European Journal of Operational Research xxx (xxxx) xxx

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing, Transportation and Logistics

Encroachment by a better-informed manufacturer

Yang Tong[a], Tao Lu[b,*], Yina Li[c,*], Fei Ye[c]

[a] College of Economics and Management, Zhejiang Normal University, China
[b] School of Business, University of Connecticut, USA
[c] School of Business Administration, South China University of Technology, China

ARTICLE INFO

Article history:
Received 15 June 2021
Accepted 14 June 2022
Available online xxx

Keywords:
Manufacturer encroachment
Information asymmetry
Information sharing
Signaling

ABSTRACT

Many manufacturers have recently taken the initiative to enhance their demand forecasts with the help of modern data analytics tools. Motivated by this trend, this paper examines the implications of encroachment when an upstream manufacturer privately observes the demand information. We analyze a signaling game between a manufacturer and a retailer. The manufacturer privately observes the actual forecast signal of the customer's marginal utility of a product, and then determines a wholesale price, which may signal its private information. Upon receiving the wholesale price, the retailer decides how much to sell in the retail channel. The manufacturer, if in possession of a direct channel, finally determines how much to sell in this channel. Our analysis reveals that encroachment by a better-informed manufacturer has many different implications that have not been documented in the literature. In particular, we find that compared with the prior literature focusing on a better-informed retailer, when the upstream manufacturer is better informed, encroachment will more likely result in a lose-lose outcome. Additionally, if better informed, the retailer may not opt to credibly share information. By contrast, we show that in the presence of a better-informed manufacturer, both supply chain parties are willing to establish the capability of credible information sharing unless it is too costly to do so. Interestingly, we demonstrate that a greater degree of information asymmetry or a larger direct selling cost has the potential to benefit both supply chain parties; however, more accurate information may hurt them and inhibit the manufacturer from encroachment.

1. Introduction

Demand uncertainty is a crucial challenge to operations in the context of supply chains. Traditionally, downstream retailers are believed to be closer to the market and thus to possess better demand information. Nevertheless, when launching a new product, increasingly many manufacturers have better knowledge of customers' product valuation and therefore the market potential than retailers, as they often have access to customer feedback and other forms of data for older generations of products. For example, Apple attributes its success to the insight it has into its consumer behavior through the data the company leverages from purchases and downloads on iTunes.[1] This information can be used to analyze the market for new products.[2] Similarly, to gain greater knowledge of its customers' habits and thus predict demand for new products, Nike, the world-famous sports brand, acquired a leading data analytics company called Zodiac.[3] With the help of machine learning technologies, Adidas can better spot consumer trends and design its new products taking those trends into account.[4] By contrast, the downstream retailers may lack the expertise and resources to collect and analyze data on that scale, and so have to rely on their upstream manufacturers for such market (Guan, Liu, Chen, & Wang 2020, Guo & Iyer 2010, Jiang, Tian, Xu, & Zhang 2016, Mohr & Sohi 1995). Such an information disadvantage may deter the retailers from purchasing large quantities of the products and thus, the manufacturers have an incentive to signal their private information to unknown retailers which they sell.

Supply chains in the aforementioned examples exhibit another important feature: the manufacturers sell not only through downstream retailers but also through their own direct channels. Such manufacturer encroachment is common in consumer electronics

* Corresponding author.
E-mail addresses: tao.lu@uconn.edu (T. Lu), bmliyina@scut.edu.cn (Y. Li).
[1] https://www.stephenzoeller.com/apple-consumer-behavior-marketing/.
[2] https://www.apple.com/usergroups/.
[3] https://www.forbes.com/sites/forbestechcouncil/2019/10/07/how-nike-is-using-analytics-to-personalize-their-customer-experience/?sh=713504491611.
[4] https://which-50.com/machine-learning-helps-adidas-recast-its-supply-chain-so-customers-can-co-create/.

https://doi.org/10.1016/j.ejor.2022.06.030
0377-2217/

(e.g., Apple, Huawei, Microsoft), clothing and fashion products (e.g., Adidas, Nike) (Guan et al. 2020, Matsui 2020, Tsay & Agrawal 2004, Yang, Luo, & Zhang 2018, Zhang, Feng, & Wang 2021a). For instance, Huawei established an official e-commerce platform to distribute its products to end consumers directly in 2012. To enter the Chinese market, in October 2009, Apple began to sell its product in China[5] and about one year later it introduced the Apple store in China (www.apple.com.cn).[6] The implications of encroachment by an upstream firm have long been studied in the academic literature. It has been shown that under symmetric information, encroachment can restrain the manufacturer's wholesale price to avoid a high retail price set by the retailer, thus mitigating double marginalization and benefiting both parties (e.g., Arya, Mittendorf, & Sappington 2007, Chiang, Chhajed, & Hess 2003, Hsiao & Chen 2014, Tsay & Agrawal 2004). In the context of a better-informed retailer, Li, Gilbert, and Lai (2014) further report that a lose-lose outcome may result from manufacturer encroachment and that the retailer may be reluctant to credibly share its private information. To the best of our knowledge, however, the implications of encroachment when the manufacturer possesses superior demand information have not been studied. As mentioned earlier, encroachment with a better-informed upstream firm has become increasingly relevant since there is a trend for manufacturers to begin enhancing their demand forecasts with modern data analytics tools. In this paper, we attempt to fill this gap in the literature and explore how the encroachment by a better-informed manufacturer influences each member's profits and whether or not each party is willing to develop the capability to enable credible information sharing.

In this paper, based on the seminal framework by Arya et al. (2007), a signaling game model between one manufacturer and one retailer that incorporates the manufacturer-side private information is developed. The customer's marginal utility of the product can be either high or low, following a two-point probability distribution. The manufacturer privately observes the actual forecast signal and first decides a wholesale price, which may reveal the true customer's marginal utility. Upon observing the wholesale price, the retailer then makes order decision. The manufacturer, if adding a direct channel, finally determines how much to distribute through that channel. Compared with the existing literature, the new feature of our model lies in the inclusion of the manufacturer-side private information. By means of this new feature, our analysis reveals several novel results that have not been documented in the extant literature. In our model, the manufacturer can signal the actual forecast signal of customer's marginal utility through the wholesale price. When observing a high signal, the manufacturer has to upwardly distort the wholesale price to convince the less-informed retailer that the customer's marginal utility of that product is indeed high, thereby inducing the retailer to order more. However, this upward distortion of the wholesale price amplifies double marginalization; consequently, manufacturer encroachment may hurt both parties, i.e., lead to a lose-lose outcome. The occurrence of this lose-lose outcome due to encroachment is reminiscent of Li et al. (2014), in which the authors focus on retailer-side private information. Furthermore, we find that with manufacturer-side private information, the lose-lose outcome arises under very different conditions than those documented in Li et al. (2014). For instance, even with a large probability of high forecast signal and a small degree of information asymmetry, encroachment hurts both parties as long as the direct selling cost is sufficiently large. Put differently, with a better-informed upstream manufacturer, encroachment will more likely result in a lose-lose outcome versus a better-informed downstream retailer. Our findings thus indicate that the implications of encroachment crucially depend on which party is better informed. Counter to intuition, we also find that due to manufacturer encroachment, a larger direct selling cost or a greater degree of information asymmetry may benefit both parties, as it can cause the equilibrium to switch from a separating equilibrium to a pooling one; however, due to encroachment, both supply chain members may be hurt as information accuracy increases and so more accurate information may inhibit the manufacturer from encroachment.

Finally, we examine if each supply chain party is willing to establish infrastructure for credible information sharing (e.g., an electronic data-interchange system). The literature has shown that information sharing may not simultaneously benefit both parties in the case of a better-informed downstream retailer (Li et al. 2014). By contrast, we reveal that information sharing benefits both supply chain parties, no matter with/without manufacturer encroachment. Thus, our results imply that it may be easier to reach an information sharing agreement between supply chain parties with respect to the manufacturer-side private information than with respect to the retailer-side private information. Additionally, we show that with manufacturer encroachment, supply chain parties may become reluctant to invest in the capability to share information, although this is not necessarily the case without manufacturer encroachment.

The remainder of this study is organized as follows. Section 2 reviews the literature to show how our study makes an important contribution and Section 3 describes the details of the model. In Sections 4 and 5, respectively, we present the equilibrium outcomes of both the No-Encroachment and Encroachment settings and then discuss the main results and managerial insights. Sections 6–8 considers four model extensions and alternative settings. This is followed by the conclusions in Section 9. Details of proofs are given in the Appendix.

2. Literature review

2.1. Encroachment

The implications of manufacturer encroachment have been widely studied in the academic literature. Due to the mitigation of double marginalization, encroachment benefits both supply chain parties (Arya et al. 2007, Chiang et al. 2003, Tsay & Agrawal 2004). Recently, based on the above classical studies, some studies have taken more factors into consideration when deciding to add a direct channel or not. For example, by extending Arya et al. (2007) to take product quality as an endogenous decision variable and two channels sell differentiated products, Ha, Long, and Nasiry (2016) find a win-lose outcome in a large variety of scenarios. A similar conclusion is drawn by Zhang et al. (2021a), who find that the manufacturer can be better off while the retailer is worse off due to encroachment. Zhang, Song, Shi, and Yang (2021b) also study quality differentiation in a dual-channel supply chain to analyze whether the manufacturer should sell the high-quality product through the direct channel or the retail channel. As the retailer becomes worse off due to channel competition caused by encroachment, Matsui (2020) and Yang et al. (2018) suggest that the two parties should negotiate over the wholesale price. Wang and Li (2021) study encroachment in a setting with a dual-purpose retailer that pursues both its own profit and consumer surplus. Zhang and Hezarkhani (2021) consider an upstream competition setting in which two manufacturers can sell their products through a common retailer as well as their direct channels. By contrast, Liu, Guan, and Wang (2021a) consider the downstream competition in which one supplier can sell the product through multiple retail-

[5] https://www.cultofmac.com/510563/today-in-apple-history-iphone-goes-on-sale-in-china-for-first-time/.

[6] https://www.apple.com/newsroom/2010/10/26Apple-Launches-Online-Store-in-China/.

ers. We differ from the above studies in that we consider manufacturer encroachment in a context of asymmetric information. We find that due to information asymmetry, it is costly for a better-informed manufacturer to signal the customer's marginal utility by distorting the wholesale price upward, which this amplifies double marginalization and, thus, leads to a lose-lose outcome.

Some work has been done on the effects of information asymmetry on upstream encroachment. Li et al. (2014) find that the retailer's costly signaling behavior of reducing the order quantity occurs if the supplier wants to encroach. Such downward order distortion may stimulate the supplier to raise the wholesale price, thus amplifying the double marginalization and hurting both of them. Li, Gilbert, and Lai (2015) also find a lose-lose outcome due to upstream encroachment with a better-informed retailer. Again with a better-informed retailer, Zhang, Li, Zhang, and Dai (2019a) study how information asymmetry affects the manufacturer's optimal decisions on encroachment and product quality. Similarly, Zhang, Wei, and Zhang (2022) also consider the supplier's encroachment and quality decisions with a better informed-retailer. Unlike these studies, we consider a better-informed manufacturer, which is likely to be the case for new products. Due to this essential difference, even with the same finding that encroachment may hurt both of them, the rationale of our study is quite different from theirs. In our study, we find that if the better-informed manufacturer who observes a high forecast signal wants to separate itself from the low type, a sufficiently high wholesale price that deviated from the first-best will be charged, thereby amplifying the double marginalization. By contrast, Gao, Guo, and Orsdemir (2021) consider a better-informed manufacturer who possesses the private selling cost and reveal that such asymmetric information can alleviate double marginalization rather than exacerbating it. Hence, our work demonstrates that the implications of encroachment with a better-informed upstream firm depend critically on the content of the upstream private information.

