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How power structure and markup schemes impact supply chain channel efficiency under price-dependent stochastic demand

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ABSTRACT

Although considerable attention has been separately given to factors such as power structures, price-dependent demand, and markup pricing schemes, there has been limited exploration of the combined effects of these factors on supply chain efficiency and the leader's advantage. We propose a game theoretic model in which a manufacturer sells a single product to a newsvendor retailer who sets both optimal order quantity and selling price under uncertain price-dependent demand. Furthermore, we examine a supply network wherein a single retailer fulfills orders using a global manufacturer for regular orders and a local manufacturer to clear any shortages. Through numerical analysis, we show that the retailer always prefers to charge a percentage markup. In a two-player game, channel efficiency is higher when the retailer is the leader under linear demand; however, under iso-elastic demand, the manufacturer being a leader brings a higher channel efficiency. When a local manufacturer is involved as a second manufacturer, channel efficiency is higher when the retailer remains a follower, as this induces more fierce wholesale price competition between the two manufacturers. Additionally, when demand uncertainty is high in the two-player game with linear demand, the retailer as a follower can achieve higher profits, whilst high uncertainty under iso-elastic demand decreases both players' profits. Moreover, it becomes advantageous for the retailer to have a local manufacturer as demand uncertainty increases, even when the local manufacturer announces the wholesale price first.

1. Introduction

Game theory finds extensive application in supply chain contract design. When the game parameters are common knowledge, a decision-maker can make optimal decisions while considering the reaction of other participants. The results under deterministic information summarized by Lau and Lau (2003) show that when a supplier sets a wholesale price and a retailer decides on a selling price, the deterministic two-echelon Stackelberg game leads to channel efficiency (CE) of 75%, and the leader's advantage (LA) brings two times more profits than the follower's under linear demand. Even though these results no longer hold for iso-elastic demand, CE and LA remain constant in the elasticity factor of the demand function (i.e., b from iso-elastic demand curve $y(p) = ap^{-b}$) as stated by Lau, Lau, and Wang (2008).

In most cases, however, the decision-maker faces demand uncertainty when making operational decisions, such as determining order quantities or pricing. Despite the extensive literature on contract design in the context of stochastic demand information, most of these studies resort to numerical methods due to challenges in achieving tractability (Lau & Lau, 2005). Additionally, the outcomes of a game-theoretic model are greatly influenced by the specific forms of price-sensitive demand functions (Chiu, Choi, & Tang, 2011; Lau & Lau, 2003; Petruzzi & Dada, 1999; Shi, Zhang, & Ru, 2013). For example, iso-elastic demand makes the dominant player lose the first-mover advantage. Therefore, if the market has iso-elastic demand, the leader of the game would search for a way to stay as a follower (Lau et al., 2008).

Further, in stochastic settings, results on channel efficiency and leader's advantages under deterministic settings do not hold (Lau et al., 2008; Shi et al., 2013; Wang, Sun, & Wang, 2016). Optimal decisions and economic benefits, in a certain game, change significantly by multiple factors such as randomness of demand, price-dependent demand function, markup schemes, and power structure. However, how these factors influence supply chain performance and whether there exists some consistent results that decision-makers can learn from is not well understood.

In this context, our focus revolves around the question of how supply chain performance is affected by decision sequences within a supply chain and pricing markup strategies in the face of uncertain

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demand. Our study addresses the following research questions: (i) Does the sequence of the game (power structure) lead to different channel efficiency and leader's advantages under stochastic price-dependent demand functions? (ii) How do different markup schemes impact each player's expected profit? and (iii) Does high demand uncertainty always reduce the players' expected profits in a supply chain or supply network?

As Matsui (2021) mentioned, the power structure in supply chains denotes the sequence of decisions in which supply chain members set their respective margins (i.e., wholesale and selling prices). Based on the definition, in our study, we refer to a dominant player as the one who demands its margin earlier than a dominated player as a leader. Initially, we delve into the optimal pricing decision within an integrated market, aiming to identify the maximum channel efficiency. Subsequently, we shift our attention to a supply chain consisting of a single manufacturer deciding on a wholesale price and a newsvendor retailer determining a market price and order quantity. Within this setup, we explore two distinct power structures: (1) where the manufacturer wields dominant bargaining power (referred to as Domi-manu) and (2) where the retailer possesses dominant bargaining power (referred to as Domi-reta).

While most existing literature predominantly focuses on a retailer and a manufacturer game, recent years have experienced the significance of supply-driven markets. This surge in importance can be attributed to global geopolitical and economic uncertainties, exemplified by incidents like shortages in gas and batteries and the global pandemic. Drawing inspiration from this observation, we further encompass a supply network characterized by a single retailer and two manufacturers, where the retailer has a local backup manufacturer. Within this network, one manufacturer assumes the role of a global player responsible for fulfilling the retailer's order requests. At the same time, the other operates as a local (backup) manufacturer, charging a higher wholesale price but offering the advantage of immediate response to the retailer's anticipated shortages. With the retailer's option to source from the local manufacturer, we examine how the sequence of decisions (power structure) influences channel efficiency in the supply chain and the leader's advantages for each player in this complex dynamic.

Regarding price-dependent demand function, linear, iso-elastic, exponential, and logit demand functions are most commonly used in economic literature (Huang, Leng, & Parlar, 2013). Although the logit function has its own benefit of capturing more precise consumer willingness-to-pay (WTP) distributions in a global range of price settings (i.e., the price-demand relationship is more sensitive in the middle range of price), the linear and iso-elastic demand functions are still found to be useful and most widely applied to derive analytical implications within a reasonable price variation (Duan & Ventura, 2021). Therefore, for tractability, we consider linear and iso-elastic demand functions. Further, the retailer can set a selling price with either an absolute markup or a percentage markup on the manufacturer's wholesale price. Especially, when the retailer is a leader, the manufacturer's wholesale price is set differently depending on which markup scheme the retailer charges.

Further, even though a wholesale price-only contract is known to be unable to coordinate the supply chain because of double marginalization (Katok, Olsen, & Pavlov, 2014), it is yet the most commonly used and preferred contract mechanism in various industry sectors (i.e., semiconductor and agriculture) due to its simplicity (Hwang, Bakshi, & DeMiguel, 2018). Conducting laboratory experiments, Ho and Zhang (2008) show that more elaborate mechanisms, such as two-part tariff and quantity discount, do not necessarily improve channel efficiency compared to the wholesale price-only contract. To this end, we also apply the wholesale price-only contract in this study based on its extensive practicality. We evaluate the supply chain performance of each setting based on two aspects: (1) channel efficiency, which quantifies the relative profit achieved in a decentralized game compared to that obtained by an integrated (centralized) system, and (2) leader's advantage, which shows the relative profit gained by the leader of a game.

In a two-player game, Domi-manu always leads to the highest channel efficiency under iso-elastic demand, while under linear demand, Domi-reta, charging a percentage markup, has the highest channel efficiency. Further, Domi-reta charging a percentage markup obtains the highest leader's advantages, regardless of the demand function. While players typically observe a decline in expected profits with rising demand uncertainty, if the manufacturer is a leader, the retailer as a follower attains a higher expected profit for linear demand. This occurs because, with an escalation in demand uncertainty, the manufacturer as a leader reduces the wholesale price considerably to induce the retailer to place larger orders in the face of high demand uncertainty. Consequently, in this scenario, the retailer, as the follower, enjoys the benefits of an increased profit margin.

In a three-player game, channel efficiency is higher when the retailer is the follower as opposed to when the global manufacturer is in that position. This result arises because when the global manufacturer directly follows the local manufacturer's wholesale price decision, both manufacturers can collectively influence the retailer's price decision. Consequently, they gain better control over the optimal order quantity, intensifying wholesale price competition between the two manufacturers. This ultimately results in lower wholesale prices for both. However, when the global manufacturer becomes the follower, the retailer indirectly moderates the wholesale price competition by announcing the selling price before the wholesale price. Hence, the retailer being a follower and awaiting two manufacturers to make decisions beforehand reduces both wholesale prices and subsequently increases channel efficiency. Further, as the demand uncertainty increases, it is beneficial for the retailer to involve the local manufacturer even though the local manufacturer announces the wholesale price first.

The remainder of this chapter is structured as follows: In Section 3, we outline assumptions and describe the model. Section 4 presents a two-player Stackelberg game and provides a numerical analysis of channel efficiency and the leader's advantages. Section 5 delves into a three-player Stackelberg game, offering insights from our numerical experiments. Finally, in Section 6, we conclude with a summary and propose potential avenues for future research.

2. Literature review

This work incorporates four streams of research: (1) price setting newsvendor, (2) markup pricing, (3) selling to the newsvendor and upstream competition, and (4) power structure in supply chains. A comprehensive overview of pricing models is given by Simon, Fassnacht, Simon, and Fassnacht (2019), and supply chain coordination under contract design is provided by Cachon (2003).

Price setting newsvendor: The price-setting newsvendor attained considerable attention in operations research (see DeYong 2020). Petruzzi and Dada (1999) establish the optimal pricing solution by assuming an increasing hazard rate and introducing a stocking factor. They provide analytical properties of optimal prices by separating riskless profit from uncertainty-relevant expected profit under stochastic demand. Kocabıyıkoğlu and Popescu (2011) introduce a novel concept called the elasticity of lost sales rate (LSR). This new concept enables them to deliver structural properties of price and quantity decisions under stochastic demand.

Jadidi, Taghipour, and Zolfaghari (2016) consider a newsvendor retailer with an option to decrease the selling price in the middle of the product lifecycle to prevent the demand from decreasing sharply. They find that the price adjustment benefits the retailer in general; however, the manufacturer prefers the buy-back contract over the retailer-driven two-price policy. Schulte and Sachs (2020) study the price-setting newsvendor by assuming that stochastic demand follows a discrete probability distribution (e.g., Poisson demand). They show that neglecting the discrete nature of demand in the pricing decision leads to a significant profit loss, and such a negative impact is exaggerated when the demand rate is small.

