximizing expected profit. We refer interested readers to Porteus (1990) Cachon (2003), and Khouja (1999) for detailed surveys of the newsvendor problem and its extensions.

Recently, game theory has become an important tool to analyze the supply chain in which multiple parties may have conflicting objectives. Specifically, Lippman and McCardle (1997) study a competitive newsvendor problem in which the total demand is allocated among multiple risk-neutral newsvendors under certain demand splitting rules. They find that due to the demand-stealing effect, i.e., the more the newsvendor orders, the less the other newsvendors' demand stochastically, competition among multiple newsvendors results in supply chain inventory overstocking, i.e., the total inventory level of a decentralized supply chain is higher than that of an integrated supply chain. Cachon (2003) (Section 5) studies a similar risk-neutral newsvendor game but with a proportional demand allocation rule (i.e., the supplier allocates demand among the newsvendors proportional to their inventory). He also finds that the demand-stealing effect leads to supply chain inventory overstocking. We refer interested readers to Cachon (2003) (Section 5) and Cachon and Netessine (2004) for detailed reviews on the applications of game theory in supply chains.

Another recent extension of the standard newsvendor problem is the adoption of an alternative choice model—loss aversion—to describe the newsvendor decision-making behavior. Originated from Kahneman and Tversky’s (1979) Prospect Theory, loss aversion means that people are more averse to losses than they are attracted to same-sized gains. We refer interested readers to Wang and Webster (2009) for a review of related research on loss aversion in economics and other applied fields. As far as we know, Schweitzer and Cachon (2000) and Wang and Webster (2009, 2007), are among the first studying the loss-averse newsvendor problem. Schweitzer and Cachon (2000) find that a loss-averse newsvendor will order less than a risk-neutral newsvendor when the shortage cost is negligible. Wang and Webster (2009) further show that a loss-averse newsvendor may order more than a risk-neutral newsvendor when the shortage cost is relatively high. Wang and Webster (2007) extend the loss-averse newsvendor problem to a supply chain in which a risk-neutral manufacturer is selling to a loss-averse newsvendor-like retailer. They investigate the role of a gain/loss sharing provision for mitigating the loss aversion effect that decreases the supply chain's inventory level and coordinating the supply chain.

This research contributes to the newsvendor literature by extending the standard newsvendor problem based upon risk neutrality to a more complex game setting where multiple newsvendors with loss aversion preferences are competing for inventory from a risk-neutral supplier. We show that if the supplier allocates demand among the newsvendors proportional to their order quantities, then there exists a unique Nash equilibrium in this newsvendor game. We also find that while the demand-stealing effect increases the newsvendors' total order quantity, the loss aversion effect decreases the newsvendors' total order quantity, and if strong enough, may dominate the demand-stealing effect and lead to supply chain inventory understocking, i.e., the total inventory level of a decentralized supply chain is lower than that of an integrated supply chain. This research...
finding contrasts with the result of supply chain inventory overstocking in the risk-neutral newsvendor game. This paper is organized as follows. In Section 2, we conduct our analysis of the loss-averse newsvendor game. In Section 3, we draw our conclusions and identify opportunities for future research.

2. Model analysis

We consider a risk-neutral supplier who produces a perishable product at a unit production cost $c$ and sells the product at a unit retail price $p > w$ during the selling season and liquidates the unsold inventory at a unit salvage value $v < w$ after the selling season. Without loss of generality, we normalize $v = 0$. Demand $X$ faced by the newsvendor $i$ is random with its probability density function (PDF) $g(x_i)$ and cumulative distribution function (CDF) $G(x_i)$ defined over the continuous interval $I = [0, \infty)$. As with most of the traditional newsvendor models, we assume $G(x_i)$ is differentiable, invertible, and strictly increasing over $I$. We also let $f(x_i)$ be the PDF and CDF of the total random demand $X$ of the $n$ newsvendors.