2.2. Information sharing

Our research also relates to information sharing in distribution channels (e.g., Guo, Li, & Zhang 2014, Ha, Tian, & Tong 2017, Zhang et al. 2019a, Zhou, Zhao, & Wang 2019). However, these studies primarily assume that downstream retailers can observe more and better information than the upstream manufacturers because retailers are closer to the market. In actual fact, many manufacturers are better informed about matters such as demand or quality information because they have invested heavily in sophisticated information gathering and demand forecasting systems, particularly when a manufacturer in fashion and seasonal goods launches a new product or enters a new market (Guo & Iyer 2010, Guan & Chen 2017). Therefore, a growing number of studies have analyzed information sharing in the context of a better-informed manufacturer (e.g., Cao, Guan, Fan, & Zhou 2020, Gal-Or, Geylani, & Dukes 2008, Guan & Chen 2017, Guan, Mantrala, & Bian 2019, Guo & Iyer 2010, Jiang et al. 2016).

For example, in the context of an upstream manufacturer and two competing retailers, Gal-Or et al. (2008) find that when all three members privately observe the information, it is in the manufacturer's interest to share information with the less-informed than with the better-informed retailer. Cao et al. (2020) study the disclosure problem in which an upstream manufacturer privately possesses information on product quality. Similarly, Guan & Chen (2017) and Guan et al. (2019) consider the joint decision on information acquisition and disclosure within a single retail channel when the manufacturer is better informed about quality information than the retailer. Thus, the biggest difference between our study and theirs is that the better-informed manufacturer has to disclose its private information through a signaling game rather than directly truthful disclosure. Although the supply chain members can benefit from more through directly truthful disclosure than the signaling game, the better-informed party may manipulate: he can share the information to improve efficiency; however, he can also abuse it to extract a greater surplus. Therefore, the uninformed party may not trust the information transmitted by the better-informed one, and, thus, it may be necessary for the better-informed party to disclose private information through a signaling game rather than directly truthful disclosure.

On this point, closer to our study is Jiang et al. (2016) who consider a better-informed manufacturer that distributes the product through a retailer within a single retail channel. Based on the pricing decision, the high-type manufacturer wants to restrain the retailer from charging a higher retail price, in order to increase the demand for its product. Therefore, they reveal that the manufacturer who possesses a higher market potential benefits from mimicking the low type and sharing information with the downstream retailer, even if the retailer is reluctant to acquire such information. However, when considering Cournot (quantity) competition between two channels, which can be more suitable to a situation with a long production lead time, we find that the low-type manufacturer has an incentive to stimulate the retailer to order more by mimicking the high type. As a result, due to the upwardly distorted wholesale price, both of them can be better off from information sharing.

Recently, some studies have investigated information sharing in the context of upstream encroachment. For example, Huang, Guan, and Chen (2018) reveal that the supplier's decision regarding whether or not to encroach will greatly affect the retailer's preference towards information sharing. Similarly, Guan et al. (2020) study how encroachment affects the supplier's disclosure strategy when the quality level is common to both the supplier and the retailer while remaining unknown to consumers. Our work differs from theirs in two important ways. On the one hand, we consider an asymmetric information setting in which only the manufacturer can privately observe the forecast signal of customer's marginal utility. On the other hand, they focus on truthful disclosure, whereby the informed party directly shares information, while we focus on a signaling game in which it is costly to convey information. Due to these essential differences, we find that manufacturer encroachment may hurt both parties.

2.3. The position of this paper

This present study aims to investigate the impact of manufacturer encroachment on profitability in the context of a manufacturer that is better informed than the retailer. While upstream encroachment and information sharing have been widely studied in the literature, the asymmetric setting with a manufacturer that processes better demand information than the retailer has been neglected. Although it is traditionally assumed that retailers can obtain better demand information than manufacturers as they are much closer to the market, manufacturers are able to obtain superior demand forecasts (e.g., Cao et al. 2020, Guan & Chen 2017, Guan et al. 2019, Guo & Iyer 2010, Jiang et al. 2016), mainly due to their advantages in terms of capital, resources and expertise. Therefore, it is necessary to study encroachment by a better-informed manufacturer. Our findings reveal that encroachment can be detrimental to the manufacturer, despite the information advantage. Additionally, the preference for information sharing of a better-informed manufacturer is different from the case with a better-informed retailer. In summary, by investigating the impact of encroachment on the profitability and the preference of information sharing within a better-informed manufacturer, we not only complement the literature on upstream encroachment and information sharing, but also provide more insights for manufactur-

Table 1
The Gap between Previous Studies and our Study.

	Encroachment	Retailer informed	Manufacturer informed	Truthful disclosure	Signaling game
Arya et al. (2007)	√				
Li et al. (2014)	√	√			√
Li et al. (2015)	√	√			√
Ha et al. (2016)	√				
Jiang et al. (2016)			√		√
Huang et al. (2018)	√	√		√	
Cao et al. (2020)			√	√	
Guan et al. (2020)	√	√	√	√	
Zhang et al. (2019a)	√	√			√
This paper	√		√		√

ers to carry out effective channel management and information sharing strategies. Table 1 summarizes the gap between previous studies and our study.

3. Model setup

Consider a better-informed manufacturer (he, referred as to M) can distribute his products either through a retail channel operated by a retailer (she, referred as to R) or through his own direct channel.

Market Demand. Denote the quantities sold in the retail and direct channels as q_r and q_m, respectively. The market clearing price can be determined according to $p = \theta - q$, where $q = q_r + q_m$ is the total amount. This inverse demand function can be derived from a representative consumer's utility function $U(q_r, q_m) = \theta(q_r + q_m) - (q_r + q_m)^2/2 - p_r q_r - p_m q_m$, a well-established approach to derive demand functions in the economics and marketing literature (Guan & Chen 2017, Guan et al. 2020, Singh & Vives 1984, Yoon 2016). Given the retail price p_r and the direct-channel price p_m, the consumer chooses q_r and q_m to maximize her utility. By taking the partial derivative of U with respect to q_r and q_m, we have $\frac{\partial U}{\partial q_r} = \theta - q_r - q_m - p_r$ and $\frac{\partial U}{\partial q_m} = \theta - q_r - q_m - p_m$. Equating them to zero, i.e., under the optimality condition, we can derive the inverse demand functions as $p_r = p_m = \theta - q_r - q_m$. Thus, we will refer to θ as the customers marginal utility in what follows.[7]

We assume that the customer's marginal utility θ is random and that its prior distribution follows a two-point distribution, which can be either in a high (H) or low (L) state, with corresponding marginal utilities of $\theta_H = 1 + \Delta$ and $\theta_L = 1 - \Delta$, respectively (Guan & Chen 2017, Guo 2009, Jiang et al. 2016).[8] These two marginal utility states occur with equal ex ante probabilities: $\Pr(H) = \Pr(L) = 1/2$, as commonly assumed in the literature (Guo 2009, Iyer, Narasimhan, & Niraj 2007, Jiang et al. 2016, Liu, Dan, Zhang, & Ma 2021b, Nasser & Turcic 2019, Zhang, Dan, & Zhou 2019b). Nevertheless, we will relax this assumption and analyze more general prior probabilities in Section 6. Note that $0 < \Delta < 1$ captures the uncertainty level of the customer's marginal utility as well as the degree of information asymmetry. The larger Δ is, the greater the degree of information asymmetry there is. As in Jiang et al. (2016), at the beginning of the season, the upstream manufacturer who possesses superior information can observe the actual value of θ, while the less-informed retailer is only aware of its prior distribution.

Demand Forecast. Although the manufacturer can privately possess more information than the retailer through demand forecast, he may still face demand uncertainty as the demand signal is not always reliable. As in Jiang et al. (2016), we assume that the manufacturer can obtain a private signal, s, about customer's marginal utility, in which the signal has two possible values: $s = h$ or $s = l$, corresponding to the two marginal utility states, H and L, respectively. Let $\rho \in [0, 1]$ denote the accuracy of the signal, where a larger value of ρ represents a more accurate signal. Additionally, we assume the forecast to be unbiased such that the unconditional probability of a signal indicating any demand state is equal to the prior probability of that state, i.e., $\Pr(h) = \Pr(H)$ and $\Pr(l) = \Pr(L)$, leading to the following properties: $\Pr(h|H) = \Pr(l|L) = \frac{1+\rho}{2}$ and $\Pr(h|L) = \Pr(l|H) = \frac{1-\rho}{2}$. Similarly, we can derive $\Pr(H|h) = \Pr(L|l) = \frac{1+\rho}{2}$ and $\Pr(L|h) = \Pr(H|l) = \frac{1-\rho}{2}$. Thus, through forecast, the manufacturer updates his belief about the customer's marginal utility with $E[\theta|l] = 1 - \rho\Delta$ and $E[\theta|h] = 1 + \rho\Delta$, where $\rho\Delta$ captures the combination of forecast accuracy and forecast variability, and the larger $\rho\Delta$ is, the greater the expected demand varies with manufacturer's forecast s will be.

To focus on interesting cases and derive incisive insights, we adopt a common assumption from the literature on dual-channel under an asymmetric information setting (e.g., Guan et al. 2020, Li et al. 2014), namely, that the retailer will not withdraw the products after observing the actual forecast signal. Thus, we assume that:

Assumption 1. $E[\theta|l] > \frac{2}{3}E[\theta|h]$, or equivalently $\rho\Delta < \frac{1}{5}$.

This assumption ensures that the retailer acquires a positive marginal profit when clearing her optimal and positive selling quantity, no matter with/without a direct channel.

Profit Functions. In line with the literature on encroachment, e.g., Arya et al. (2007), Guan et al. (2020), and Li et al. (2014), we normalize the manufacturer's production cost to be zero for ease of exposition; however, he additionally incurs a per-unit selling cost c when selling the product through his own direct channel, whereas the retailer incurs no selling cost in her retail channel. Such a direct selling cost is due to the management of the online websites and the required personnel and facilities (Gao et al. 2021), as well as the manufacturers less efficiency in the sales process (Arya et al. 2007, Guan et al. 2020, Li et al. 2014) as compared to the retailer. In practice, the manufacturer often incurs a higher sales cost than the retailer. For example, a retailer, like Walmart, usually leverages the economies of scale in distribution and shipping by consolidating shipments of multiple brands. However, a manufacturer is relatively small in scale, selling its own brand only. Thus, it usually pays a higher logistics cost for direct sales. To rule out uninteresting cases, we make the following assumption.

Assumption 2. $0 < c < E[\theta|l]$.

This assumption is consistent with the literature on encroachment (e.g., Arya et al. 2007, Li et al. 2014, Li et al. 2015, Yang et al. 2018, Yoon 2016). Otherwise, if $c \geq E[\theta|l]$, no sales will occur in either the retail or the direct channel when the signal is

[7] More precisely speaking, the consumer's marginal utility from consuming one additional unit of product is given by $\theta - q$.