Markup pricing: Typically, a retailer sets her price by charging either absolute or percentage markup (Arcelus & Srinivasan, 1987). While markup schemes are decided by retailers based on wholesale prices they receive from suppliers, little justification is provided for the selection of a specific markup scheme (i.e., percentage or absolute) in the literature. Irmen (1997) states that without a power structure between a retailer and a manufacturer, percentage markup is preferred to absolute markup by the retailer while offering lower final prices. Furthermore, even in a Stackelberg game, von Ungern-Sternberg et al. (1994) demonstrates that not only the retailer's profit is higher, but the total supply chain achieves higher efficiency under percentage markup compared to absolute markup.

In practice, Wang, Lau, and Lau (2013) explain that absolute markup is widely used in the agricultural industry or luxurious products such as jewelry, while in consumer retailing, percentage markup is common practice. Another common usage of percentage markup is in the mobile application industry (Avinadav, Chernonog, & Perlman, 2015). By incorporating the risk-taking attitude of a supplier (developer) and a retailer (distribution platform) in a Domi-reta game, they compare the performance between percentage markup (revenue-sharing) and absolute markup (wholesale price). The percentage markup leads to higher expected profits for the retailer and the entire supply chain, while the supplier benefits more from the absolute markup scheme as long as he is not too risk seeking.

Wang et al. (2016) extend their previous work by including a competition framework where two substitutable retailers are the leaders of the game, having dedicated suppliers as the followers. They claim that the percentage markup under competition leads to a prisoner's dilemma, which contradicts the conventional belief that the percentage markup benefits the retailer under the Domi-reta game. Canyakmaz, Özekici, and Karaesmen (2022) consider a percentage markup for a retailer who encounters stochastic price volatility under a Poisson process. They demonstrate that as inventory increases, the optimal markup decreases, whilst the optimal base stock level decreases as markup increases. Avinadav and Levy (2023) compare both percentage (commission-rate model) and absolute markup (fixed-fee model) schemes, focusing on platforms. They demonstrate that an absolute markup is always preferred by a platform (retailer). However, in the event that the platform has better and hidden knowledge about market information than a developer (supplier), then channel efficiency may be higher under the percentage markup. Wang, Tan, Wang, and Lai (2023) focus on two retailers' optimal markup choice decisions (absolute or percentage) and a supplier's wholesale price decision between retailer-specific or uniform wholesale prices under a Domi-reta game. They demonstrate that while both retailers always prefer percentage markup over absolute markup, the supplier opts for a uniform wholesale price as the uniform pricing can mitigate the market power of two retailers, especially if the competition between the retailers is high.

Selling to the newsvendor and upstream competition: Lariviere (2006) studies a decentralized supply chain where a supplier decides on a wholesale price, and then a newsvendor retailer sets an optimal quantity. With the condition of increasing IGFR, they use the concept of price elasticity to derive an optimal wholesale price decision of the manufacturer anticipating the retailer's order quantity. McGuire and Staelin (1983) explore a supply network involving two competing manufacturers, each faced with the choice of distributing their products independently or through dedicated retailers. They illustrate that in cases where the substitutability between the products of these two manufacturers is high, the manufacturers prefer to distribute their products through decentralized retailers.

Li, Wang, and Cheng (2010) consider a retailer, two competing manufacturers with unreliable supplies, and a spot market manufacturer who is perfectly reliable. While the retailer is a follower, they investigate the retailer's optimal sourcing strategy while the manufacturers set their prices simultaneously. Chiu et al. (2011) focus on different impacts of additive and multiplicative price-dependent demand functions on the profits of a retailer and a manufacturer. They argue that a manufacturer can achieve channel coordination under a Domi-manu game by employing channel rebate and return policy.

Power structure in supply chains: Choi (1991) considers two competing manufacturers and a retailer for both Domi-manu and Domi-reta games. He presents the equilibrium price of each player and explores linear and nonlinear deterministic demands. Without a strictly dominating power of one player, all supply chain members can benefit from higher profits. Also, he argues that when the manufacturers' products are easily substitutable, having a common retailer reduces their profits. Lee and Staelin (1997) consider dominant retailer power. They study the relationship between a manufacturer's and retailer's equilibrium price decisions and introduce the concept of vertical strategic interaction under different price-sensitive demand models.

Lau and Lau (2005) study the system behavior in the Domi-reta game with stochastic price-dependent demand functions in combination with asymmetric demand information. They show that when demand uncertainty is high, the manufacturer, being a leader, has a higher channel efficiency by charging his wholesale price than enforcing a close-to-retailer price. Similarly, Raju and Zhang (2005) study the Domi-reta game and suggest two contract design mechanisms that can coordinate channel inefficiency: quantity discount and two-part tariffs.

Shi et al. (2013) consider a retailer and a manufacturer and the impact of different power dominance on the players. They demonstrate that a retailer being a leader under a linear demand brings higher channel efficiency, while under an iso-elastic demand, the manufacturer as a leader results in higher channel efficiency. They also show that lower demand uncertainty increases the manufacturer's profit while the retailer benefits only when demand follows an iso-elastic function. Luo, Chen, Chen, and Wang (2017) study a retailer and two manufacturers offering differentiated products under horizontal and vertical competition. They show that no dominance among the players yields the highest channel efficiency, while the manufacturer who announces a wholesale price first makes a lower profit as the competing manufacturer learns from the pricing decision and takes over bargaining power. Chakraborty and Mandal (2021) consider two competing retailers and a manufacturer. They show that when the two retailers sequentially decide on order quantities, channel efficiency is higher than that of a simultaneous setting, as the double marginalization effect can be mitigated.

Gaps and contributions: Although sequential games between a retailer and a supplier have been widely studied, a comprehensive overview of the impact of power structure on channel efficiency under different conditions, such as demand function under uncertainty and markup scheme, is limited. We give guidance on which settings a certain power structure brings a higher channel efficiency, leader's advantage, and expected profits. The contribution to the literature is threefold: First, in the two-player game, we show that increasing demand uncertainty can contribute to a higher expected profit for the retailer being a follower under linear demand due to the significant wholesale price reduction from the manufacturer acting as the leader. Moreover, we demonstrate that if two manufacturers compete over wholesale prices, channel efficiency is higher when the retailer is a follower rather than a leader. The direct price competition between manufacturers results in lower wholesale prices, consequently prompting the retailer to set a lower selling price. Lastly, contrary to the common belief that consumer surplus decreases in demand uncertainty, in the three-player game, having the retailer as a follower can lead to higher consumer surplus due to the mitigated double marginalization effect.

3. Model formulation

We consider a Stackelberg game with one manufacturer (He) who sets the wholesale price w and one retailer (She) who decides the order quantity q and markup u. The power structure of the game consists of two cases: (1) the manufacturer plays as the leader (Domi-manu), and (2) the retailer plays as the leader (Domi-reta). Under the Domi-manu game, the sequence of decisions is: (1) wholesale price w, (2) markup u and order quantity q, while under the Domi-reta game: (1) markup u, (2) wholesale price w, and (3) order quantity q. The retailer has two options to set her markup: absolute markup u_+ ($p = u+w$), or percentage markup $u_{\%}$ ($p = (1+u)\cdot w$). The manufacturing cost c, and retailer's salvage cost s are exogenously given. All cost parameters, s and c, are common knowledge to the manufacturer and retailer where $s \le c$. The decisions are made before uncertain demand is realized over a single selling season. The market has a price-sensitive demand function $D(p)$. We apply the most commonly used price-sensitive demand functions from price theory, linear and iso-elastic demands in the following form (see Simon et al. 2019):

1. Linear demand curve: $y(p) = a - bp$, where $a > 0$ and $b > 0$
2. Iso-elastic demand curve: $y(p) = ap^{-b}$, where $a > 0$ and $b > 2$.

Price-dependent demand is subject to uncertainty. The random variable $\tilde{x}$ has a probability density $f(\cdot)$ and a cumulative distribution $F(\cdot)$. Newsvendor-type problems typically assume that the random demand distribution has an increasing generalized failure rate (IGFR) (Ziya, Ayhan, & Foley, 2004). By definition, the generalized failure rate is $x \cdot f(x)/[1 - F(x)]$. The IGFR assumption is a relatively mild restriction compared to the other two assumptions, and IGFR distributions contain the most frequently employed distributions such as normal, exponential, and uniform distributions (Kocabıyıkoğlu & Popescu, 2011).

Conventionally, the randomness of demand ($\tilde{x}$) is applied additively (location) or multiplicatively (scale) to the demand function (Mills, 1959). Especially, when demand uncertainty is formed in a multiplicative way, the demand follows $\tilde{D}(p,\tilde{x}) = y(p)\tilde{x}$ and the coefficient of variation (CV) is independent of price as $CV = \frac{\sigma\left[\tilde{D}(p,\tilde{x})\right]}{\mathbb{E}\left[\tilde{D}(p,\tilde{x})\right]} = \frac{\sigma y(p)}{\mu y(p)} = \frac{\sigma}{\mu}$. To avoid the endogenous pricing decision impacts on the CV through the price-dependent demand function $y(p)$, we consider multiplicative randomness in our study where the CV is purely defined by the moments of distribution such as μ and σ and investigate the effect of demand stochasticity represented as CV on each supply chain member's profit.

Based on Gal-Or (1985), we consider two types of leaders' advantages. Type-I leader's advantage represents that the player with dominant power always prefers to move first rather than second. Type-II leader's advantage implies that the leader gains more than the follower in a game. To investigate the supply chain performance, this study analyzes the individual player's profit, channel efficiency and these two types of leader's advantages. We denote each player's profit π_j^i, where superscript $i \in \{I, M, R\}$ denotes a game setting (I integrated market, M Domi-manu, and R Domi-reta) and subscript $j \in \{m, s, r\}$ for the respective player. For instance, π_r^M represents the retailer's profit under the Domi-manu game. The players are risk-neutral and maximize expected profits. As Petruzzi and Dada (1999) and Lariviere and Porteus (2001), we use the stocking factor z and the modified price elasticity $\varepsilon(z)$ for the analytical tractability. All notations are summarized in Table 1.