Let $Q_i$ be the newsvendor $i$’s order quantity and $Q_{-i}$ be the total order quantity of the other $(n - 1)$ newsvendors. We assume that the total demand $X$ is divided among the newsvendors proportionally to their ordering quantities. Specifically, the newsvendor $i$’s demand $X_i$ is:

$$X_i = \frac{Q_i}{Q_i + Q_{-i}} X.$$  

It follows from (1) that:

$$g(x_i) = \frac{Q_i + Q_{-i}}{Q_i} f \left( \frac{Q_i + Q_{-i}}{Q_i} x_i \right).$$  

Such a demand allocation rule is known as the proportional demand allocation rule in the literature (e.g., Cachon (2003) and Wang and Gerchak (2001)). As pointed out by Cachon (2003), the proportional demand allocation rule is a reasonable model when customers have relatively low search cost (e.g., online shopping) and the qualitative insights from this rule are consistent with other demand allocation rules considered in the literature (e.g., Lippman and McCardle (1997)).

We assume that the newsvendors are loss-averse and have the following piecewise-linear loss aversion utility function $U(W)$ that has been used in Schweitzer and Cachon (2000) and Wang and Webster (2009, 2007):

$$U(W) = \begin{cases} W - W_0 & W \geq W_0 \\ \lambda(W - W_0) & W < W_0 \end{cases} \quad (3)$$

where $W_0$ is the newsvendor’s reference wealth level (e.g., his initial wealth) at the beginning of the selling season; $W$ is the newsvendor’s final wealth level after the selling season; and $\lambda > 1$ is defined as the loss aversion level. Without loss of generality, we normalize $W_0 = 0$.

Then we can express the newsvendor $i$’s expected utility function $E[U(\pi(Q_i, Q_{-i}))]$ as follows:

$$E[U(\pi(Q_i, Q_{-i}))] = \int_0^{Q_i} (px_i - wQ_i)g(x_i)dx_i + \int_{Q_i}^{\infty} (p - w)Q_ig(x_i)dx_i + (\lambda - 1) \int_0^{Q_{-i}} (px_i - wQ_{-i})g(x_i)dx_i$$  

where the function $q_i(Q) = wQ/p$ is defined as the newsvendor’s break-even quantity if his order quantity is $Q$. From (1) and (2), we can further rewrite (4) as follows:

$$E[U(\pi(Q_i, Q_{-i}))] = \frac{Q_i}{Q_i + Q_{-i}} \left( \int_0^{Q_{-i}} (px_i - wQ_{-i})f(x_i)dx_i + (\lambda - 1) \int_{Q_{-i}}^{Q_{-i} + Q_i} (px_i - wQ_{-i})f(x_i)dx_i \right)$$  

(5)

**Proposition 1.** For any $Q_{-i} \geq 0$, the newsvendor $i$’s expected utility function $E[U(\pi(Q_i, Q_{-i}))]$ is concave in $Q_i$. Hence, there exists a unique optimal order quantity $Q_i^*(Q_{-i})$ that satisfies the following first-order condition:

$$p - w - pf(Q_i^*(Q_{-i}) + Q_{-i}) - (\lambda - 1) wQ_i(Q_i^*(Q_{-i}) + Q_{-i}) + \frac{pQ_{-i}}{(Q_i + Q_{-i})^2} \left( \int_0^{Q_{-i}} xdf(x_i)dx_i + (\lambda - 1) \int_{Q_i}^{Q_i + Q_{-i}} xdf(x_i)dx_i \right) = 0.$$  

(6)

**Proof of Proposition 1.** After taking the first and derivatives of (5) with respect to $Q_i$, we get:

$$dE[U(\pi(Q_i, Q_{-i}))]/dQ_i = p - w - pf(Q_i + Q_{-i}) - (\lambda - 1) wQ_i(Q_i + Q_{-i}) + \frac{pQ_{-i}}{(Q_i + Q_{-i})^2} \left( \int_0^{Q_{-i}} xdf(x_i)dx_i + (\lambda - 1) \int_{Q_i}^{Q_i + Q_{-i}} xdf(x_i)dx_i \right)$$  

$$+ \frac{p}{Q_i + Q_{-i}} \left( \int_0^{Q_{-i}} xdf(x_i)dx_i \right) - \frac{Q_i}{Q_i + Q_{-i}} \left( pf(Q_i + Q_{-i}) + (\lambda - 1) w^2 \right) < 0.$$  

(7)

Expression (8) implies that $E[U(\pi(Q_i, Q_{-i}))]$ is concave in $Q_i$. So the optimal order quantity $Q_i^*(Q_{-i})$ must satisfy the first-order condition (6). □

Proposition 1 characterizes the newsvendor $i$’s best response, i.e., his optimal order quantity $Q_i^*(Q_{-i})$, to the other $(n - 1)$ newsvendors’ total order quantity $Q_{-i}$. In other words, given any other $(n - 1)$ newsvendors’ total order quantity $Q_{-i}$, there exists a unique optimal order quantity $Q_i^*(Q_{-i})$ that maximizes the newsvendor $i$’s expected utility function.