[8] A more general setting is to assume $\theta_H = n + \hat{\Delta}/2$ and $\theta_L = n - \hat{\Delta}/2$, or equivalently, $\theta_H - \theta_L = \hat{\Delta}$. However, we can normalize the marginal utility states to $\theta_H = 1 + \Delta$ and $\theta_L = 1 - \Delta$ without loss of generality. See the proof in Appendix A.

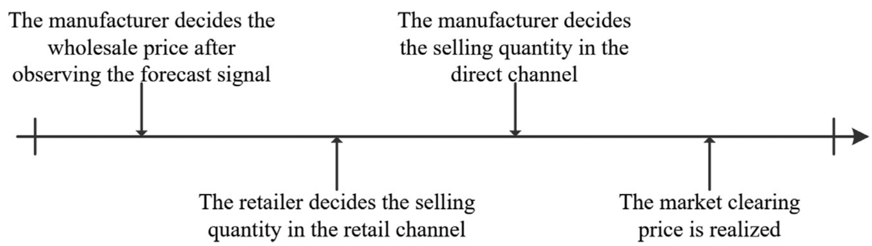

Fig. 1. The Game Sequence.

low, even if sales may occur in both channels when the signal is high. For the sake of presentation, we label the regime when $c \geq 1 - \rho\Delta$ as "No sales occur in either channel if $s = l$". Therefore, given the forecast s, the manufacturer will maximize his profit, $w(\theta|s)E[q_r(\theta|s)] + (p-c)E[q_m(\theta|s)]$, by choosing an optimal wholesale price w and quantity q_m for his direct channel, successively. Note that after the manufacturer receives the forecast signal, we may view s as the manufacturer's type; that is, we will refer to the manufacturer observing a forecast signal $s = h$ $(s = l)$ as the h-type (l-type) manufacturer. The retailer, even if she cannot observe the forecast signal, can make rational inferences about s through the wholesale price w. Therefore, the retailer will maximize her profit, $(p-w)E[q_r(w)]$, by choosing how much to sell in her channel q_r.

Following a rather standard assumption in the encroachment literature (e.g., Gao et al. 2021, Li et al. 2014), we assume the retailer decides the quantity q_r before the manufacturer decides q_m for his own direct channel; that is, the less-informed retailer can only infer the forecast signal based on the manufacturer's wholesale price.

Equilibrium Concept. Although the retailer cannot observe the forecast signal directly, she can make rational inferences through the wholesale price. Because the manufacturer anticipates the retailer's response to his wholesale price, a signaling game arises in which the manufacturer may distort the wholesale price. We focus on pure-strategy Bayesian Nash equilibria in this study. There can be two types of equilibria, namely, separating and pooling equilibria. In the separating equilibrium, the manufacturer chooses a distinct wholesale price for each type of forecast signal, and his wholesale price thus reveals his type, i.e., the true forecast signal, to the retailer. In the pooling equilibrium, the same wholesale price will be set independent of the realized forecast signal; therefore, the wholesale price is uninformative to the retailer.

As is common in the signaling game, there can be multiple Bayesian Nash equilibria. In this paper, we use the lexicographically maximum sequential equilibrium (LMSE) concept (Mailath, Okuno-Fujiwara, & Postlewaite 1993), which has been widely adopted in the marketing and operations management literature (Jiang et al. 2016, Jiang & Yang 2019, Tian & Jiang 2017), to refine the multiple equilibria. The definition of LMSE is given below.

Definition 1. (LMSE) In a signaling game S, the strategy profile $\gamma' \in PBE(S)$ dominates (h-dominates) $\gamma \in PBE(S)$ if $\pi_h(\gamma') > \pi_h(\gamma)$, or $\pi_h(\gamma') = \pi_h(\gamma)$ and $\pi_l(\gamma') > \pi_l(\gamma)$. The strategy profile $\gamma \in PBE(S)$ is a LMSE if there does not exist $\gamma' \in PBE(S)$ that h-dominates γ. Where $PBE(S)$ is the set of pure-strategy prefect Bayesian equilibria, $\pi_i(\cdot)$ is the i-type player's payoff, and $i \in \{h, l\}$ denotes the set of types.

Based on the LMSE refinement, a unique and most efficient equilibrium is chosen for the γ-type manufacturer when revealing his type. For instance, a PBE is LMSE if it is the most profitable outcome among all PBE for both h-type and l-type manufacturers.

Sequence of Events. We summarize the game sequence of the model in Fig. 1. First, the manufacturer who privately receives the forecast signal of the customer's marginal utility of the product decides the wholesale price w, followed by the retailer's order quantity q_r. Then, the manufacturer chooses how much to distribute in his own direct channel q_m. And finally, the clearing price is resolved based on $p = \theta - (q_r + q_m)$.

4. Analysis

4.1. Benchmark: No-encroachment setting (N)

We start by analyzing a benchmark in which the manufacturer does not sell through a direct channel. This corresponds with the situation in which the manufacturer does not have the necessary infrastructure of a direct channel and can thus credibly commit to not competing with the retailer in the end market.

4.1.1. Symmetric information

Here, the manufacturer's forecast s is shared with the retailer. For notation convenience, we use subscript $\bar{\square}$ to denote the optimal decisions/profits under this symmetric information setting. Thus, the manufacturer and the retailer decide the wholesale price and order quantity by maximizing their profit functions, $\bar{\pi}_M^N(w)|s = \bar{w}\bar{q}_r$ and $\bar{\pi}_R^N(\bar{q}_r)|s = (E[\theta|s] - \bar{q}_r - \bar{w})\bar{q}_r$, leading to $\bar{q}_r^{N*}|s = \frac{E[\theta|s]}{4}$ and $\bar{w}^{N*}|s = \frac{E[\theta|s]}{2}$, respectively.

4.1.2. Asymmetric information

Next, we consider the asymmetric information setting. Absent of a direct channel, the manufacturer always benefits from convincing the retailer that the forecast signal is indeed high so that she will order a large quantity. This is because in the symmetric information setting, even if the wholesale price with a high forecast signal is greater than that with a low one (that is, $\bar{w}^{N*}|h > \bar{w}^{N*}|l$), the retailer can still benefit from ordering a larger quantity (i.e., $\bar{q}_r^{N*}|h > \bar{q}_r^{N*}|l$). Therefore, driven by a higher profit, the l-type manufacturer prefers to pretend to receive a high forecast signal so that the retailer will order more. Additionally, the h-type manufacturer also wants to separate himself from the low type so that the retailer will indeed order a large quantity corresponding to the high forecast signal. Thus, the h-type manufacturer has to upwardly distort his wholesale price enough until the l-type manufacturer finds it less profitable to mimic the high type. The upwardly distorted wholesale price will, however, deter the retailer from ordering more. Therefore, the h-type manufacturer weighs a trade-off between the benefit of revealing his true type in equilibrium and the signaling cost due to the reduced wholesale profit. In Proposition 1, we establish that without a direct channel, a pooling equilibrium is the unique LMSE, in which the manufacturer always chooses the same wholesale price, which is independent of the realized forecast signal. In other words, absent of a direct channel, the signaling cost always dominates the benefit of separating himself in equilibrium.

Proposition 1. *Under the No-Encroachment setting, the manufacturer will always pool at* $w^{N*} = \frac{1}{2}$, *leading to* $\pi_M^{N*} = \frac{1}{8}$ *and* $\pi_R^{N*} = \frac{1}{16}$, *respectively.*

The result of Proposition 1 can be explained by the fact that it is rather inexpensive for the l-type manufacturer to mimic the high type when there is no direct channel. This is because the manufacturer's profit depends solely on the wholesale profit from the retailer, the l-type manufacturer can mimic a high type only at the expense of deviating from his first-best reaction. This makes the h-type manufacturer opt for a pooling equilibrium rather than separating himself from the low type.

4.2. Encroachment setting (E)

Here, the manufacturer establishes a direct channel and can (possibly) sell the product through both channels.

4.2.1. Symmetric information

Again, we first consider the symmetric information setting to reveal how the manufacturer's equilibrium is affected by the direct selling cost c. Note that the Encroachment setting has been discussed by Guan et al. (2020) and Wang & Li (2021). For the sake of brevity, we only present the equilibrium solutions here, as the rationale and the solving process are set out in theirs. Using backward induction, we can derive the optimal wholesale price and the quantities for the retail and direct channels as:

$$(\bar{w}^{E*}|s, \bar{q}_r^{E*}|s, \bar{q}_m^{E*}|s) = \begin{cases} (\frac{3E[\theta|s]-c}{6}, \frac{2c}{3}, \frac{3E[\theta|s]-5c}{6}) & \text{if } c < \frac{3E[\theta|s]}{5}; \\ (\frac{3c-E[\theta|s]}{2}, E[\theta|s]-c, 0) & \text{if } c \geq \frac{3E[\theta|s]}{5}. \end{cases}$$

It can be seen that c influences the wholesale price and the retail channel's selling quantity in two opposite ways, depending on whether direct selling actually occurs. With a small value of c ($c < \frac{3E[\theta|s]}{5}$), the manufacturer can benefit from both channels, and the larger c is, the smaller $\bar{w}^{E*}|s$ and $\bar{q}_m^{E*}|s$ will be, while the larger $\bar{q}_r^{E*}|s$ will be. However, when $c \geq \frac{3E[\theta|s]}{5}$, the direct selling does not happen, and a larger c conversely enables the manufacturer to charge a higher wholesale price, while the retailer will be reluctant to order more as c increases. In this case, the direct channel can be viewed as a threat of direct selling.[9] Similar phenomenons have been observed in practice. For some small brands that is not famous, consumers will mostly purchase the product through the retail channel; however, the direct channel exists. Among many other examples, Skyworth Group, an intelligent home appliance and information technology enterprise in China, sells its products through JD.com (https://mall.jd.com/index-1000002826.html); meanwhile, it has its own official website (https://shop.skyworth.com/) although few people know it. Compared with the retail channel (JD.com), the sales in its direct channel (its official website) are negligible, i.e., approximately zero.

4.2.2. Asymmetric information

Under the Encroachment setting, the manufacturer's profit comes from not only the sales profit from his own direct channel but also the wholesale profit from the retail channel. While persuading the retailer to order more increases his wholesale profit, it may intensify the competition between these two channels, thus leading to a lower direct-channel profit. Intuitively, the l-type manufacturer is more sensitive to the intensified competition than the high type because of the low customer marginal utility. For this reason, the presence of a direct channel makes it more costly for an l-type manufacturer to mimic the high type. Proposition 2 shows that a separating equilibrium can arise under the Encroachment setting, which differs from the setting absent of a direct channel.