4. Two-player Stackelberg game

4.1. Integrated decision

We first analyze the decisions where an integrated market needs to set the price p and the order quantity q. The objective function to be maximized is the expected profit given in (1).

$$\mathbb{E}\left[\pi^I(p,q)\right] = (p-c)\cdot q - (p-s)\cdot \mathbb{E}\left[q - y(p)\cdot\tilde{x}\right]^+ \tag{1}$$

Using the stocking factor expression $z = \frac{q}{y(p)}$, the expected profit of the integrated market can be rearranged to

$$\mathbb{E}\left[\pi^I(p,z)\right] = (p-c)y(p)\mu - y(p)[(c-s)\Lambda(z) + (p-c)\Theta(z)]. \tag{2}$$

where $\Lambda(z) = \int_A^z (z-\tilde{x})f(\tilde{x})d\tilde{x}$ and $\Theta(z) = \int_z^B (\tilde{x}-z)f(\tilde{x})d\tilde{x}$. Under the integrated market, the two decision variables (p and z) are set simultaneously before demand realization. The optimal solutions can be found by substituting z to p (Whitin, 1955) or p to z (Zabel, 1970). The first- and second-order conditions with respect to the stocking factor z from the expected profit are

$$\frac{\partial \mathbb{E}\left[\pi^I(p,z)\right]}{\partial z} = y(p)\left[(c-s) - (p-s)(1-F(z))\right]$$
$$\text{and } \frac{\partial^2 \mathbb{E}\left[\pi^I(p,z)\right]}{\partial z^2} = -(p-s)f(z) < 0. \tag{3}$$

From (3), the expected profit $\mathbb{E}\left[\pi^I(p,z)\right]$ is concave in z for a given p; hence the optimal stocking factor satisfies $F(z^*) = \frac{p-c}{p-s}$. Further, the optimality condition of price p for a given z is

$$\frac{\partial \mathbb{E}\left[\pi^I(p,z)\right]}{\partial p} = (\mu - \Theta(z))\cdot\left\{y(p) + y'(p)\cdot(p-c)\right\} - y'(p)\cdot(c-s)\Lambda(z).$$

In an integrated market, for a given stocking factor z, the optimal price is

$$p^*(z) = p_0 + \frac{\Lambda(z)(c-s)}{2(\mu-\Theta(z))} \text{ where, } p_0 = \frac{a+bc}{2b} \text{ for linear demand function}$$
$$p^*(z) = p_0 + \frac{b}{b-1}\left[\frac{(c-s)\Lambda(z)}{\mu-\Theta(z)}\right] \text{ where, } p_0 = \frac{bc}{b-1} \text{ for iso-elastic demand function.} \tag{4}$$

p_0 is the price that maximizes the riskless profit, $(p-c)y(p)\mu$ stated by Petruzzi and Dada (1999). From (3), $\mathbb{E}\left[\pi^I(p,z)\right]$ is concave in z for a given p. Therefore, by replacing the price decision variable p with the stocking factor z, we have single equation in one variable to obtain an optimal solution. Substituting $p = p^*(z)$ from (4) into (2), the first-order condition yields:

$$\frac{\partial \mathbb{E}\left[\pi^I(p(z),z)\right]}{\partial z} = y(p(z))\cdot[1-F(z)]\,R(z),$$
$$\text{where } R(z) = p(z) - s - \frac{c-s}{1-F(z)}. \tag{5}$$

As the multiplication term $y(p(z))$ and $[1-F(z)]$ is strictly positive, the optimal stocking factor satisfies the first-order condition (FOC) equal to zero, $R(z^*) = 0$. Therefore, the optimal $z^*(p)$ for a given p and $p^*(z)$ for a given z suffice $F(z^*) = \frac{p-c}{p-s}$ and $p^*(z) = s + \frac{c-s}{1-F(z)}$. It is noteworthy that even if the optimal stocking factor, z, and price p are the same under two demand functions (i.e., linear and iso-elastic demands), it does not imply that the optimal quantity of both demand functions are equal as the stocking factor $z = \frac{q}{y(p)}$ is a relative indicator of order quantity q depending on different demand functions $y(p)$.

4.2. Decentralized decision

Power structure with Domi-manu. The retailer's profit is analogous to the integrated market since both the retailer's price and quantity decisions need to be made before the demand has materialized. Therefore, u and q are simultaneous decisions. However, now the cost is the wholesale price w, instead of the manufacturing cost c. We can proceed with the same approach for the retailer's optimal solution. Another structural difference in the retailer's profit is that now the price-dependent demand depends on the retailer's markup decision u and the manufacturer's wholesale price decision w.

Table 1
Summary of notation.

Notation	Description
Superscripts and Subscripts	
$I,\ M,\ R$	Integrated, dominant manufacturer and retailer game, respectively
$m,\ s,\ r$	Global manufacturer, local manufacturer, retailer, respectively
$+\ ,\ \%$	Absolute market and percentage market of retailer, respectively
Parameters	
s	Unit salvage cost
$c,\ c_m,\ c_s$	Unit production cost, global manufacturer's cost, local manufacturer's cost in three-player game, respectively
$\widetilde{x}$	Random variable $\widetilde{x} \in [A, B]$
$f(\cdot), F(\cdot)$	Probability density and cumulative distribution function of $\widetilde{x}$
$y(p)$	Price dependent demand function where, $y(p) = a - bp$ or $y(p) = ap^{-b}$
$D(p, \widetilde{x})$	Stochastic demand $D(p, \widetilde{x}) = y(p) \cdot \widetilde{x}$
Decision Variables	
u_t	Retailer's markup under scheme t where, $t \in \{+, \%\}$
$w,\ w_m,\ w_s$	Manufacturer price in a two-player game, global manufacturer's price, local manufacturer's price in three-player game, respectively
p	Market price where, $p = w + u$ or $p = w \cdot (1 + u)$
q	Order quantity of retailer
Functions	
π_j^i	Profit function of j in setting i where $i \in \{I, M, R\}$ and $j \in \{m, s, r\}$
Definitions	
z	Stocking factor $z = q/y(p)$
$\varepsilon(z)$	Price elasticity $\varepsilon(z) = -w(z, p)/\left[z\partial w(z, p)/\partial z\right]$
$g(x)$	Generalized increasing failure rate $g(x) = x \cdot f(x)/[1 - F(x)]$
CE^i	Channel Efficiency in setting i $CE^i = \pi_r^i + \pi_m^i/\pi^I$ where $i \in \{I, M, R\}$
LA_1^i	Type 1 leader's advantage in setting i $LA_1^i = \pi_r^R/\pi_r^M$ or π_m^M/π_m^R
LA_2^i	Type 2 leader's advantage in setting i $LA_2^i = \pi_r^R/\pi_m^R$ or π_m^M/π_r^M

The retailer's expected profit functions for absolute - and percentage markup are:

$$\mathbb{E}\left[\pi_r^M(u, z; w)\right] = \begin{cases} u \cdot y(u+w)\mu - y(u+w)[(w-s)\Lambda(z) + u \cdot \Theta(z)] & \text{for } p = u + w \\ u \cdot w \cdot y(w \cdot (1+u))\mu \\ \quad -y(w \cdot (1+u))[(w-s)\Lambda(z) + u \cdot w \cdot \Theta(z)] & \text{for } p = w(1+u). \end{cases} \tag{6}$$

The retailer, as a follower, simultaneously sets selling price p and corresponding order quantity $q = y(p) \cdot z$. As the retailer determines the price p that maximizes her expected profit, the optimal selling price remains unchanged, irrespective of the markup scheme: $p^* = w + u_+^* = w(1 + u_\%^*)$ for a given wholesale price w. This implies that, even if the retailer uses a percentage markup, in the Domi-manu game, as the retailer's margin is determined after the manufacturer announces w, the retailer seeks the optimal price p^* that maximizes expected profit. For this reason, our focus is on optimizing z in conjunction with the selling price p. Based on the partial derivative of the retailer's expected profit with respect to z, the retailer's optimal stocking factor is $z^*(p, w) = F^{-1}\left(\frac{p-w}{p-s}\right)$. Further, the equilibrium price is

$$\begin{aligned} p^*(w, z) &= u_0 + \frac{\Lambda(z)(w-s)}{2(\mu - \Theta(z))} + w \text{ where,} \\ u_0 &= \frac{a - bw}{2b} \text{ under linear demand,} \\ p^*(w, z) &= u_0 + \frac{b}{b-1}\left[\frac{(w-s)\Lambda(z)}{\mu - \Theta(z)}\right] + w \text{ where,} \\ u_0 &= \frac{w}{b-1} \text{ under iso-elastic demand.} \end{aligned} \tag{7}$$

u_0 denotes the riskless markup, which differs from the riskless price of p_0 under the integrated market. Note that the retailer's price under the decentralized market is influenced by the wholesale price w decision of the manufacturer and the stocking factor z. Hence, the manufacturer observes the reaction function of the retailer from (7). To derive the optimal wholesale price decision of the manufacturer, we define the manufacturer's expected profit function and apply the modified price elasticity term of $\varepsilon(z)$ based on Lariviere and Porteus (2001). Given the retailer's decision, the manufacturer's profit is

$$\pi_m^M(w; p, z) = (w - c) \cdot y(p) \cdot z(w). \tag{8}$$

The response function of z from the retailer concerning the wholesale price w, the manufacturer uses this relationship between w and z to maximize his profit, $w(p, z) = p(1 - F(z)) + sF(z)$ from (7). By definition, the modified price elasticity represents the ratio of proportionate change in stocking factor z caused by a given proportional change in wholesale price w. We derive the optimal decision of z from the manufacturer's profit function by deriving the FOC in z and use the price elasticity term $\varepsilon(z)$ to obtain an optimal decision on $w(z)$ for the manufacturer.

$$\begin{aligned} \frac{\partial \pi_m^M(w, p, z)}{\partial z} &= w(p, z) \cdot y(p) + w'(p, z) \cdot y(p) \cdot z - c \cdot y(p) \\ &= y(p)\left(w(p, z)\left[1 - \frac{1}{\varepsilon(z)}\right] - c\right) \end{aligned} \tag{9}$$

The optimal solution for the manufacturer is

$$w^*(z) = \frac{\varepsilon(z)c}{\varepsilon(z) - 1}. \tag{10}$$

Even though our study addresses the optimal wholesale price w based on the retailer's stocking factor z, the optimal result $w^*(z)$ can be driven in the same way when the manufacturer optimizes his wholesale price by using the reaction function of the retailer's price p since the retailer's p and z are set simultaneously in Domi-manu game. Further, the impact of the demand function $y(p)$ is negligible to derive the equilibrium wholesale price w ($\frac{\partial \pi_m^R(u,w,z)}{\partial z} = 0$) when the manufacturer optimizes his decision concerning the stocking factor z as shown in (10). Hence, the optimal solution for the manufacturer under iso-elastic demand has the same structure as for linear demand.