**Theorem 1.** There exists at least one symmetric pure strategy Nash equilibrium in the loss-averse newsvendor game.

**Proof of Theorem 1.** The sufficient conditions for the existence of a pure strategy Nash equilibrium are (i) nonempty compact convex strategy space, (ii) continuity of player’s payoff functions, and (iii) quasi-concavity of each player’s objective function (Fudenberg and Tirole, 1991, Theorem 1.2). In the game’s only move, the newsvendors simultaneously choose their strategies, i.e., order quantities, $Q_i \in \sigma = [0, S]$, where $\sigma$ is the newsvendor’s strategy space and $S$ is sufficiently large so that it never constrains the newsvendors (see e.g., Lippman and McCardle, 1997 and Cachon and Netessine, 2004). Condition (i) is satisfied by choosing a large enough bounded and closed set $[0, S] \times [0, S] \times \ldots \times [0, S]$ which is also compact and convex. Condition (ii) is satisfied since we assume $f(x_i)$ is continuous so that the expected profit function is also continuous. Finally, condition (iii) is also satisfied by Proposition 1. Thus, there exists at least one pure strategy Nash equilibrium in the loss-averse newsvendor game. Since all newsvendors are identical, the pure strategy Nash equilibrium is symmetric. □
From Theorem 1, we know that there may exist a unique Nash equilibrium or multiple Nash equilibria in the newsvendor game. To see if the Nash equilibrium is unique, let \( Q' \) be the newsvendor \( i \)'s equilibrium order quantity, \( Q_{-i} \) be the equilibrium total order quantity of other \((n-1)\) newsvendors, and correspondingly, \( Q' = Q' + Q_{-i} \) be the equilibrium total order quantity of the \( n \) newsvendors. Since the Nash equilibrium is symmetric (by Theorem 1), we must have \( Q'_{i} = (n-1)Q' \) and \( Q' = nQ' \).

**Theorem 2.** There exists a unique symmetric pure strategy Nash equilibrium in the loss-averse newsvendor game. Specifically, for any \( i \in \{1, 2, \ldots, n\} \), the newsvendor \( i \)'s unique equilibrium order quantity \( Q'_{i} \) satisfies

\[
Q'_{i} = \frac{n}{n}\,
\]

where \( Q' \) is the unique equilibrium total order quantity of all newsvendors satisfying

\[
p - w - pF(Q') - (\lambda - 1)wF(Q_{i}(Q')) + \int_{0}^{Q'} x f(x)dx + (\lambda - 1) \int_{0}^{Q} x f(x)dx = 0.
\]

**Proof of Theorem 2.** Replacing \( Q'_{i}(Q_{-i}) \) and \( Q_{-i} \) in (6) with \( Q'_{i} \) and \( Q'_{-i} \), respectively, then the equilibrium total order quantity \( Q' \) satisfies expression (10). To see if \( Q' \) is unique, we define a function \( g(Q, n, \lambda) \) as follows:

\[
g(Q, n, \lambda) = p - w - pF(Q) - (\lambda - 1)wF(Q_{i}(Q)) + \frac{(n-1)p}{n Q} \left( \int_{0}^{Q} x f(x)dx + (\lambda - 1) \int_{0}^{Q} x f(x)dx \right).
\]

After taking the first derivative of \( g(Q, n, \lambda) \) with respect to \( Q \), we have:

\[
g'(Q, n, \lambda) = \frac{(n-1)p}{nQ^{2}} \left( \int_{0}^{Q} x f(x)dx + (\lambda - 1) \int_{0}^{Q} x f(x)dx \right) - \frac{p^{2}f(Q) + (\lambda - 1)w^{2}f(Q_{i}(Q))}{p} + \frac{n-1}{n} \left( pf(Q) + (\lambda - 1)wf(Q_{i}(Q)) \right) - \frac{q_{i}(Q)}{Q}.
\]