Proposition 2. *Under the Encroachment setting, given* $c_1 = \frac{(7+4\sqrt{2})\rho\Delta}{4}$, $c_2 = \frac{3(1-\rho\Delta)}{5}$, c_3 *is the second smallest solution to* $18\rho^2\Delta^2 + (3-5c)^2 - 2\rho\Delta(9-17c) - 4\rho\Delta\beta(\rho\Delta, c) = 0$, $c_4 = \frac{3-2\rho\Delta}{5}$, *and* $c_5 = \frac{15-8\rho\Delta+\sqrt{60\rho\Delta+111\rho^2\Delta^2}}{25}$, *a unique LMSE exists that is characterized by one of the following cases.*

(a) *In* $\psi_{SD} = \{(\rho\Delta, c)|\rho\Delta \in [0, \frac{1}{5}), c \in (0, \min(c_1, c_2))\}$, *there is a separating equilibrium with direct selling (SD) where the optimal separating wholesale prices are* $w^{SD*}|l = \frac{3(1-\rho\Delta)-c}{6}$ *and* $w^{SD*}|h = \frac{3-\rho\Delta-c+4\sqrt{\rho^2\Delta^2+2\rho\Delta c}}{6}$; *consequently,* $q_r^{SD*}|l = \frac{2c}{3}$, $q_m^{SD*}|l = \frac{3(1-\rho\Delta)-5c}{6}$, $q_r^{SD*}|h = \frac{2(\rho\Delta+c)-2\sqrt{\rho^2\Delta^2+2\rho\Delta c}}{3}$, *and* $q_m^{SD*}|h = \frac{3+\rho\Delta-5c+2\sqrt{\rho^2\Delta^2+2\rho\Delta c}}{6}$;

(b) *In* $\psi_{PD} = \{(\rho\Delta, c)|\rho\Delta \in [0, \frac{564-240\sqrt{2}}{1409}), c \in [c_1, c_4), \text{or} \rho\Delta \in [\frac{564-240\sqrt{2}}{1409}, \frac{1}{5}), c \in [c_3, c_4)\}$, *there is a pooling equilibrium with direct selling (PD) where the optimal pooling wholesale price is* $w^{PD*} = \frac{3+2\rho\Delta-c}{6}$; *consequently,* $q_r^{PD*} = \frac{2c-\rho\Delta}{3}$, $q_m^{PD*}|l = \frac{3-2\rho\Delta-5c}{6}$, *and* $q_m^{PD*}|h = \frac{3+4\rho\Delta-5c}{6}$;

(c) *In* $\psi_{PT} = \{(\rho\Delta, c)|\rho\Delta \in [0, \frac{1}{5}), c \in [c_4, c_5)\}$, *there is a pooling equilibrium with a threat of direct selling (PT) where the optimal pooling wholesale price is* $w^{PT*} = \frac{2\rho\Delta+3c-1}{2}$; *consequently,* $q_r^{PT*} = 1-\rho\Delta-c$, $q_m^{PT*}|l = 0$, *and* $q_m^{PT*}|h = \rho\Delta$;

(d) *Otherwise, there is a separating equilibrium with a threat of direct selling (ST) where the optimal separating wholesale prices are* $w^{ST*}|l = \frac{3c+\rho\Delta-1}{2}$ *and* $w^{ST*}|h = \frac{3-\rho\Delta-c+2\beta(\rho\Delta,c)}{6}$; *consequently,* $q_r^{ST*}|l = 1-\rho\Delta-c$, $q_m^{ST*}|l = 0$, $q_r^{ST*}|h = \frac{2\rho\Delta+2c-\beta(\rho\Delta,c)}{3}$, *and* $q_m^{ST*}|h = \frac{3+\rho\Delta-5c+\beta(\rho\Delta,c)}{6}$, *where* $\beta(\rho\Delta, c) = \sqrt{13\rho^2\Delta^2 + (3-5c)^2 - 2\rho\Delta(9-19c)}$.

Proposition 2 shows that there can be four types of LMSE, depending on the values of the combination of the degree of information asymmetry (Δ) and the forecast accuracy (ρ) as well as the direct selling cost (c). For ease of exposition, we classify the equilibria into two regimes, depending on whether direct selling actually occurs in equilibrium. In the *direct regime*, the equilibrium can be a separating equilibrium with direct selling (SD) or a pooling equilibrium with direct selling (PD), as characterized in cases (a) and (b), respectively; while in the *threat regime*, the equilibrium can be a pooling equilibrium with a threat of direct selling (PT) or a separating equilibrium with a threat of direct selling (ST), as characterized in cases (c) and (d), respectively. Recall that the value of c oppositely affects the wholesale price and the retailer's selling quantity in these two different regimes under symmetric information; such opposite effects will also play a role in the equilibrium outcome under asymmetric information, as discussed below.

When $\rho\Delta < 0.1594$, then in the direct regime (i.e., $c < c_4$), the manufacturer will be better off with the separating equilibrium if $c < c_1$ or the pooling equilibrium if $c \in [c_1, c_4)$. This is because when $c < c_1$, on the one hand, a pooling equilibrium cannot exist if c is sufficiently small, as a sufficiently small c enables the l-type manufacturer to charge a higher wholesale price (note that in the direct regime, the wholesale price decreases in c) to deviate from the first-best one; thus, the retailer orders zero quantity (i.e., $q_r = 0$), leading to the failure of the constraints of the pooling equilibrium. Even when both separating and pooling equilibria exist, on the other hand, the manufacturer can still benefit more from separating than from pooling. This is because a smaller c enables the manufacturer to acquire a higher marginal profit through dual channels, as the benefit of revealing his true type outweighs the signaling cost; that is, the manufacturer benefits more from SD than PD. Otherwise, when $c \in [c_1, c_2)$, the h-

[9] Note that the threat of direct channel has been identified in Guan et al. (2020); however, we differ from them in these two ways. First, in their model, the private quality information only remains unknown to the consumers, but is known to the supplier and the retailer. Second, they consider truthful disclosure rather than signaling.

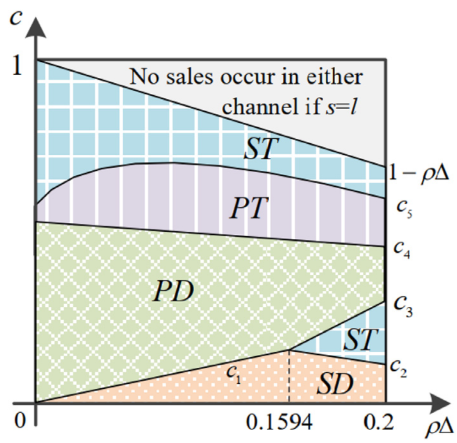

Fig. 2. The Equilibrium Outcome under Asymmetric Information Setting.

type manufacturer has to charge a higher wholesale price that deviates from the first best one (i.e. $w^{SD*}|h = \frac{3-\rho\Delta-c+4\sqrt{\rho^2\Delta^2+2\rho\Delta c}}{6} > \bar{w}^{E*}|h = \frac{3+3\rho\Delta-c}{6}$), and the larger c is, the greater the deviation will be (i.e., $w^{SD*}|h - \bar{w}^{E*}|h$ increases in c). Therefore, it is costly for the manufacturer to separate himself from the low type. When $c \in [c_2, c_4)$, the retailer will order a threatening quantity to deter the manufacturer's direct sales. Thus, as in the symmetric information setting, the manufacturer would deliberately charge a high wholesale price to extract the most profit as the retailer's order quantity is unrelated to the wholesale price. Such an upward distortion of the wholesale price results in a substantial signaling cost and greatly hurts the manufacturer's wholesale profitability. Therefore, the manufacturer benefits more from *PD* than *SD* (*ST*).

In the threat regime (i.e., $c \geq c_4$), the retailer will over-order the product and the l-type manufacturer will deliberately choose a high wholesale price to threaten direct selling. Recall that in the threat regime, an increase in c results in a higher wholesale price. Thus, to separate himself from the low type, the h-type manufacturer has to upwardly distort the wholesale price, leading to the signaling cost outweighs the benefit of revealing his true type; thus, the manufacturer benefits more from *PT* than *ST* when $c \in [c_4, c_5)$. However, when c exceeds c_5, the manufacturer's equilibrium switches to separating, as no feasible pooling equilibrium can satisfy the constraints. This is because the larger c is, the higher wholesale price will be, which inhibits the retailer from ordering a larger quantity. In addition, the retailer orders a smaller quantity based on her prior belief due to the uninformative wholesale price (as prior belief $E[\theta] = 1$ is less than the high-type $E[\theta|h] = 1 + \rho\Delta$). This pricing strategy hurts the manufacturer, leading to the failure of the constraints of the pooling equilibrium.

However, as $\rho\Delta$ increases and exceeds 0.1594, we find that in some ranges (like $c \in [c_2, c_3)$ in Fig. 2), the manufacturer may still benefit more from the separating equilibrium than from the pooling equilibrium; that is, *ST* may outweigh *PD*. This is because a large value of $\rho\Delta$ means that the expected demand for the h-type manufacturer is very different from that for the l-type manufacturer, which gives the h-type manufacturer more incentive to separate so as to induce the retailer to order more quantity. By contrast, in the pooling equilibrium, the retailer will order a smaller quantity based on the prior belief. Therefore, even if the h-type manufacturer has to charge a higher wholesale price to separate himself from the low type, he can still benefit from separating equilibrium due to a larger value of $\rho\Delta$.

Note that the manufacturer's type, i.e., the received forecast signal, is also a random outcome. Thus, in the following we will examine the supply chain members' ex ante expected profits *before the signal is realized*. Taking the expectation over signal s, we can derive the supply chain members' ex ante expected profits as follows.

$$(\pi_M^{E*}, \pi_R^{E*}) = \begin{cases} \left(\frac{3-c(6-7c+4\rho\Delta)-\rho^2\Delta^2+4\rho\Delta\sqrt{\rho\Delta(\rho\Delta+2c)}}{12}, \frac{2(\rho\Delta+c)[\rho\Delta+c-\sqrt{\rho\Delta(\rho\Delta+2c)}]}{9}\right) & \text{if } (\rho\Delta, c) \in \psi_{SD}; \\ \left(\frac{\rho\Delta\beta(\rho\Delta,c)+\rho\Delta(9-17c)-5\rho^2\Delta^2-3+12c-9c^2}{6}, \frac{9(1-\rho\Delta-c)^2+[2\rho\Delta+2c-\beta(\rho\Delta,c)]^2}{36}\right) & \text{if } (\rho\Delta, c) \in \psi_{ST}; \\ \left(\frac{3+2\rho^2\Delta^2-c(6-7c)}{12}, \frac{(2c-\rho\Delta)^2}{18}\right) & \text{if } (\rho\Delta, c) \in \psi_{PD}; \\ \left(\frac{\rho\Delta(3-\rho\Delta-5c)-1+4c-3c^2}{2}, \frac{(1-\rho\Delta-c)^2}{2}\right) & \text{if } (\rho\Delta, c) \in \psi_{PT}. \end{cases}$$

We next focus on how c and Δ affect the above ex ante profits, especially when the equilibrium changes. For simplicity, we will refer to the supply chain parties' ex ante profits as their payoffs. The following two propositions reveal some interesting and counterintuitive findings.