Power structure with Domi-reta. Under the Domi-reta setting, the retailer announces her markup u before the manufacturer sets his wholesale price w. As the retailer knows that the manufacturer's optimal wholesale price of w is derived based on the reaction function of z, up to the second stage (Stage 1: z and Stage 2: w), we employ the same procedure to the Domi-manu game. By doing so, the stocking factor and the wholesale price decisions suffice, $F(z^*) = \frac{p-w}{p-s}$ and $w^*(z) = \frac{\varepsilon(z)c}{\varepsilon(z)-1}$ under both linear and iso-elastic demand functions. The

Table 2
Channel efficiency under different power structures.

CV	Iso-elastic			Linear		
	Domi-M	Domi-R(%)	Domi-R(+)	Domi-M	Domi-R(%)	Domi-R(+)
0.1	0.78	0.78	0.73	0.75	0.94	0.76
0.2	0.76	0.76	0.73	0.73	0.93	0.75
0.3	0.77	0.76	0.76	0.72	0.91	0.74
0.4	0.78	0.77	0.77	0.74	0.93	0.75

retailer, as a leader, anticipates the manufacturer's optimal wholesale decision for a given u. Hence, by substituting $w(z)$ into the retailer's expected profit $\mathbb{E}\left[\pi_r^R(u(z), w(z), z)\right]$, an optimal absolute markup u_+^* and a percentage markup $u_\%^*$ are the solution to

$$u_+^*(w(z), z) = (w(z)-s)\frac{F(z)}{1-F(z)} \quad \text{and} \quad u_\%^*(w(z), z) = \frac{w(z)-s}{w(z)}\frac{F(z)}{1-F(z)}. \tag{11}$$

Defining $G_+(u, w) := u_+ - (w-s)\frac{F(z)}{1-F(z)} = 0$ based on (11), from the implicit function theorem we have $0 = \frac{\partial G_+}{\partial dw} = \frac{\partial G_+}{\partial u}\frac{du}{dw} + \frac{\partial G_+}{\partial w}\frac{dw}{dw} \Leftrightarrow \frac{du}{dw} = \frac{-\frac{\partial G_+}{\partial w}}{\frac{\partial G_+}{\partial u}}$. As $\frac{\partial G_+}{\partial w} = -\frac{F(z)}{1-F(z)}$ and $\frac{\partial G_+}{\partial u} = 1$, $\frac{du_+}{dw} > 0$, implying that a higher wholesale price leads to a higher markup price from the retailer; hence, a higher selling price p. Similarly, for $G_\%(u, w) := u_\% - \frac{w-s}{w}\frac{F(z)}{1-F(z)} = 0$, as $\frac{\partial G_\%}{\partial w} = -\frac{s}{w^2}\frac{F(z)}{1-F(z)}$ and $\frac{\partial G_\%}{\partial u} = 1$, $\frac{du_\%}{dw} > 0$. However, as an increasing wholesale price reduces the order quantity, the retailer as a leader may balance between a higher price and a lower quantity. Based on the optimal decision of each player, u^*, w^*, and z^*, hereafter, we conduct numerical experiments to better understand the impact of various factors on the players' profits, channel efficiency, and leader's advantages.

4.3. Numerical results

We set the following parameter values: $c = 1.5$, $s = 0.5$, $a = 80$ and $b = 3$ for $y(p) = a - bp$ under the linear demand for numerical studies suggested by Shi et al. (2013). Under the iso-elastic demand we set $d = 230$, and $e = 2$ for $y(p) = dp^{-e}$ while economic parameters remain the same (e.g., $c = 1.5$, and $s = 0.5$).

4.3.1. Supply chain performance

The impact of sequence on channel efficiency. Table 2 shows that under iso-elastic demand, channel efficiency does not show significant differences among different power structures. However, under linear demand, when the retailer is the leader charging a percentage markup, channel efficiency is notably higher than under the other power structures, making the supply chain achieve close to the integrated market profit.

Such a high efficiency occurs because when the retailer imposes a percentage markup, the stocking factor z^* is $F^{-1}(\frac{u \cdot w}{p-s})$ while under an absolute markup $z^* = F^{-1}(\frac{w}{p-s})$. These optimal stocking factors show that by announcing a high percentage markup u as a leader, the retailer induces the manufacturer to lower his wholesale price to ensure sufficient demand $y(p)$ where $p = w(1+u)$ as indicated in the numerator. Since the retailer exploits more control over the wholesale price by announcing a percentage markup beforehand, the double marginalization effect is mitigated; hence, the supply chain achieves a high channel efficiency.

The impact of sequence on leader's advantages. By definition, Type 1 leader's advantage is a relative gain that a player can obtain as being a leader than a follower ($LA_1^m = \frac{\pi_m^M}{\pi_m^R}$ and $LA_1^r = \frac{\pi_r^R}{\pi_r^M}$). Hence, in case the Type 1 leader's advantage is below 1, $LA_1^m < 1$ or $LA_1^r < 1$, the leader tries to gain a higher profit by enforcing to be a follower. Similar to the deterministic iso-elastic demand model, where the leader's advantage equals $\frac{b-1}{b} < 1$ (Wang et al., 2016), Table 3 shows that when demand is iso-elastic, none of the players can benefit from being a leader and, hence, the leader is better off by remaining a follower. However, a clear benefit exists to being the leader under a linear demand function. In particular, the retailer charging a percentage markup can profit significantly by being a leader.

Table 3
Type 1 leader's advantage under different power structures.

CV	Iso-elastic			Linear		
	Domi-M	Domi-R(%)	Domi-R(+)	Domi-M	Domi-R(%)	Domi-R(+)
0.1	0.44	1.00	0.42	1.91	3.24	1.95
0.2	0.47	1.00	0.44	1.78	3.06	1.83
0.3	0.48	0.99	0.50	1.61	2.75	1.61
0.4	0.50	0.98	0.53	1.51	2.55	1.45

Table 4
Type 2 leader's advantage under different power structures.

CV	Iso-elastic			Linear		
	Domi-M	Domi-R(%)	Domi-R(+)	Domi-M	Domi-R(%)	Domi-R(+)
0.1	0.39	2.53	0.50	1.89	8.44	1.97
0.2	0.40	2.50	0.59	1.71	8.01	1.91
0.3	0.39	2.46	0.64	1.46	7.38	1.78
0.4	0.39	2.41	0.62	1.33	6.87	1.65

Table 5
Comparison of supply chain performance.

	Iso-elastic demand	Linear demand
Channel Efficiency	$\{CE^{R(+)}, CE^{R(\%)}\} < CE^M$	$\{CE^{R(+)}, CE^M\} < CE^{R(\%)}$
Leader's Advantage (Type I)	$\{LA_1^{R(+)}, LA_1^M\} < LA_1^{R(\%)}$	$\{LA_1^{R(+)}, LA_1^M\} < LA_1^{R(\%)}$
Leader's Advantage (Type II)	$LA_2^M < LA_2^{R(+)} < LA_2^{R(\%)}$	$LA_2^M < LA_2^{R(+)} < LA_2^{R(\%)}$

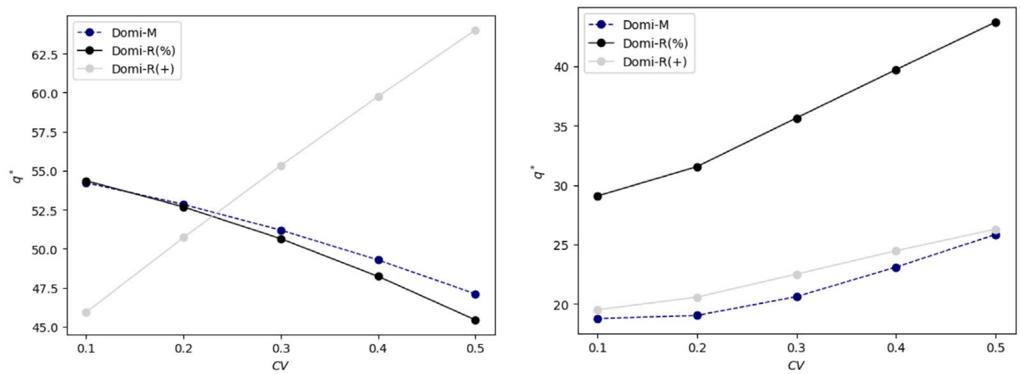
Type 2 leader's advantage denotes that a leader in a game yields a higher profit than a follower ($LA_2^m = \frac{\pi_m^M}{\pi_r^M}$ and $LA_2^r = \frac{\pi_r^R}{\pi_m^R}$). Similar to the observation from Table 3, when demand is linear, the Type 2 leader's advantage is evident, as depicted in Table 4. This implies that under a linear demand function, being the leader lets the player obtain a higher profit than being a follower and secure a higher proportion of gain compared to the follower.