Since

\[
q_{i}(Q) = \frac{w}{p}
\]

by the definition of \( q_{i}(Q) \), after applying some algebraic manipulations to (12), we can further rewrite \( g'(Q, n, \lambda) \) as follows:

\[
g'(Q, n, \lambda) = \frac{(n-1)p}{nQ^{2}} \left( \int_{0}^{Q} x f(x)dx + (\lambda - 1) \int_{0}^{Q} x f(x)dx \right) - \frac{p^{2}f(Q) + (\lambda - 1)w^{2}f(q_{i}(Q))}{np} < 0.
\]

Hence, \( g(Q, n, \lambda) \) is decreasing in \( Q \). Since \( \lim_{Q \to 0} g(Q, n, \lambda) = \frac{n-1}{n} \int_{0}^{Q} p f(x)dx - \frac{w}{p} \) and \( \lim_{Q \to \infty} g(Q, n, \lambda) = 0 \), there must exist a unique equilibrium total order quantity \( Q' > 0 \) that satisfies \( g(Q', n, \lambda) = 0 \), i.e., expression (10). It follows immediately that each newsvendor's equilibrium order quantity \( Q' \) is unique and satisfies (9).

Theorem 2 characterizes the unique equilibrium order quantity, \( Q'_{i} = Q'_{2} = \ldots = Q'_{n} \), of each newsvendor, and the unique equilibrium total order quantity, \( Q' \), of all newsvendors in the loss-averse newsvendor game.

**Proposition 2.** The equilibrium total order quantity \( Q' \) is increasing in \( n \).

**Proof of Proposition 2.** For any \( n_{2} > n_{1} > 1 \), let \( Q'_{i} \) and \( Q'_{2} \) be the equilibrium total order quantity of the \( n_{1} \) and \( n_{2} \) newsvendors, respectively. From Theorem 2, we have \( g(Q', n_{i}, \lambda) = g(Q'_{2}, n_{2}, \lambda) = 0 \). Since from (11), it is easy to verify that \( dg(Q', n_{i}, \lambda)/dn > 0 \), we must have \( g(Q', n_{i}, \lambda) > g(Q'_{2}, n_{i}, \lambda) = g(Q'_{2}, n_{2}, \lambda) > g(Q', n_{2}, \lambda) \). Since \( g(Q', n_{2}, \lambda) < 0 \), we must have \( Q'_{2} < Q'_{2} \) if \( n_{2} > n_{1} \), i.e., the equilibrium total order quantity \( Q' \) is increasing in \( n \).

Proposition 2 shows that the more newsvendors in the supply chain, the higher the total supply chain’s inventory level. In other words, competition makes the loss-averse newsvendors order more inventory because of the demand-stealing effect, i.e., the more the newsvendors order, the less the other newsvendors’ demand stochastically. This demand-stealing effect is consistent with the result found in the competitive risk-neutral newsvendor models (e.g., Cachon (2003) and Lippman and McCardle (1997)).

**Proposition 3.** The equilibrium total order quantity \( Q' \) is decreasing in \( \lambda \).

**Proof of Proposition 3.** For any \( \lambda_{2} > \lambda_{1} > 1 \), let \( Q'_{i} \) and \( Q'_{2} \) be the equilibrium total order quantity when the newsvendor’s loss aversion level is \( \lambda_{1} \) and \( \lambda_{2} \), respectively. From Theorem 2, we have \( g(Q', n_{i}, \lambda_{2}) = g(Q'_{2}, n_{2}, \lambda_{2}) = 0 \). From (11), we can verify that:

\[
dg(Q', n, \lambda)/d\lambda = -wF(Q_{i}(Q)) + \frac{(n-1)p}{nQ} \frac{w^{2}(Q)}{f(Q)} f(Q_{i}(Q)) < 1/\int_{0}^{Q} f(Q_{i}(Q)) \left( px - wQ_{i}(Q) \right) dx < 0.
\]

Therefore, \( g(Q', n, \lambda_{2}) < g(Q', n, \lambda_{1}) = g(Q'_{2}, n_{2}, \lambda_{1}) = 0 \). Since \( g(Q', n, \lambda_{2}) < 0 \), we must have \( Q'_{2} < Q'_{1} \) if \( \lambda_{2} > \lambda_{1} \), i.e., the equilibrium total order quantity \( Q' \) is decreasing in \( \lambda \).