Proposition 3. *In the direct regime, both supply chain parties' payoffs may increase in c when the equilibrium shifts from SD to PD.*

Intuitively, the retailer can benefit from a larger c; however, counter to what one might expect, the manufacturer can also benefit from a larger c. To understand this, recall from Proposition 2 that the manufacturer's equilibrium shifts from *SD* to *PD* as c increases; that is, a larger c makes it difficult for the h-type manufacturer to separate himself from the low type, which may hurt his profitability. Conversely, an appropriately large c restrains the manufacturer from charging a higher pooling wholesale price and benefiting the manufacturer. Due to this reduction in the wholesale price, the retailer also sees a discontinuous jump up in profit. We use a numerical example to illustrate this proposition, as shown in Fig. 3. Figure 3 reveals that both supply chain parties benefit from a larger c when the equilibrium evolves from separating to pooling at $c = 0.336$ (approximately).[10]

Proposition 4. *In the threat regime, both supply chain parties' payoffs may increase in Δ when the equilibrium shifts from ST to PT.*

Proposition 4 shows another counterintuitive finding, namely, that both parties can benefit from a greater degree of information asymmetry. It is intuitive that a larger Δ can lead to a larger profit due to the increased customer's marginal utility; however, the h-type manufacturer has to charge a higher separating wholesale price (i.e., $w^{ST*}|h$ increases in Δ), inhibiting the retailer from ordering more quantity (i.e., $q_r^{ST*}|h$ decreases in Δ), consequently hurting both supply chain members. By contrast, the manufacturer can charge a medium pooling wholesale price (note that $w^{ST*}|h > w^{PT*} > w^{ST*}|l$ always holds) so that the retailer will order more quantity if the customer's marginal utility is high. Therefore, both the manufacturer and the retailer earn more as the equilibrium switches from separating to pooling. We use a numerical example to illustrate this proposition, as shown in Fig. 4. Figure 4 reveals that a greater degree of information asymmetry benefits both members when the equilibrium switches at $\Delta = 0.05$; see the discontinuous jump up in profit.

[10] It can be seen from Fig. 3 that in *PD* and/or *PT*, the manufacturer's payoff may increase in c. This finding is also revealed in the symmetric information setting of Guan et al. (2020).

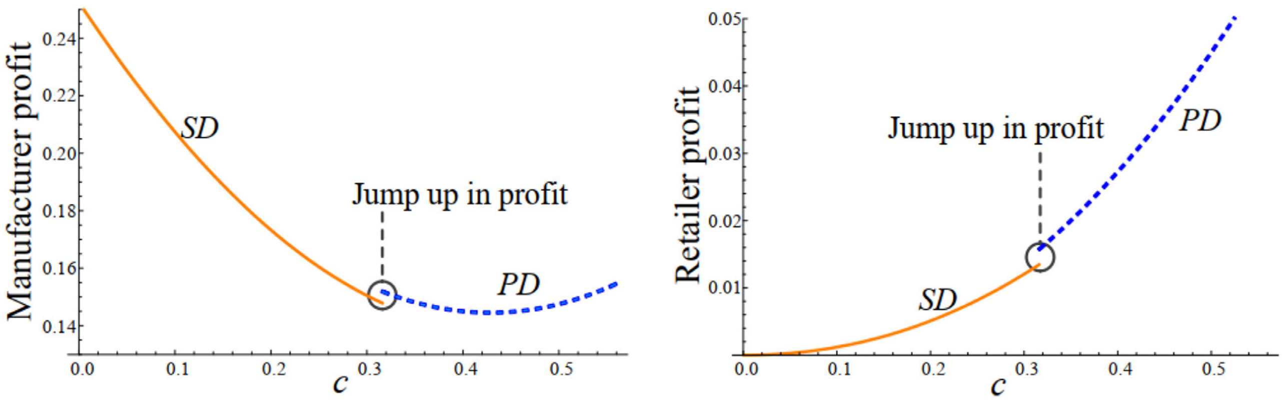

Fig. 3. The Effect of c on Payoffs, where $\rho\Delta = 0.1$.

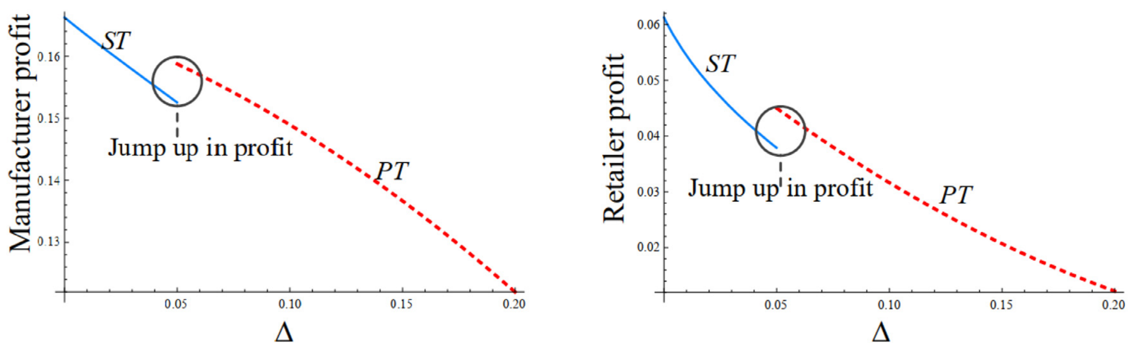

Fig. 4. The Effect of Δ on Profits, where $c = 0.65$ and $\rho = 1$.

5. Discussions

5.1. The effect of encroachment

This subsection focuses on how encroachment affects the profitability of the manufacturer and the retailer by comparing their equilibrium payoffs under the No-Encroachment and Encroachment settings. By doing so, we can provide helpful insights for either the companies planning to encroach and build a direct channel, or those who want to rethink their existing dual-channel strategies.

Proposition 5. *With information asymmetric, there exist direct selling cost thresholds c_6 and c_7 such that encroachment leads to the following outcomes:*

(a) *When $\rho\Delta \in [0, \frac{8-5\sqrt{2}}{12})$: a win-lose outcome (i.e., encroachment benefits the manufacturer but hurts the retailer) if $c \in (0, \frac{3\sqrt{2}+4\rho\Delta}{8}) \cup [c_6, c_7)$, a win-win outcome (i.e., encroachment benefits both the manufacturer and the retailer) if $c \in [\frac{3\sqrt{2}+4\rho\Delta}{8}, c_6)$, and a lose-lose outcome (i.e., encroachment hurts both the manufacturer and the retailer) if $c \in [c_7, 1-\rho\Delta)$;*

(b) *When $\rho\Delta \in [\frac{8-5\sqrt{2}}{12}, \frac{1}{5})$: a win-lose outcome if $c \in (0, c_7)$ and a lose-lose outcome if $c \in [c_7, 1-\rho\Delta)$.*

Where $c_6 = \begin{cases} c^* & \text{if } 0 \leqslant \rho\Delta < 0.0078 \\ c_5 & \text{if } 0.0078 \leqslant \rho\Delta < 0.0144 \\ \frac{4-\sqrt{2}-4\rho\Delta}{4} & \text{if } 0.0144 \leqslant \rho\Delta < 0.0774 \end{cases}$, $c_7 = \begin{cases} c^{**} & \text{if } 0 \leqslant \rho\Delta < 0.0909 \\ c^{***} & \text{if } 0.0909 \leqslant \rho\Delta < 0.147 \\ c_5 & \text{if } 0.147 \leqslant \rho\Delta < 0.191 \\ \frac{4-5\rho\Delta+\sqrt{1-4\rho\Delta+13\rho^2\Delta^2}}{6} & \text{if } 0.191 \leqslant \rho\Delta < 0.2 \end{cases}$, *$c^*$ is the smallest solution to* $9 - 36(1-\rho\Delta-c)^2 - 4[2(\rho\Delta+c) - \beta(\rho\Delta, c)]^2 = 0$, *$c^{**}$ (c^{***}) is the largest (second smallest) solution to* $15 + 20\rho^2\Delta^2 - 48c + 36c^2 - 4\rho\Delta(9-17c) - 4\rho\Delta\beta(\rho\Delta, c) = 0$.

Proposition 5 provides the effect of encroachment on the manufacturer and the retailer under the asymmetric information setting, which will be greatly affected by two model parameters including $\rho\Delta$ and c. Specifically, when the expected demand changes not greatly regardless of the forecast is h or l (i.e., $\rho\Delta < \frac{8-5\sqrt{2}}{12}$), encroachment leads to the win-lose, win-win, win-lose and lose-lose outcomes as c increases. With a sufficiently small c (i.e., $c < \frac{3\sqrt{2}+4\rho\Delta}{8}$), adding a direct channel benefits the manufacturer but hurts the retailer. For the manufacturer, although he has to upwardly distort the wholesale price from the first-best one, encroachment can still benefit him, as he will control pricing to lower the wholesale price. For the retailer, channel competition caused by adding a direct channel will hurt the retailer as she loses the monopoly position in the retail market, even if she can enjoy a lower wholesale price. At an intermediate c (i.e., $c \in [\frac{3\sqrt{2}+4\rho\Delta}{8}, c_6)$), the retailer also benefits from the manufacturer's adding a direct channel as she gains a selling advantage as the benefit of the lower wholesale price outweighs the channel competition. Thus, the benefit from a higher marginal profit caused by a reduction in the wholesale price dominates the loss of demand resulting from channel competition.

However, as c continues to increase (i.e., $c \in [c_6, c_7)$), again, encroachment hurts the retailer. Even with the same outcome, the rationale is different from that with a sufficiently smaller c. This is because, for a relatively large c, the manufacturer will pool at $w^{PT*} = \frac{2\rho\Delta+3c-1}{2}$ under encroachment setting, which may even larger than that under no-encroachment setting (note that $w^{PT*} = \frac{2\rho\Delta+3c-1}{2} > w^{N*} = \frac{1}{2}$ may hold with a larger c). Therefore, the smaller order quantity caused by a larger wholesale price as well as channel competition caused by adding a direct channel will greatly hurt the retailer. Additionally, when c exceeds a threshold (i.e., $c \geq c_7$), adding a direct channel will hurt both the manufacturer and the retailer, and thus, the manufacturer will be reluctant to add a direct channel. This is because, with a sufficiently large c, the manufacturer separates himself with $w^{ST*}|l = \frac{3c+\rho\Delta-1}{2}$ and $w^{ST*}|h = \frac{3-\rho\Delta-c+2\beta(\rho\Delta,c)}{6}$ when $c > c_5$ under encroachment setting, while pooling at $w^{N*} = \frac{1}{2}$ under no-encroachment setting. One can verify that with a sufficiently large c, the manufacturer may set an even larger wholesale price under encroachment setting than that under no-encroachment setting, i.e., $w^{ST*}|h > w^{ST*}|l > w^{N*}$, thus resulting in an amplified double marginalization and hurting both of them. As a result, in addition to the win-win and win-lose outcomes revealed by Arya et al. (2007), a lose-lose outcome can also arise under the dual-channel setting when c is sufficiently large.

What is worse, when the expected demand for the h-type manufacturer is very different from that for the l-type manufacturer, i.e., $\rho\Delta \geq \frac{8-5\sqrt{2}}{12}$, adding a direct channel is more likely to hurt the manufacturer and the retailer, while the win-win outcome cannot exist. This is because, with a sufficiently larger $\rho\Delta$, the retailer may order a smaller quantity as the wholesale price increases in $\rho\Delta$, which has a negative effect on the retailer's profitability; consequently, both the manufacturer and the retailer will be worse off under the Encroachment setting. This conclusion reveals the negative effect of information asymmetry (Δ) and forecast accuracy (ρ), which does not exist in Arya et al. (2007), who consider a symmetric information setting. This is really an alarm over adding a direct channel in the context of a better-informed upstream manufacturer.