Under the iso-elastic function, generally, being a leader does not lead to a higher gain than that of being the follower. However, when the retailer charges a percentage markup, although her expected profit is not as high as being a follower of the game, she can at least extract a higher profit than the manufacturer by being a leader due to the increased control over the manufacturer's wholesale price. This outcome, indicating that a retailer, as a leader, charging a percentage markup results in substantial leader's advantages, elucidates why a majority of consumer goods retailers prefer percentage markups (Wang et al., 2013).

To summarize the results from channel efficiency and leader's advantage analysis, Table 5 shows that under iso-elastic demand, Domi-manu always leads to higher channel efficiency, while under linear demand, Domi-reta charging a percentage markup has the highest channel efficiency. Further, Domi-reta charging a percentage markup obtains the highest leader's advantages, regardless of the demand function.

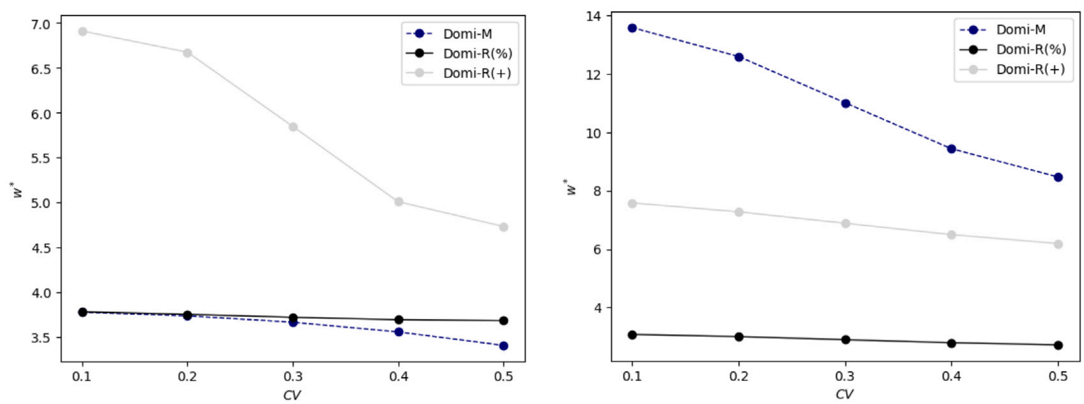
4.3.2. Equilibrium decisions and expected profits

The impact of sequence on equilibrium quantity. Under iso-elastic demand (Fig. 1(a)), high demand uncertainty makes the retailer reduce her order quantity under any power structure. Compared to the order quantity of the retailer setting an absolute markup, the order quantity set by the retailer charging a percentage markup is similar to the quantity when the manufacturer is a leader. When demand is linear, the retailer charging a percentage markup orders the most while the manufacturer, being a leader, makes the retailer reduce the optimal order quantity compared to the other cases (Fig. 1(b)).



(a) Iso-elastic Demand: $y = ap^{-b}$ (b) Linear Demand: $y(p) = a - bp$

Fig. 1. Equilibrium quantity q^*.



(a) Iso-elastic Demand: $y = ap^{-b}$ (b) Linear Demand: $y(p) = a - bp$

Fig. 2. Equilibrium wholesale price w^*.

Further, the Domi-manu case does not lead to the largest order quantity under both demand functions. This result is intriguing as one may conjecture that the manufacturer, being a leader, may force the retailer to order more by reducing the selling price p (equivalently, by increasing the price-dependent demand $y(p)$) so that he can increase profit. We delve into this question by investigating the optimal wholesale price and selling price decisions of the players.

The impact of sequence on equilibrium wholesale price. When demand is iso-elastic, although the manufacturer is the leader of the game, he does not charge a higher wholesale price than when he is the follower, as depicted in Fig. 2(a). Aligned with the finding that the iso-elastic demand function makes the leader's advantage disappear (Lau et al., 2008), this observation partly explains the reason that the manufacturer, even being a leader, cannot yield a higher expected profit than being a follower; hence, it is better to let the retailer be the leader instead. Such a result that a dominant player sometimes prefers to use his superior power balance in supply chains to be a follower in his favor is also supported by Avinadav, Chernonog, and Perlman (2014). When demand is linear, however, the manufacturer imposes the highest wholesale price when he is the leader, as shown in Fig. 2(b).

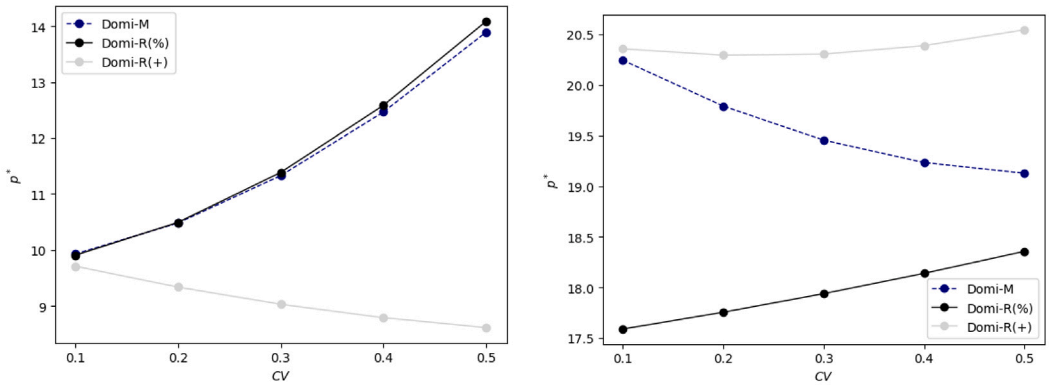
The impact of sequence on equilibrium selling price. Regarding the retailer's optimal selling price (Fig. 3), one observation is that when the retailer is the leader charging an absolute markup, the optimal price is the lowest under the iso-elastic demand, while under the linear demand, the retailer charges the highest price. Note that the difference between absolute markup price and percentage markup price under the iso-elastic demand function increases as demand uncertainty increases. On the other hand, the price difference between the two schemes decreases under the linear demand function as the demand uncertainty increases. Under the Domi-manu, when the demand follows a linear function, the manufacturer being a leader enforces the retailer to reduce her optimal price by announcing a considerably lower wholesale price as demand uncertainty increases (Fig. 3(b)). Table 6 summarizes the comparison among equilibrium decisions in different power structures and demand functions.

Table 6
Comparison of equilibrium decisions.

	Iso-elastic demand	Linear demand
Stocking Factor (z^*)	$z^{R(+)} < \left\{z^{R(\%)}, z^M\right\}$	$z^M < z^{R(+)} < z^{R(\%)}$
Wholesale Price (w^*)	$\left\{w^{R(\%)}, w^M\right\} < w^{R(+)}$	$w^{R(\%)} < w^{R(+)} < w^M$
Selling Price (p^*)	$p^{R(+)} < \left\{p^{R(\%)}, p^M\right\}$	$p^{R(\%)} < p^M < p^{R(+)}$

The impact of sequence on players' profits. Under the iso-elastic demand function, demand uncertainty decreases all players' profits for any given power structure, as shown in Table 7. More interestingly, under the linear demand function, a high demand uncertainty does not always harm the players' profits. Ridder, Van Der Laan, and Salomon (1998) state that an increasing demand variability does not always reduce the expected profit under newsvendor settings. Similarly, our results indicate that as demand uncertainty increases, the retailer, when acting as a follower under the linear demand function, achieves higher profits (i.e., π_r^M).

The interpretation of this counterintuitive benefit for the retailer acting as a follower is as follows. Initially, under a linear demand function, an increase in demand uncertainty prompts the manufacturer to significantly decrease the wholesale price w when acting as a leader (Domi-manu), compared to the Domi-reta scenario. This reduction is



(a) Iso-elastic Demand: $y = ap^{-b}$ (b) Linear Demand: $y(p) = a - bp$

Fig. 3. Equilibrium selling price p^*.

Table 7
Expected profit of each player under different power structures.

	Iso-elastic Demand Function: $y = ap^{-b}$							Linear Demand Function: $y(p) = a - bp$						
CV	Int	Domi-M		Domi-R(%)		Domi-R(+)		Int	Domi-M		Domi-R(%)		Domi-R(+)	
		π_m^M	π_r^M	π_m^R	π_r^R	π_m^R	π_r^R		π_m^M	π_r^M	π_m^R	π_r^R	π_m^R	π_r^R
0.1	559	123	314	124	313	266	139	461	227	120	46	389	119	233
0.2	548	118	298	119	298	233	138	461	212	124	48	380	119	227
0.3	509	110	279	112	275	216	137	457	195	134	50	367	121	215
0.4	465	103	260	106	254	205	127	436	185	139	52	354	123	202

Table 8
Comparison of expected profits.

	Iso-elastic demand	Linear demand
Domi-manu	$\pi_m^M < \pi_r^M$	$\pi_m^M > \pi_r^M$
Domi-reta (%)	$\pi_m^{R(\%)} < \pi_r^{R(\%)}$	$\pi_m^{R(\%)} < \pi_r^{R(\%)}$
Domi-reta (+)	$\pi_m^{R(+)} > \pi_r^{R(+)}$	$\pi_m^{R(+)} < \pi_r^{R(+)}$

primarily to induce the retailer to set a lower selling price p. Accordingly, the order quantity q also increases while both the wholesale price and the retailer price decrease as shown in Fig. 1(b), 2(b), and 3(b). However, as the retailer's price changes only moderately under the Domi-manu, the retailer as a follower can benefit from a considerable reduction of the wholesale price while keeping her selling price relatively the same in increasing demand uncertainty.

Table 8 summarizes the relationships among each player's expected profit in different settings. Similar to Table 3, the leader of the game obtains a higher profit than the follower under linear demand. However, under iso-elastic, the follower has a higher profit than the leader, unless the retailer is the leader, charging a percentage markup.