In contrast with Proposition 2 that shows that the demand-stealing effect increases the newsvendors’ total order quantity, Proposition 3 shows that the loss aversion effect decreases the newsvendors’ total order quantity, i.e., the more loss-averse the newsvendors are, the less their total order quantity. This loss aversion effect is consistent with the result found in Wang and Webster (2007) in which a single risk-neutral supplier is selling to a single loss-averse retailer without competition.

To see how the demand stealing and loss aversion effects interact in the supply chain, we next compare the equilibrium total order quantity of the decentralized supply chain with that of an integrated supply chain, in which a risk-neutral supplier owns her retail channels. It follows from the standard newsvendor model that the integrated supply chain’s optimal inventory level, \( Q'_{i} \), satisfies the following expression:

\[
Q'_{i} = F^{-1} \left( \frac{p-c}{p} \right).
\]

To facilitate our analysis, we define:

\[
\bar{\lambda}_{a} = 1 + \frac{n-1}{n} \int_{0}^{Q'_{i}} p f(x)dx \frac{1}{wQ_{i}^{2}(Q') \frac{w^{2} f(Q)}{f(Q_{i}(Q))}} \frac{w^{2} f(Q_{i}(Q))}{f(Q_{i}(Q))} dx \]

as the threshold loss aversion level when there are \( n \) newsvendors in the supply chain, and

\[
\bar{n}_{a} = \frac{n-1}{n} \int_{0}^{Q'_{i}} p f(x)dx \frac{1}{wQ_{i}^{2}(Q') \frac{w^{2} f(Q)}{f(Q_{i}(Q))}} \frac{w^{2} f(Q_{i}(Q))}{f(Q_{i}(Q))} dx \]

as the threshold number of newsvendors in the supply chain when each newsvendor’s loss aversion level is \( \lambda \). Then we have the following two propositions.
Proposition 4. For any \( n > 1 \), if \( l > \overline{\tau}_n \), then \( Q^* < Q_0 \), otherwise \( Q^* \geq Q_0 \).

Proof of Proposition 4. After plugging \( Q^0 = F^{-1}(\frac{p^*}{C_0}) \) into (11), we have:

\[
g(Q^0, n, \lambda) = -(w-c) + \frac{(n-1)p}{nQ^0} \int_0^{Q^0} x f(x) dx + (\lambda-1) \left( \frac{(n-1)p}{nQ^0} \int_0^{Q^0} x f(x) dx - W q_1(Q^0) \right)
\]

If \( l > \overline{\tau}_n \), then we can verify that \( g(Q^0, n, \lambda) < 0 \), which implies \( Q^* < Q_0 \). Similarly, if \( l \leq \overline{\tau}_n \), then we can verify that \( g(Q^0, n, \lambda) \geq 0 \), which implies \( Q^* \geq Q_0 \). \( \square \)

Proposition 4 indicates that when there are \( n \) newsvendors in the supply chain, if each newsvendor’s loss aversion level \( \lambda \) is higher than a threshold value \( \overline{\tau}_n \), then the loss aversion effect that decreases the decentralized supply chain’s total inventory level is more significant than the demand-stealing effect that increases the total inventory level of the decentralized supply chain. Consequently, supply chain inventory understocking occurs. On the other hand, if each newsvendor’s loss aversion level \( \lambda \) is lower than the threshold value \( \overline{\tau}_n \), then the demand-stealing effect is more significant than the loss aversion effect, and supply chain inventory overstocking occurs.

Proposition 5. For any \( \lambda > 1 \), if \( n < \pi_n \), then \( Q^* < Q_0 \), otherwise \( Q^* \geq Q_0 \).