Proposition 5 provides insightful suggestions for the better-informed manufacturer regarding encroachment. To signal the true forecast signal, the encroachment setting may create a serious wholesale price distortion, leading to a lower channel efficiency. Therefore, on the one hand, manufacturers that have established direct channels should rethink whether or not to continue selling products through both the direct and the retail channels; on the other hand, manufacturers that have not yet established direct channels should be mindful about this issue when adding a direct channel.

Corollary 1. *Encroachment may become more detrimental for the manufacturer and the retailer as the degree of information asymmetry becomes greater (i.e., a larger Δ).*

As can be seen from Fig. 5, as Δ increases, the region of the win-win outcome shrinks sharply, while the lose-lose outcome becomes larger. Put differently, asymmetric information has a large negative impact on encroachment for both supply chain parties. Although a larger Δ means a larger market potential; however, it is more costly for the manufacturer to separate himself from the low type as the separating wholesale price increases in Δ. Therefore, a greater degree of information asymmetry may negatively impact the manufacturer's and retailer's payoffs under encroachment.

Remark 1. A fundamental difference between Li et al. (2014) and our study lies that the better-informed party has diametrically different incentives to separate from another type in the two signaling games. Specifically, with a better-informed retailer, Li et al. (2014) reveal that the high-type retailer has an incentive to mimic the low type so that the manufacturer will choose a smaller selling quantity in the direct channel. By contrast, we find that when the manufacturer is better-informed, the low-type manufacturer will mimic the high-type so that the retailer will order more quantity of the product. As such, the binding incentive compatibility constraint for separating equilibria in our problem is different from that in Li et al. (2014).

As a result, our findings are different from Li et al. (2014) in these three aspects. To begin with, unlike Li et al. (2014), in which encroachment may lead to a lose-win outcome, we find that this lose-win outcome cannot happen in our study. This is because the less-informed manufacturer will lower the wholesale price when the retailer orders less to mimic the L-type, thus benefiting the retailer but hurting the manufacturer. However, in our paper, the better-informed manufacturer always distorts the wholesale price upward, which hurts the retailer. As a result, the lose-win outcome cannot occur in our study. Additionally, although the lose-lose outcome has been reported by Li et al. (2014), the rationale of our study differs from that of theirs due to the difference in distortion incentives. Last but not least, encroachment may lead to completely different outcomes in our study versus those of theirs. For instance, Li et al. (2014) find that given $r = 0.5$ and $\rho\Delta \approx 0.149$, a sufficiently large c leads to a win-win outcome, which is different from the lose-lose outcome revealed in our model. In general, our findings indicate that the outcome of encroachment by the upstream party in a supply chain depends on which party is better informed. When assessing the benefit of encroachment, firms should take into account which party possesses superior demand information.

5.2. The effect of information accuracy

This subsection focuses on how information accuracy affects the payoffs as well as the effect of encroachment on supply chain parties.

Proposition 6. *Under the No-Encroachment setting, the payoffs of both the manufacturer and the retailer are unrelated to information accuracy ρ (i.e., $\frac{\partial \pi_M^{N*}}{\partial \rho} = \frac{\partial \pi_R^{N*}}{\partial \rho} = 0$); under the Encroachment setting, both the manufacturer and the retailer may earn more (less) as accuracy improves (i.e., $\frac{\partial \pi_M^{E*}}{\partial \rho}$ and $\frac{\partial \pi_R^{E*}}{\partial \rho}$ may be larger (less) than zero).*

Put differently, due to encroachment, as information accuracy increases, both the manufacturer and the retailer may not be better off. Intuitively, a more accurate signal reduces demand uncertainty and facilitates the wholesale price decision, thus benefiting the manufacturer and inducing him to improve accuracy. However, due to the signaling cost, which means that the manufacturer has to charge a higher wholesale price to separate himself from the low type as ρ increases, the manufacturer may conversely become worse off by improving information accuracy. Therefore, acquiring more accurate information is not necessarily beneficial for either supply chain member.

Proposition 6 reveals an interplay between information accuracy and encroachment. On the one hand, due to encroachment, the firm's performance may deteriorate as information accuracy improves and thus, under some conditions, it is not necessary for a dual-channel manufacturer to obtain perfect demand information, even if it is costless to do so. On the other hand, more accurate information may inhibit the manufacturer from adding a direct channel.

5.3. Credible information sharing

In practice, some mechanisms/infrastructures (e.g., an electronic data-interchange system) can be implemented to enable the manufacturer to share information, instead of relying solely on signaling through the wholesale price. In this subsection, we explore the following questions. Is each party better off when information sharing is undertaken? How does manufacturer encroachment influence the value of information sharing? As in Jiang et al. (2016), we assume that the supply chain parties commit to sharing information or not before the forecast signal is realized. This is a rea-

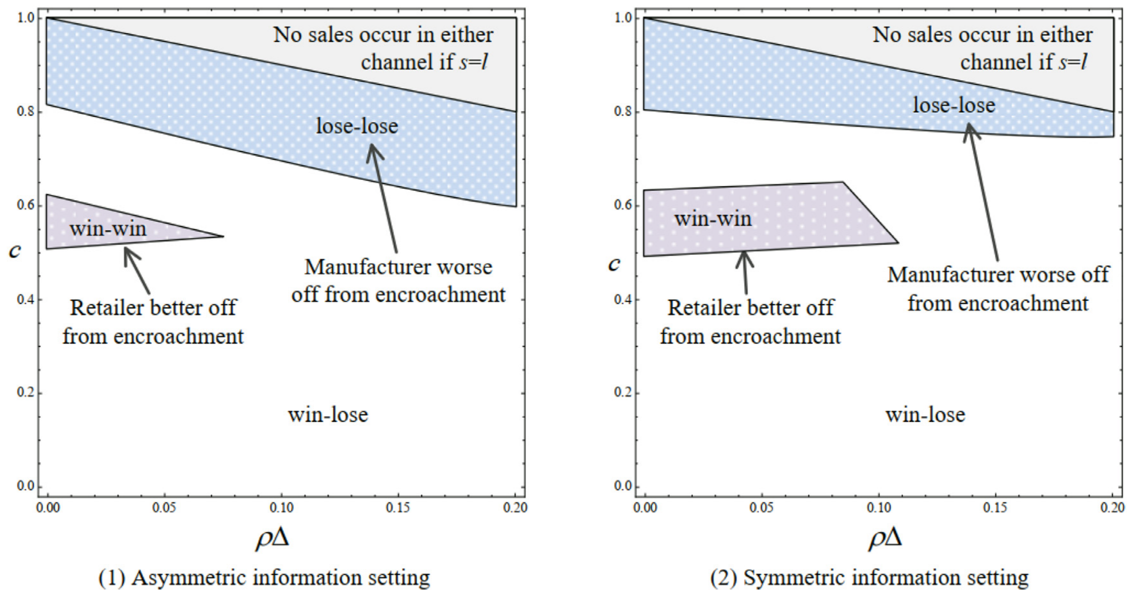

Fig. 5. The Impacts of encroachment.

sonable setting as the installation of the necessary infrastructure is often a long-term decision. So, in the following discussion we focus on the supply chain members' ex ante profits (before the forecast signal is realized).

For convenience, $\Gamma_j^N = \bar{\pi}_j^{N*} - \pi_j^{N*}$ ($\Gamma_j^E = \bar{\pi}_j^{E*} - \pi_j^{E*}$) is defined to represent the values of information sharing under the No-Encroachment channel (the Encroachment) setting, where $j = M, R$, respectively. Additionally, information sharing can be costly due to investments in the IT infrastructure. Let us assume that if the manufacturer (resp. retailer) wants to share information, then he (resp. she) will incur a cost $F \geq 0$ for launching the information sharing mechanism. We start with a special case in which information sharing can be achieved freely, i.e., $F = 0$.

Proposition 7. *If $F = 0$, both supply chain parties always benefit from information sharing under both the No-Encroachment and Encroachment settings, i.e., $\Gamma_M^N > 0$, $\Gamma_R^N > 0$, $\Gamma_M^E > 0$, and $\Gamma_R^E > 0$.*

Intuitively, the better-informed manufacturer is reluctant to share information, while the uninformed retailer benefits from obtaining the information. However, as Proposition 7 shows, information sharing benefits both parties. The rationale hinges on the signaling cost. Specifically, the manufacturer who observes a high forecast signal has to distort his wholesale price upward to signal his type in the separating equilibrium, whereas the pooling wholesale price will deviate from the first-best one under both high and low forecast signals, which amplifies double marginalization and hurts both parties. However, such a signaling cost can be avoided in the symmetric information setting. Therefore, both of them always benefit from information sharing.

We note that the above finding stands in stark contrast to what is documented in the literature. First, our finding differs from the observations of Li et al. (2014) who report that the better-informed retailer may be reluctant to share her private information, in order to maintain the information advantage (Proposition 7 of Li et al. 2014). By contrast, we reveal that with a better-informed upstream manufacturer, both supply chain parties can be much better off through sharing information. In some sense, our results imply that with a manufacturer-side private information setting, it is easier to reach an information sharing agreement between supply chain parties as compared to the retailer-side private information.

Additionally, our results also differ from that of Jiang et al. (2016), who study a single retail channel supply chain with a better-informed upstream manufacturer and conclude that the retailer prefers no information sharing (Proposition 2 of Jiang et al. 2016). This result is diametrically different from ours, for the following reason. They focus on the pricing decision rather than the quantity decision and the retailer can always receive a quantity equal to the realized demand. Consequently, in their model, the h-type manufacturer will downward distort the wholesale price to mimic the low type so that the retailer will lower the retail price and, thus, boost sales. Such a wholesale price distortion therefore benefits the retailer; consequently, she prefers asymmetric information. However, in our model, based on the quantity decision, the l-type manufacturer benefits from mimicking the high type by raising the wholesale price instead. Therefore, the retailer opts for symmetric information to avoid an upwardly distorted wholesale price.

Broadly speaking, our results demonstrate that the impact of information sharing on a downstream retailer hinges critically on whether the retailer commits to an order quantity or a retail price in the wholesale contract, as well as which party possesses private information.

It is important to note that our analysis assumes truthful information sharing. In practice, this requires investment in credible information sharing infrastructure, e.g., a shared database.[11] Hence, we further consider the case in which information sharing is costly. Then, will manufacturer encroachment encourage or discourage information sharing? Proposition 8 indicates that encroachment may even discourage information sharing.

Proposition 8. *With a positive cost of sharing information (i.e., $F > 0$), there exists $\hat{c}$ and $\hat{F}$ such that:*

(a) *If $F \in (\hat{F}, \frac{\rho^2\Delta^2}{8})$, the manufacturer who benefits from information sharing under the No-Encroachment setting may become*

[11] Without the infrastructure that guarantees truthful information transmission, the better-informed party may manipulate its information. So, the information transmitted may not be credible and the less informed party may not trust the shared information at all. Consequently, the game that is eventually played out will be a signaling game as analyzed in this paper; the better-informed party can only distort its decision to credibly signal its type.

reluctant to share information under the Encroachment setting, i.e., $\Gamma_M^N - F > 0$ *while* $\Gamma_M^E - F < 0$.

(b) *If* $\rho\Delta \in (0, \frac{1}{5})$, $c \in (0, \hat{c})$, $F \in (\frac{2(\rho\Delta+c)\sqrt{\rho^2\Delta^2+2\rho\Delta c}-2\rho\Delta(\rho\Delta-c)}{9}, \frac{\rho^2\Delta^2}{16})$, *the retailer who benefits from information sharing under the No-Encroachment setting may become reluctant to share information under the Encroachment setting, i.e.,* $\Gamma_R^N - F > 0$ *while* $\Gamma_R^E - F < 0$.