5. Three-player Stackelberg game

5.1. Decentralized decision

Now consider that a retailer sources from both a global and a local manufacturer offering identical products. The retailer decides its order quantity q from the global manufacturer, charging a wholesale price w_m before demand is realized. For any shortage, the local manufacturer can instantaneously deliver additional products to the retailer with another wholesale price of w_s. Such a local manufacturer charges a premium wholesale price for its dedicated fulfillment service. Due to the local manufacturer's premium service, the wholesale price set by the local manufacturer is higher than that of the global manufacturer $w_s \geq w_m$. Both manufacturers decide their wholesale prices, w_m and w_s, for the retailer before the selling season. Our focus is to investigate how the power structure between the retailer and the global manufacturer impacts the leader's advantage and channel efficiency with the existence of the local manufacturer.

Note that when the local manufacturer is a follower (M-S-R, R-S-M, M-R-S, or R-M-S), the optimal solution leads to an extreme case, where w_s^* is either $w_s^* = w_m^*$ for the sequence M-S-R, M-R-S, and R-M-S, or $w_s^* = p^*$ for the sequence R-S-M. Suppose that the global manufacturer's w_m^* is announced before the local manufacturer's wholesale price decision (i.e., M-S-R, M-R-S, and R-M-S), and the local manufacturer has an incentive to set $w_s^* = w_m^*$ as he acts as a monopolistic manufacturer, making the retailer fulfill demands from the local manufacturer ($z = F^{-1}(0)$ and $\Theta(z) = 1$). Even if w_m^* is set after w_s^*, if the retailer's price p^* is preannounced before w_s^* (i.e., R-S-M), as the price-dependent market demand is fixed to $y(p^*)$, the local manufacturer has only marginal influence on the expected shortage quantity defined by $y(p^*)\Theta(z)$; hence he has an incentive to set $w_s^* = p^*$ to ensure a high profit margin ($w_s^* - c_s$).

To avoid those trivial results, therefore, we consider the case where the local manufacturer is a leader ($w_m^* \leq w_s^* \leq p^*$) in this study. One sequence is where the retailer announces an optimal selling price p after the local manufacturer's wholesale price decision w_s. Upon the retailer's announcement of a selling price p, and the global manufacturer sets his wholesale price w_m to charge to the retailer's upcoming order quantity q. Based on p, w_m, and w_s, finally, the retailer sets the order quantity q, and the shortage is defined accordingly. We refer to this sequence as Domi-reta under the involvement of a local manufacturer (S-Domi-reta). In the other sequence, the local manufacturer announces his wholesale price w_s first, and the global manufacturer sets the wholesale price w_m based on the local manufacturer's price w_s. Finally, the retailer sets both of selling price p and order quantity q simultaneously. Hereafter, this sequence of the game is denoted as Domi-manu under the involvement of a local manufacturer (S-Domi-manu).

Retailer's profit function. The retailer's expected profit for given w_m and w_s is

$$\mathbb{E}\left[\pi_r(p, z; w_m, w_s)\right] = y(p)\left\{(p - s)\mu - (w_s - s)z - (w_s - s)\int_z \overline{F}(\widetilde{x})d\widetilde{x}\right\}. \tag{12}$$

For the retailer, the involvement of the local manufacturer is considered to be an emergency purchasing cost. Using $\Lambda(z) = z - \mu + \Theta(z)$, the retailer's expected profit is rearranged to:

$$\mathbb{E}\left[\pi_r(p,z;w_m,w_s)\right] = p\cdot y(p)\cdot \mu - w_m\cdot y(p)\cdot z + y(p)[s\cdot \Lambda(z) - w_s\cdot \Theta(z)]. \quad (13)$$

The first-order derivative with respect to z yields:

$$\frac{\partial \mathbb{E}\left[\pi_r(p,z;w_m,w_s)\right]}{\partial z} = y(p)\left\{-w_m + s + \overline{F}(z)(w_s - s)\right\}.$$

Therefore, the optimal stocking factor and the order quantity of the retailer are

$$z^*(w_s,w_m) = F^{-1}\left(\frac{w_s - w_m}{w_s - s}\right) \text{ and } q^*(p,w_s,w_m) = y(p)\cdot F^{-1}\left(\frac{w_s - w_m}{w_s - s}\right) \quad (14)$$

The optimal quantity decision of the retailer shows that when the local manufacturer imposes a high wholesale price w_s, she increases the order quantity from the global manufacturer. In contrast, a high wholesale price w_m from the global manufacturer reduces the order quantity. Note that the optimal stocking factor z^* no longer depends on the retailer's selling price p as the underage and the overage costs are defined by w_s, w_m, and s. Further, for given wholesale prices from two manufacturers (w_m and w_s) and the stocking factor z, the retailer's optimal prices satisfy:

$$\begin{aligned} p^*(z,w_s,w_m) &= \frac{a+bs}{2b} + \frac{(w_m - s)z + (w_s - s)\Theta(z)}{2} \text{ for linear demand} \\ p^*(z,w_s,w_m) &= \frac{bs}{b-1} + \frac{b}{b-1} \\ &\quad \times \left[(w_m - s)z + (w_s - s)\Theta(z)\right] \text{ for iso-elastic demand.} \end{aligned} \quad (15)$$

Similar to the optimal price in (7) under the two-player setting, the first term of the retailer's price is interpreted as a riskless price that the retailer, without demand uncertainty, would charge. Notably, as the retailer's shortage cost increases by w_s, an additional term of a risk premium for the expected underage $\Theta(z)$ is imposed in her optimal price as the last term.

Manufacturers' profit functions. As both manufacturers' profits are generated by the retailer's order quantity and subsequent expected shortages, we present the optimization problems of the manufacturers below.

$$\begin{aligned} &\mathbb{E}\left[\pi_m(w_m;p,z,w_s)\right] = (w_m - c_m)\cdot y(p)\cdot z \\ &\text{and } \mathbb{E}\left[\pi_s(w_s;p,z,w_m)\right] = (w_s - c_s)\cdot y(p)\cdot \Theta(z) \end{aligned} \quad (16)$$

As the global manufacturer's w_m decision is set after the local manufacturer's wholesale price w_s, the global manufacturer's optimal decision is analogous to the selling to a newsvendor retailer problem as presented in (10), sufficing $w^*_m(z) = \frac{\varepsilon(z)c_m}{\varepsilon(z)-1}$ for a given stocking factor z. The structure of the local manufacturer's expected profit function is similar to that of the global manufacturer. However, as the local manufacturer fulfills the retailer's expected shortages, the expected profit is composed of his profit margin, $w_s - c_s$, multiplied by the expected shortage from the retailer, $y(p)\cdot\Theta(z)$. The local manufacturer's necessary condition for the optimal wholesale price w_s for a given z is:

$$w^*_s(z) = \frac{-y(p)\cdot\theta(z)}{\left\{\frac{\partial y(p)}{\partial w_s}\theta(z) + \frac{\partial \theta(z)}{\partial w_s}y(p)\right\}} + c_s \quad (17)$$

From (17), as $\frac{\partial y(p)}{\partial w_s} = \frac{\partial y(p)}{\partial p}\frac{\partial p}{\partial w_s} < 0$ and $\frac{\partial \theta(z)}{\partial w_s} = \frac{\partial \theta(z)}{\partial z}\frac{\partial z}{\partial w_s} < 0$, the local manufacturer's wholesale price is $w_s \geq c_s$. From the optimal stocking factor z^* in (14), an increasing global manufacturer's wholesale price w_m reduces the retailer's order quantity q^* while the local manufacturer's increasing w_s reversely increases the retailer's order quantity to the global manufacturer. Based on the expected profit functions of three players in (13) and (16), we investigate how the power structure (i.e., S-Domi-reta and S-Domi-manu) affects channel efficiency and leader's advantages when an additional manufacturer is involved.

Table 9
Channel efficiency under different power structures.

CV	Iso-elastic demand		Linear demand	
	S-Domi-M	S-Domi-R	S-Domi-M	S-Domi-R
0.1	0.82	0.70	0.78	0.76
0.2	0.88	0.70	0.90	0.76
0.3	0.96	0.83	0.93	0.78
0.4	0.97	0.94	0.97	0.82

With the involvement of the local manufacturer, we consider the case where the retailer sets a single selling price p to the market, not charging a certain markup (+ or %) to the global manufacturer. This pricing construct is needed because with the existence of two wholesale price offers (e.g., w_m and w_s) it is unclear based on which wholesale price the retailer should impose the markup as both manufacturers offer identical products. Further, if the retailer's markup is charged only to the global manufacturer, $p = w_m + u_+$ or $p = w_m(1+u_\%)$, the optimal local manufacturer's wholesale price follows $w_s = p$ (i.e., the local manufacturer as a leader sets a highest possible wholesale price) as the impact of local manufacturer's wholesale price w_s on the retailer's markup u is significantly small; hence, has little impact on $y(p)$.

5.2. Numerical results

We now observe how the equilibrium decisions of the manufacturers and the retailer change compared to the two-player settings.

5.2.1. Supply chain performance

The impact of sequence on channel efficiency. Table 9 shows that channel efficiency is higher when the global manufacturer is the second mover, following directly the local manufacturer (S-Domi-manu) than when the retailer is the second mover. Especially, compared to the two-player game where channel efficiency is higher in Domi-reta under linear demand (Table 2), the global manufacturer setting his wholesale price w_m, before the retailer's price decision p leads to a higher channel efficiency due to the local manufacturer and the early announcement of w_s. This is because when the global manufacturer's decision directly follows the local manufacturer's wholesale price decision, they both can influence the retailer's price decision p and, hence, have better control over the optimal order quantity q^*. Such a sequence (S-Domi-manu) leads to more fierce wholesale price competition between the two manufacturers, resulting in lower w_m and w_s. However, in the case of S-Domi-reta, the retailer indirectly serves as a moderator in the wholesale price competition by announcing p before the wholesale price w_m, which essentially increases both wholesale prices w_m and w_s and decreases channel efficiency.