Proof of Proposition 5. We omit the proof since it is similar to the proof of Proposition 4. \( \square \)

Proposition 5 indicates that for any newsvendor loss aversion level \( (\lambda > 1) \), if the number of newsvendors in the supply chain is smaller than the threshold value \( \pi_n \), then the loss aversion effect is more significant than the demand-stealing effect, and supply chain inventory understocking occurs. On the other hand, if the number of newsvendors is larger than the threshold value \( \pi_n \), then the demand-stealing effect is more significant than the loss aversion effect, and supply chain inventory overstocking occurs. Interestingly, if there are exactly \( n = \pi_n \) loss-averse newsvendors in the supply chain, then the optimal stock level of the decentralized supply chain is exactly the same as that of an integrated system, i.e., the decentralized supply chain can be coordinated by a wholesale price-only contract. Results in Proposition 5 lend insights into how a supplier can choose an optimal number of loss-averse newsvendors to improve or the supply chain’s performance. In particular, since inventory overstocking occurs when the number of newsvendors in the supply chain is sufficiently large, from the supplier’s perspective, she would like to encourage newsvendor competition in the supply chain and sell to as many newsvendors as possible to increase her expected profit. However, since inventory overstocking hurts the total supply chain performance, from the supply chain’s perspective, it is important for the supplier to select an optimal number of newsvendors (i.e., \( n = \pi_n \)) to balance out the loss aversion effect so as to maximize the total expected profit of the decentralized supply chain.

3. Conclusion

In the traditional newsvendor game, it is well known that if a supplier is selling to multiple risk-neutral newsvendors, then due to the demand-stealing effect, i.e., the more the newsvendor orders, the less the other newsvendors’ demand stochastically, competition among multiple newsvendors will result in supply chain inventory overstocking, i.e., the total inventory level of a decentralized supply chain is higher than that of an integrated supply chain. However, it is unclear whether or not inventory overstocking still exists in the supply chain if each newsvendor has an alternative preference of loss aversion, which has been recently adopted in the newsvendor model to describe the newsvendor decision-making behavior under risk.

To fill in this research gap, we investigate a newsvendor game in which a risk-neutral supplier is selling to multiple competing loss-averse newsvendors. We show that if the supplier allocates the total demand among the newsvendors proportional to their order quantities, then there exists a unique Nash equilibrium order quantity in this newsvendor game. We further show that the optimal inventory level of the decentralized supply chain is increasing in the number of newsvendors due to the demand-stealing effect but decreasing in the loss aversion level of the newsvendors due to the loss aversion effect. Our research findings lend insights into the interplay of the demand-stealing effect and loss aversion effect in the supply chain. More specifically, we find that for a given number of newsvendors in the supply chain, if the newsvendor’s loss aversion level is higher than a threshold value, then the loss aversion effect is more significant than the demand-stealing effect, and supply chain inventory overstocking occurs. However, if the newsvendor’s loss aversion level is lower than a threshold value, then the demand-stealing effect is more significant than the loss aversion effect, and supply chain inventory understocking occurs.

We also find that for a given level of loss aversion, if the number of newsvendors in the supply chain is smaller than a threshold value, then the loss aversion effect is more significant than the demand-stealing effect, and supply chain inventory understocking occurs. However, if the number of newsvendors in the supply chain is larger than a threshold value, then the demand-stealing effect becomes more significant than the loss aversion effect and supply chain inventory overstocking occurs.

Our results also lend insights into how a supplier can choose the optimal number of loss-averse newsvendors to improve the supply chain’s performance. In particular, from the supply chain perspective, since both inventory overstocking and inventory understocking are suboptimal, it is important for the supplier to select an optimal number of newsvendors in the market to balance out the loss aversion effect so that the expected profit of the decentralized supply chain is the same as that of the integrated supply chain.

In this paper, we focus on a proportional demand allocation rule that has been used in Cachon (2003) and Wang and Gerchak (2001). Future research should consider other more complex demand splitting rules. In addition, in this paper we assume that the newsvendors are identical. Future research should consider heterogeneity in the newsvendors. Finally, although loss aversion is commonly used in the research literature and well supported in practice, future research should consider other alternative choice models (e.g., Choi et al., 2008 and Wu et al., 2008) to investigate the competitive newsvendor problem.

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