Where

$$\hat{F} = \begin{cases} \frac{\rho\Delta(\rho\Delta+c-\sqrt{\rho^2\Delta^2+2\rho\Delta c})}{3} & \text{if } \rho\Delta \in (0, \frac{1}{5}), c \in (0, \frac{(3+4\sqrt{3})\rho\Delta}{8}) \\ \frac{\rho^2\Delta^2}{12} & \text{if } \rho\Delta \in (0, \frac{8-5\sqrt{2}}{12}), c \in (c_1, c_2) \\ \frac{6\rho\Delta(3-5c)-7\rho^2\Delta^2-(3-5c)^2}{24} & \text{if } \rho\Delta \in (0, \frac{8-5\sqrt{2}}{12}), c \in (c_2, c_4) \\ & or\, \rho\Delta \in [\frac{8-5\sqrt{2}}{12}, \frac{1}{5}), c \in (c_3, c_4) \\ \frac{(3-3\rho\Delta-5c)^2}{24} & \text{if } \rho\Delta \in [0, \frac{1}{5}), c \in (c_4, \frac{3-(3-\sqrt{3})\rho\Delta}{5}) \end{cases}$$

and $\hat{c}$ *is the smallest solution to* $657\rho^3\Delta^3 + 1152\rho^2\Delta^2 c - 1024\rho\Delta c^2 - 2048c^3 = 0$.

We find that both members who benefit from information sharing if the manufacturer does not add a direct channel may become reluctant to share information in the presence of a direct channel, provided that c is relatively small and F is at an intermediate range. This is because with a relatively small c, the manufacturer does not necessarily charge a sufficiently higher wholesale price to separate himself from the low type or a sufficiently high pooling wholesale price due to the pricing constraint under the Encroachment setting. As a result, both parties are reluctant to share information, as the increased profit through information sharing cannot offset the cost of information sharing. However, absent of a direct channel, the pooling wholesale price is so high that it greatly deviates from the first-best one and, thereby, inhibits the retailer from ordering a larger quantity, thus hurting both parties. Therefore, both are willing to share information as the increased profit outweighs the cost associated with information sharing.

6. General two-state demand function

In the base model, we assumed that the two marginal utility states are equally likely, i.e., $\Pr(H) = \Pr(L) = 1/2$. In this section, we examine a general two-state distribution, in which we assume $\Pr(H) = r$ and $\Pr(L) = 1 - r$, where $r \in [0, 1]$.

Proposition 9. *Suppose* $\rho = 1$, *then under the No-Encroachment setting, the payoffs of both the manufacturer and the retailer are increasing in r (i.e.,* $\frac{\partial \pi_M^{N*}}{\partial r} > 0$ *and* $\frac{\partial \pi_R^{N*}}{\partial r} > 0$*); under the Encroachment setting, the manufacturer's payoff is increasing in r while the retailer's payoff may be increasing in (decreasing in or unrelated to) r, i.e.,* $\frac{\partial \pi_M^{E*}}{\partial r} > 0$ *always hold while* $\frac{\partial \pi_R^{E*}}{\partial r}$ *may be larger than (less than or equal to) zero.*

This is because under the No-Encroachment setting, the manufacturer will always pool at $w^{N*} = \frac{1-\Delta+2r\Delta}{2}$, leading to $\pi_M^{N*} = \frac{(1-\Delta+2r\Delta)^2}{8}$ and $\pi_R^{N*} = \frac{(1-\Delta+2r\Delta)^2}{16}$, respectively. Therefore, a larger r enables the manufacturer to charger a higher wholesale price, and further benefits both the manufacturer and the retailer. However, things are different under the Encroachment setting. For the manufacturer, he can still benefit from a larger r as the larger payoff with a high forecast signal always outweighs the signaling cost. In contrast, a larger r may hurt the retailer as the h-type manufacturer will charge a higher wholesale price to separate himself from the low type, which inhibits the retailer from ordering a larger quantity.

Proposition 9 has implications regarding how the probability of demand states affects the impact of encroachment on supply chain members. For the manufacturer, a larger r cannot always stimulate the manufacturer to encroach if and only if the increased profit under the Encroachment setting is larger than that under the No-Encroachment; for the retailer, she may become worse off from encroachment as $\frac{\partial \pi_R^{E*}}{\partial r} \le 0$ may exist. Nonetheless, as can be seen from Fig. 6 that the magnitude of r will not greatly impact the results.

7. Channel differentiation

In practice, some consumers may prefer to make purchases via one type of channel rather than another, even though the products are identical. This subsection considers a scenario with channel differentiation. Again, we derive the demand function through a representative consumer's purchase utility function with $U \equiv \theta q_r + x\theta q_m - \frac{q_r^2+q_m^2+2kq_rq_m}{2} - p_rq_r - p_mq_m$, where θ and $x\theta$ measure the marginal utility that the consumer obtains from consuming one unit of product bought through the retail channel and direct channel, respectively. So by introducing a factor $x \in [0, 1]$, we allow the consumer to obtain different utility when buying from different channels. The consumer chooses q_r and q_m to maximize the utility, leading to the inverse demand functions for these two channels: $p_r = \theta - q_r - kq_m$ and $p_m = x\theta - q_m - kq_r$, respectively. $k \in (0, 1)$ represents the degree of substitution between two channels, and as k increases, the competition between two channels becomes more intense.

Proposition 10. *Suppose* $c = 0$, *then under the Encroachment setting, when consumers obtain different utilities when buying from different channels, there exists* x_1, x_2, x_3, *and* x_4 *such that a unique LMSE exists that is characterized by the one of the following cases.*

(a) *When* $x \in [0, \min(x_1, x_2)]$, *the optimal separating wholesale prices are* $w^{E*}|l = \frac{(1-\rho\Delta)(k^2x+2k-4x)}{2k}$ *and* $w^{E*}|h = \frac{\left(2-k^2\sqrt{\begin{array}{c}4k^2(1+\rho\Delta)^2-4kx[8(1-\rho\Delta)^2\\ -k^2(3-12\rho\Delta+5\rho^2\Delta^2)]+x^2[16(1-\rho\Delta)^2(4-3k^2)\\ +k^4(9-10\rho\Delta+5\rho^2\Delta^2)]\end{array}}\right)}{2(8-5k^2)} + \frac{8-6k^2+k^3x+\rho\Delta(8-8kx-6k^2+5k^3x)}{2(8-5k^2)}$;

(b) *When* $x \in (\min(x_1, x_2), x_3]$, *the optimal pooling wholesale price is* $w^{E*} = \frac{2k-4x(1-\rho\Delta)+k^2x(1-2\rho\Delta)}{2k}$;

(c) *When* $x \in (x_3, \min(x_4, 1)]$, *the optimal pooling wholesale price is* $w^{E*} = \frac{8-6k^2+k^3x+2\rho\Delta kx(2-k^2)}{2(8-5k^2)}$;

(d) *When* $x \in (\min(x_4, 1), 1]$, *the optimal separating wholesale prices are* $w^{E*}|l = \frac{(1-\rho\Delta)(8-6k^2+k^3x)}{2(8-5k^2)}$ *and* $w^{E*}|h = \frac{8-6k^2+k^3x+\rho\Delta(8-8kx-6k^2+5k^3x)+20(2-k^2)\sqrt{\rho\Delta(2-kx)[2-kx(2-\rho\Delta)]}}{2(8-5k^2)}$.

$$\text{Where}\quad x_1 = \frac{\begin{array}{c}64k(1-\rho^2\Delta^2)-8k^3(5-6\rho\Delta-3\rho^2\Delta^2)\\ +2k^5(3-12\rho\Delta+5\rho^2\Delta^2)-4k^2(1-\rho\Delta)\sqrt{\rho\Delta}(8\\ -5k^2)[32-24k^2-4k^4+\rho\Delta(32-16k^2+k^4)]\end{array}}{\begin{array}{c}256(1-\rho\Delta)^2-128k^2(2-5\rho\Delta\\ +3\rho^2\Delta^2)+4k^4(21-54\rho\Delta\\ +37\rho^2\Delta^2)-k^6(9-10\rho\Delta+5\rho^2\Delta^2)\end{array}},$$

$x_2 = \frac{2k}{8-3k^2}$, $x_3 = \frac{2k}{8(1-\rho\Delta)-k^2(3-4\rho\Delta)}$, *and* x_4 *is the smallest solution to* $8 + 4kx(3-kx) - \rho\Delta(4-12kx+5k^2x^2) + 4kx\sqrt{\rho\Delta(2-kx)[2-kx(2-\rho\Delta)]} = 0$.

Proposition 10 reveal that, consumer's acceptance to the direct channel plays a critical role in affecting the manufacturer's optimal wholesale price decisions. Specifically, when consumer's acceptance to the direct channel is either smaller or large enough, the manufacturer has an incentive to separate himself from the low type; otherwise, he will choose a pooling equilibrium. We further compare the expected profits for both supply chain members to reveal the effect of encroachment in Fig. 7. Recall from

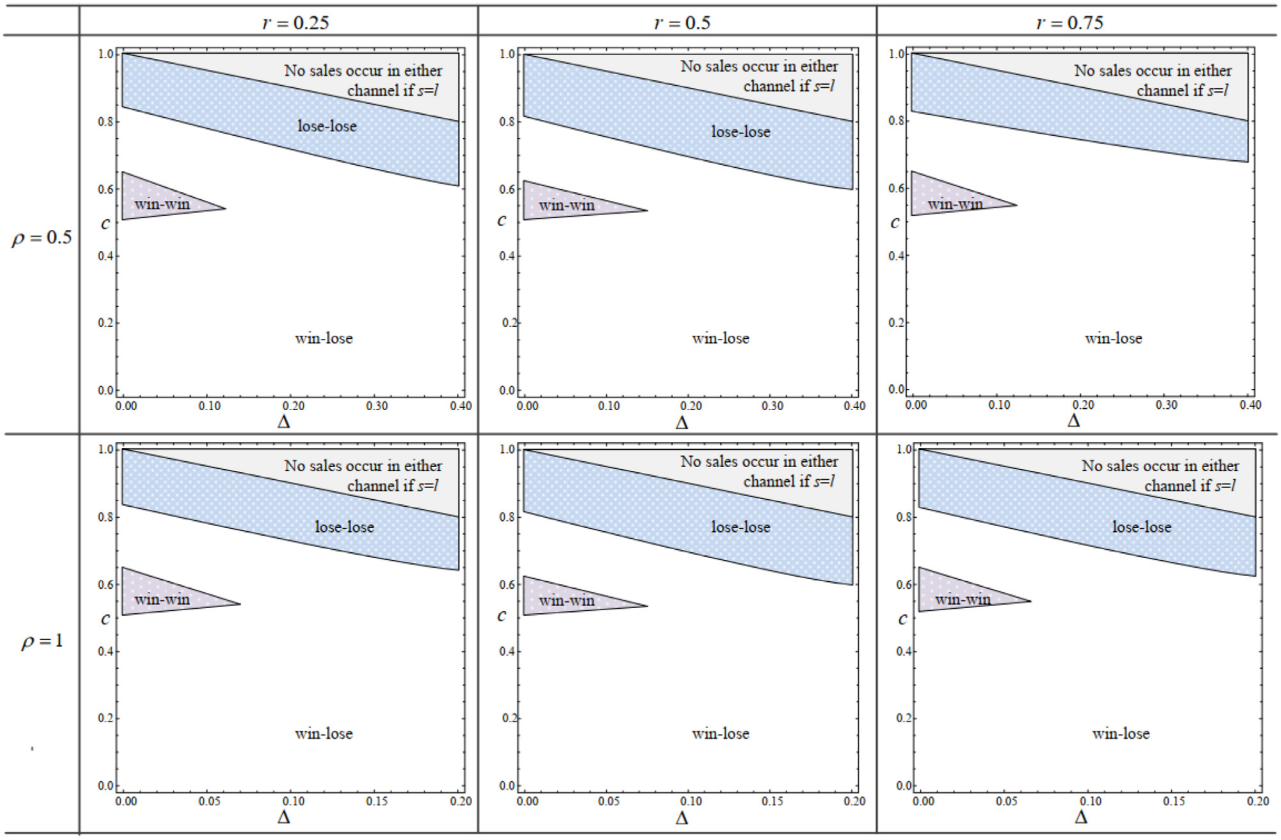

Fig. 6. The Impacts of Encroachment on the Payoffs under General Demand Function.