5.2.2. Equilibrium decisions and expected profits

The impact of sequence on equilibrium quantity. We investigate how the existence of the local manufacturer changes the optimal decision of the manufacturers and the retailer. In the three-player game, if the global manufacturer's wholesale price decision w_m follows the local manufacturer's wholesale price decision w_s (S-Domi-manu), the order quantity is higher than in the case where the retailer's price decision p is made directly after the local manufacturer's wholesale price w_s announcement (S-Domi-reta). This is because the direct wholesale price competition between two manufacturers leads to lower wholesale prices for both players (w_m and w_s) under S-Domi-manu and consecutively induces a lower selling price p of the retailer; hence a higher demand from the market $y(p)$ (see Table 10).

The impact of sequence on equilibrium wholesale prices. Comparing the cases where the global manufacturer's wholesale decision w_m precedes the retailer's price decision p under two-player and three-player games (i.e., Domi-manu and S-Domi-manu), the existence of the

Table 10
Optimal order quantity decision q^*.

CV	Int	Two-player			Three-player	
		Domi-M	Domi-R(%)	Domi-R(+)	S-Domi-M	S-Domi-R
Iso-elastic Demand Function: $y(p) = ap^{-b}$						
0.1	297.99	54.38	54.25	46.00	55.55	32.61
0.2	258.95	52.47	52.90	50.85	61.05	25.74
0.3	225.55	51.35	50.58	54.50	65.17	29.73
0.4	202.73	49.45	48.10	60.72	66.20	37.59
Linear Demand Function: $y(p) = a - bp$						
0.1	50.97	18.77	29.08	19.51	18.39	17.58
0.2	50.97	19.03	31.55	20.57	18.44	13.88
0.3	50.53	20.61	35.65	22.51	21.84	13.72
0.4	50.03	23.10	39.71	24.47	25.02	16.03

Table 11
Optimal manufacturers' wholesale price decisions w_m^* and w_s^*.

CV	Two-player			Three-player			
	Domi-M	Domi-R(%)	Domi-R(+)	S-Domi-M	S-Domi-R	S-Domi-M	S-Domi-R
	w_m^*			w_m^*		w_s^*	
Iso-elastic Demand Function: $y(p) = ap^{-b}$							
0.1	3.77	3.78	6.90	3.07	5.08	3.42	5.45
0.2	3.75	3.75	6.72	2.66	3.94	3.49	4.43
0.3	3.64	3.72	5.78	2.43	3.21	3.50	4.30
0.4	3.57	3.69	5.05	2.29	2.83	3.50	4.17
Linear Demand Function: $y(p) = a - bp$							
0.1	13.58	3.08	7.58	10.28	14.33	10.57	14.89
0.2	12.65	3.01	7.29	8.00	12.60	11.79	15.97
0.3	10.94	2.89	6.87	6.95	10.81	12.69	17.31
0.4	9.49	2.80	6.51	6.20	9.49	12.81	17.49

local manufacturer makes the wholesale price of the global manufacturer w_m reduce as they compete over the wholesale prices to achieve more favorable order quantity from the retailer as shown in Table 11. Under a linear demand function, when the retailer's price decision p precedes the global manufacturer's wholesale price w_m (i.e., Domi-reta and S-Domi-reta), the wholesale price of the global manufacturer w_m is higher in the three-player game than in the two-player scenario. Because given an announced selling price p of the retailer, under the two-player game, the stocking factor $z^* = F^{-1}(\frac{p-w}{p-s})$ depends on both p and w. Hence, the retailer as the leader can induce the manufacturer to lower his wholesale price w_m by imposing a high selling price, p. However, under the three-player game, the stocking factor $z^* = F^{-1}(\frac{w_s-w_m}{w_s-s})$ is no longer based on the retailer's selling price p but the wholesale prices between two manufacturers, w_s and w_m. Therefore, the retailer as a leader cannot impact the global manufacturer's wholesale price through the optimal stocking factor decision z^*, and the global manufacturer sets w_m in relation to w_s.

When the wholesale price w_m follows directly the local manufacturer's decision on w_s (S-Domi-manu), the local manufacturer imposes a lower w_s compared to the S-Domi-reta case. Further, the global wholesale price w_m decreases regardless of demand functions in demand uncertainty to induce the retailer's lower price p and a sufficiently high stocking factor z. On the other hand, anticipating such a reaction from the global manufacturer, the local manufacturer as the leader increases the wholesale price w_s under the linear demand whilst under the iso-elastic demand he reduces w_s as demand uncertainty increases. Such differences are caused by the marginal demand decrease in the retailer's price p. Note that if the demand is linear, $y(p) = a - bp$, $y'(p) = -b$. If the demand is iso-elastic, $y(p) = ap^{-b}$, $y'(p) = -abp^{-b-1}$. Hence, the local manufacturer's incentive to lower the retailer's price p hence increase $y(p)$ is more prominent under the iso-elastic demand function. This implies that when demand follows an iso-elastic function, the local manufacturer has a higher incentive to reduce his wholesale price w_s so that the retailer sets a lower price p subsequently. In contrast, when the demand follows a linear function, as inducing the retailer to lower p leads to a constant marginal increase in demand, the local manufacturer focuses on ensuring his profit margin $(w_s - c_s)$ by increasing his wholesale price w_s as demand uncertainty increases.

Table 12
Optimal selling price decision p^*.

CV	Int	Two-player			Three-player	
		Domi-M	Domi-R(%)	Domi-R(+)	S-Domi-M	S-Domi-R
Iso-elastic Demand Function: $y(p) = ap^{-b}$						
0.1	3.73	9.93	9.94	9.60	9.33	12.89
0.2	4.12	10.48	10.42	9.57	8.00	10.55
0.3	4.53	11.33	11.41	9.01	7.50	9.63
0.4	4.87	12.47	12.63	8.59	7.48	9.35
Linear Demand Function: $y(p) = a - bp$						
0.1	14.21	19.89	17.73	20.31	18.47	20.50
0.2	14.32	19.42	17.98	20.35	17.96	20.29
0.3	14.46	19.18	18.15	20.38	17.95	20.23
0.4	14.56	19.16	18.35	20.55	17.96	20.20

Table 13
Comparison of equilibrium decisions.

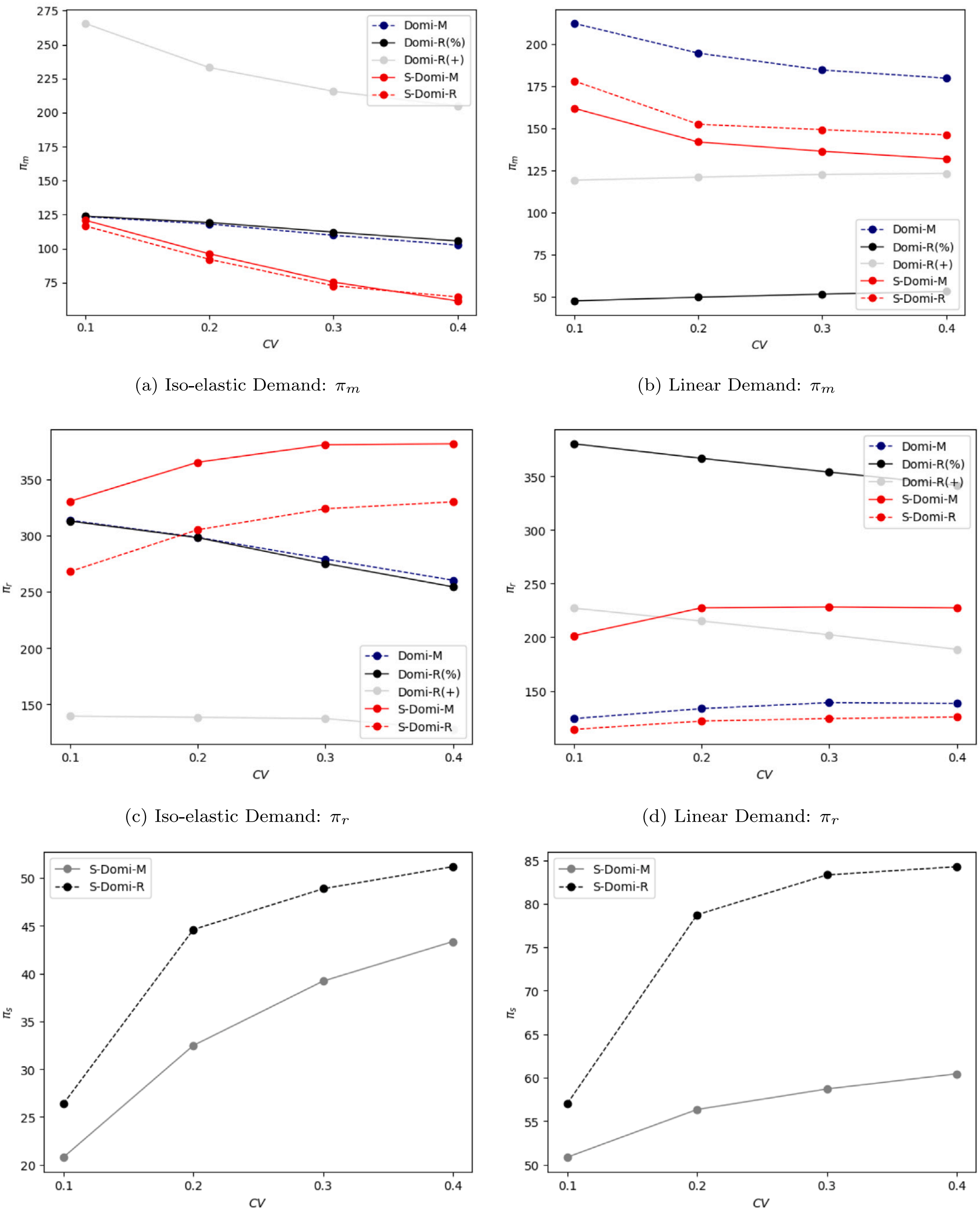
	Iso-elastic demand	Linear demand
Stocking Factor (z^*)	$z^{S-R} < z^{S-M}$	$z^{S-R} < z^{S-M}$
Local Wholesale Price (w_s^*)	$w_s^{S-R} > w_s^{S-M}$	$w_s^{S-R} > w_s^{S-M}$
Global Wholesale Price (w_m^*)	$w_m^{S-R} > w_m^{S-M}$	$w_m^{S-R} > w_m^{S-M}$
Selling Price (p^*)	$p^{S-R} > p^{S-M}$	$p^{S-R} > p^{S-M}$

The impact of sequence on equilibrium selling price. Table 12 shows that involving a local manufacturer and the retailer being a follower (S-Domi-manu) leads to a lower price than having only a global manufacturer (Domi-manu). This result is counter-intuitive as one anticipates the retailer may increase its price due to the double marginalization effect of having two manufacturers as leaders. However, when the two manufacturers compete over the wholesale prices before the retailer sets the price, the global manufacturer's optimal wholesale price w_m (S-Domi-manu) becomes smaller than without the local manufacturer (Domi-manu). This consecutively enables the retailer to offer a lower selling price p.

Table 13 summarizes the relationships among the optimal stocking factors, global and local wholesale prices, and selling prices in different settings. Aligned with the observation that S-Domi-manu leads to higher channel efficiency under both demand functions, the equilibrium prices of three players are lower under S-Domi-manu, while the stocking factor of the retailer is higher.

Comparison of expected profits between two-player and three-player games. Under iso-elastic demand in Fig. 4(a), competition between the global and the local manufacturers harms the profit of the global manufacturer in general. Further, with the involvement of the local manufacturer, for the retailer the sequence of S-Domi-manu brings higher profits than S-Domi-reta, even though she is the follower. Especially, the retailer being a follower under the three-player game implies that there exists a trade-off between being a leader against the global manufacturer and exploiting the upstream manufacturers' wholesale price competition. As the demand uncertainty increases, it is beneficial for the retailer to involve the local manufacturer even though the local manufacturer announces the wholesale price first (Fig. 4(c)).

Under linear demand, although the global manufacturer's profit in S-Domi-manu is worse than without having the local manufacturer (Domi-manu), Fig. 4(b) shows that if the retailer's price decision precedes the global manufacturer's wholesale price decision (i.e., Domi-reta, S-Domi-reta), it is better for him to involve the second manufacturer as the existence of the local manufacturer prevents the retailer from extracting significant benefit from the global manufacturer, while the wholesale price competition is not as fierce as S-Domi-manu. Similar to the iso-elastic demand, the retailer benefits from being a follower



(a) Iso-elastic Demand: π_m (b) Linear Demand: π_m

(c) Iso-elastic Demand: π_r (d) Linear Demand: π_r

(e) Iso-elastic Demand: π_s (f) Linear Demand: π_s

Fig. 4. Expected profits of the players under iso-elastic and linear demand functions.

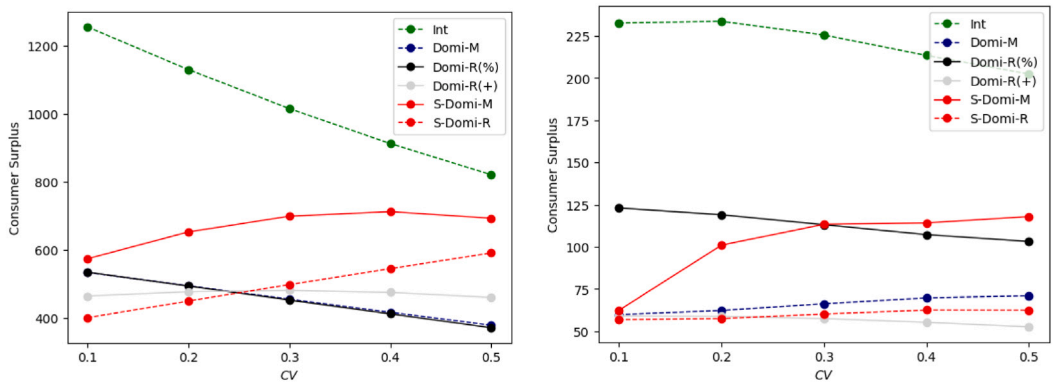
under linear demand when the local manufacturer exists (S-Domi-manu). In particular, compared to the two-player game (Domi-manu), considerable profit improvement from being a follower (S-Domi-manu) can be achieved by the retailer.

Moreover, regardless of demand functions, the involvement of a local manufacturer makes the both retailer's and the local manufacturer's expected profits increase as the demand uncertainty increases. However, the local manufacturer prefers the retailer to be the leader upon his wholesale price decision (S-Domi-reta) to avoid direct competition with the global manufacturer as shown in Fig. 4(e) and 4(f).

Lastly, the relationships among the players' expected profits in different settings from Table 14 show that upstream competition brings the retailer the highest profit. However, when demand is linear, the retailer being a leader benefits the global manufacturer. This can be explained by the fact that the reduced wholesale price competition under S-Domi-reta induces the global manufacturer to increase the wholesale price significantly.

Table 14
Comparison of expected profits.

	Iso-elastic demand	Linear demand
S-Domi-manu	$\pi_s^{S-M} < \pi_m^{S-M} < \pi_r^{S-M}$	$\pi_s^{S-M} < \pi_m^{S-M} < \pi_r^{S-M}$
S-Domi-reta	$\pi_s^{S-R} < \pi_m^{S-R} < \pi_r^{S-R}$	$\pi_s^{S-R} < \pi_r^{S-R} < \pi_m^{S-R}$



(a) Iso-elastic Demand: $y = ap^{-b}$ (b) Linear Demand: $y = a - bp$

Fig. 5. Consumer Surplus under different Power Structure.

Comparison of consumer surplus under different power structure. Under uncertain demand, consumer surplus is derived in expectation given the retailer's price p and the order quantity q. In numerical analysis, following the logic from Xue, Demirag, and Niu (2014) and Cohen, Perakis, and Thraves (2022) (i.e., random allocation rule), the expected consumer surplus is calculated as $\mathrm{CS}(p,q) = \mathbb{E}_{\tilde{x}}\left[\int_p^{p_{\max}} y(\tilde{x})\tilde{x}\mathrm{d}\tilde{x} \cdot \frac{\min\{y(p)\tilde{x}, q\}}{y(p)\tilde{x}}\right]$. Consumer surplus significantly decreases due to double marginalization between the manufacturer and retailer. Contrary to the common belief that consumer surplus declines with increasing demand uncertainty, Fig. 5(b) demonstrates that under Domi-manu, consumer surplus increases when the demand is linear due to a substantial reduction in wholesale prices, which subsequently lowers the retailer's selling price. Lastly, in a three-player game, having the retailer as a follower enhances consumer surplus by mitigating the double marginalization effect through wholesale price competition (see Fig. 5).

6. Conclusion

We study the effect of power structure, demand function, and markup scheme on supply chain performance, such as channel efficiency and leader's advantages. Beyond a single retailer and a manufacturer problem, we introduced a supply network where two manufacturers offer an identical product to a retailer, but a global manufacturer is used for a regular order and a local manufacturer for shortages under a newsvendor setting.

Our numerical results in the two-player game show that the retailer being a leader leads to higher channel efficiency under linear demand while the manufacturer being a leader brings higher channel efficiency under iso-elastic demand. Especially, under the Domi-reta game, the retailer as a leader always charges a percentage markup (%) in both linear and iso-elastic demand functions as it leads to higher leader's advantages than an absolute markup (+). Further, although expected profits of the players decrease in general as the demand uncertainty increases, when the manufacturer is the leader, the retailer as the second mover can achieve higher expected profit under linear demand. This is because the manufacturer as a leader reduces the wholesale price significantly to induce the retailer to order more under high demand uncertainty. Hence, the retailer as the follower benefits from the mitigated double marginalization effect.

In the three-player game, channel efficiency is higher when the retailer is the follower, regardless of demand functions. The reason is that when the global manufacturer's wholesale price decision directly follows the local manufacturer's wholesale price decision, both can influence the retailer's price decision. As such, the two manufacturers experience a more fierce wholesale price competition, resulting in lower wholesale prices. However, when the global manufacturer is the follower, the retailer indirectly serves as a moderator in the wholesale price competition by announcing the selling price before the wholesale price, which essentially increases both wholesale prices and decreases channel efficiency. As demand uncertainty increases, the local manufacturer, as a first-mover of the game, gains a higher profit. At the same time, it is beneficial for the retailer to involve the local manufacturer even though the local manufacturer announces the wholesale price first.

Our study is limited to showing channel efficiency under a simple price-only contact. This motivates the consideration of other contract mechanisms, such as revenue sharing and a contract menu (i.e., Liu, Yang, & Dai, 2020; Pan, Lai, Leung, & Xiao, 2010). In our study, the local manufacturer fulfills the retailer's shortages. However, a dual-sourcing option for the retailer in which both manufacturers simultaneously decide on their wholesale prices can derive further insights (i.e., Niu, Li, Zhang, Cheng, & Tan, 2019). Furthermore, we assume that information is symmetric and commonly known to the players. Therefore, one natural extension is introducing private demand information of the retailer and investigating the impact of asymmetric information on the manufacturers' decisions and channel efficiency (i.e., Shen, Choi, & Minner, 2019).

Another direction for future research is to compare the current non-cooperative equilibrium solutions to Nash bargaining solutions (i.e., Guan, Ye, & Yin, 2020). For instance, as observed in the numerical analysis, channel efficiency under a particular setting can exceed the follower's disadvantages. Further, the retailer being a follower under the three-player game may benefit both the global manufacturer and the retailer, while the local manufacturer prefers the global manufacturer to be the follower to avoid direct wholesale price competition. Based on these observations, investigating the players' negotiation over switching the sequence with the agreement to share the greater surplus generated from the market is worth exploring.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.ejor.2024.05.019.

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