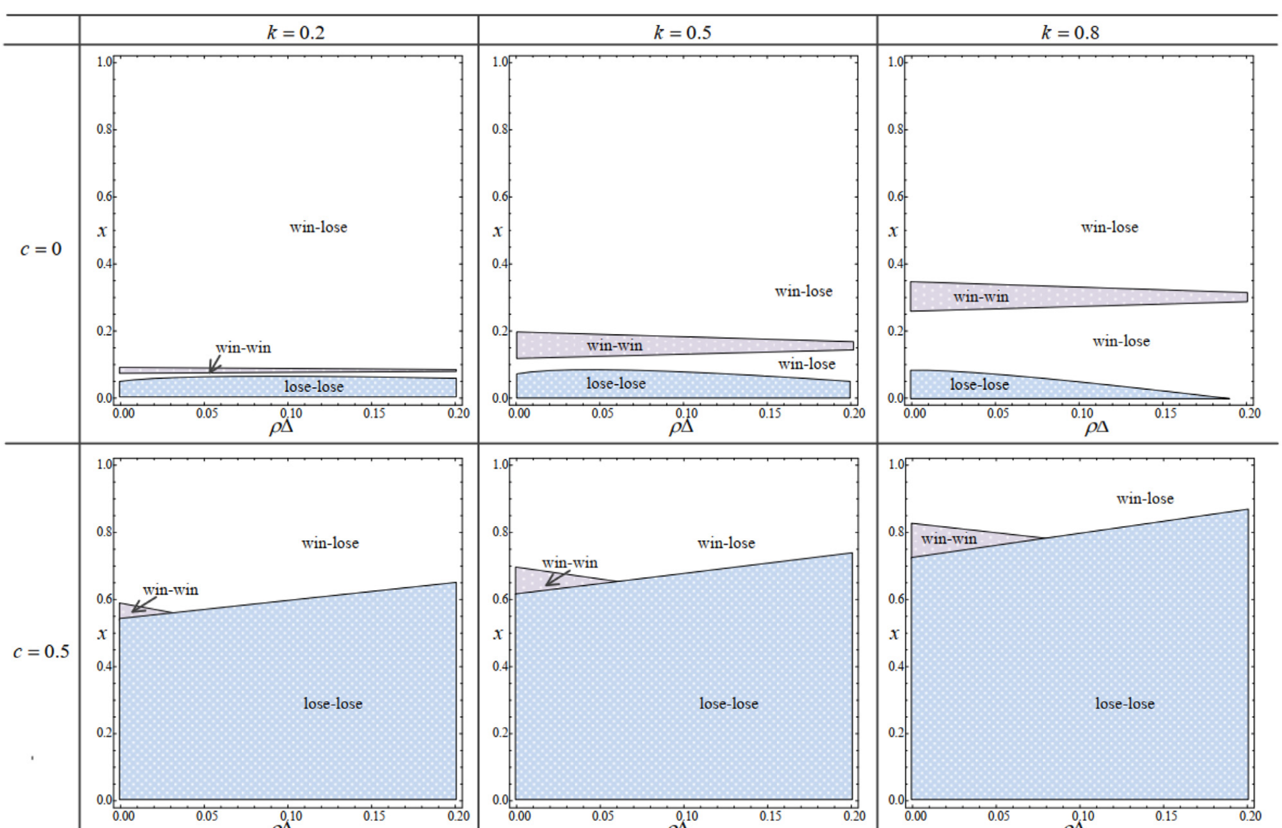

Fig. 7. The Impacts of Encroachment on the Payoffs under Channel Differentiation.

Proposition 5 in the basic model that encroachment leads to a win-lose outcome if given $c=0$ or $c=0.5$; however, when consumers obtain different utility when buying from different channels, encroachment leads to lose-lose, win-lose, and win-win outcomes, depending on the magnitude of x. Intuitively, with a relatively small x, adding a direct channel will hurt both the manufacturer and the retailer due to the channel competition. Interestingly, as x increases, encroachment can benefit both of them. The rationale hinges on the benefit of the mitigation of double marginalization.

8. Alternative settings

In this section, we consider two alternative model settings to check the robustness of our results.

8.1. Simultaneous quantity decision

In the base model, we consider a sequential quantity decision in which the manufacturer decides how much to sell through his direct channel after observing the retailer's order quantity (Arya et al. 2007, Ha et al. 2016, Li et al. 2014). However, it would also be possible for the manufacturer and the retailer decide their selling quantities simultaneously (Huang et al. 2018, Yoon 2016). We characterize how encroachment affects supply chain members' payoffs in the following proposition.

Proposition 11. *When the manufacturer and the retailer decide their selling quantities simultaneously, manufacturer encroachment leads to:*

(a) *a win-lose outcome if* $\rho\Delta \in (0, 0.178)$ *and* $c \in (0, \frac{5\sqrt{2}-\sqrt{5-158\rho^2\Delta^2}}{18})$, *or* $\rho\Delta \in [0.178, 0.2)$ *and* $c \in (0, \frac{18-28\rho\Delta+\sqrt{17\rho^2\Delta^2-3\rho\Delta}}{12})$;
(b) *a lose-win outcome if* $\rho\Delta \in (0, 0.005)$ *and* $c \in (\frac{4\rho\Delta+5\sqrt{9+32\rho^2\Delta^2}}{24}, \frac{69+13\rho\Delta}{93})$, *or* $\rho\Delta \in [0.005, 0.077)$ *and* $c \in (\frac{4\rho\Delta+5\sqrt{9+32\rho^2\Delta^2}}{24}, \frac{12-16\rho\Delta-\sqrt{9+32\rho^2\Delta^2}}{12})$;
(c) *a lose-lose outcome otherwise.*

Compared with Proposition 5, Proposition 11 reveals an interesting finding: in the simultaneous quantity decision setting, manufacturer encroachment can hurt a better-informed manufacturer but benefit a less-informed retailer, leading to a lose-win outcome rather than a win-win outcome. This is because in the sequential quantity decision setting, the manufacturer can strategically make his quantity decision based on the retailer's order quantity. However, such a strategic advantage will disappear and encroachment leads to a lose-win outcome rather than a win-lose outcome.

8.2. Price competition

Thus far, we have examined the effect of encroachment in the context of the quantity competition between the manufacturer and the retailer. In practice, this might be a setting in which the retailer faces a long lead time to get the products. In this section, we consider price competition, where both firms make the pricing decisions rather than quantity decision. Other model settings remain the same as in the basic model. We assume the demand functions are $q_r = \theta - p_r + kp_m$ and $q_m = \theta - p_m + kp_r$, respectively. The following proposition characterizes the equilibria under the price competition setting.

Proposition 12. *Under the price competition,*

(a) *Under the No-Encroachment setting, the manufacturer will pool at* $w^{N*} = \frac{1-2\rho\Delta}{2}$ *if* $\rho\Delta \in (0, \frac{74-48\sqrt{2}}{217})$; *otherwise, the manufacturer will separate and choose* $w^{N*}|h = \frac{1+\rho\Delta}{2}$ *and* $w^{N*}|l = \frac{1+3\rho\Delta-2\sqrt{\rho\Delta+2\rho^2\Delta^2}}{2}$;
(b) *Under the Encroachment setting, the manufacturer will pool at* $w^{E*} = \frac{8-\rho\Delta(16-8k+k^2)+k^3(1-c+kc)}{2(1-k)(8+k^2)}$ *when* $\rho\Delta \in (0, \frac{2(1-k)(4-k^2)^2}{208+48k-168k^2+72k^3+13k^4(1-k)+k^6(1+k)})$ *and* $c \in (\min(1-\rho\Delta, \max(0, c^{****})), 1-\rho\Delta)$; *otherwise, the manufacturer will separate and choose* $w^{E*}|h = \frac{(1+\rho\Delta)(8+k^3)+k^3c(1-k)}{2(1-k)(8+k^2)}$ *and* $w^{E*}|l = \min(\frac{(1-\rho\Delta)(8+k^3)+k^3c(1-k)}{2(1-k)(8+k^2)}, \frac{8+\rho\Delta(24-16k+k^3)+k^3(1-c+kc)}{2(1-k)(8+k^2)} - \frac{2(4-k^2)\sqrt{\rho\Delta(1-k^2)(1+2\rho\Delta+kc)}}{(1-k)(8+k^2)})$. *Where* $c^{****} = -\frac{2}{k} + \frac{\rho\Delta(16-8k+k^3)\sqrt{288+512k-48k^2-192k^3+98k^4-2k^6(8-2k-k^2)}}{k(1-k)(4-k^2)^2} + \frac{\rho\Delta[592+176k-488k^2+200k^3+37k^4(1-k)+3k^6(1+k)]}{k(1-k)(4-k^2)^2}$.

The above proposition reveals that, under the price competition setting, the manufacturer has an incentive to mimic the L-type so that the retailer will lower the retail price and boost the selling quantity (Jiang et al. 2016), regardless of whether the manufacturer establishes a direct channel or not. Due to this difference, Proposition 12 finds that under the No-Encroachment setting, the manufacturer can benefit from separating himself from the L-type. We further compare the expected profits for both members of the supply chain under the No-Encroachment and Encroachment settings in Fig. 8 to reveal how encroachment affects their payoffs under the price competition setting. It can be seen from Fig. 8 that a lose-win outcome occurs and the larger the degree of substitution between these two channels is, the larger the range of the lose-win outcome will be. This is because, to induce the retailer to lower the retail price and thus boost sales, the manufacturer has to downward distort the wholesale price, which will benefit the retailer but hurt himself.

9. Conclusions

Increasingly, many supply chains rely on upstream manufacturers to obtain superior demand forecasts with the help of state-of-the-art data analytics technologies. These manufacturers usually sell not only through downstream retailers but also through their own direct channels. Although conventional wisdom holds that in the symmetric information setting, manufacturer encroachment might benefit each supply chain member due to the mitigation of double marginalization, this study extends the analysis to an asymmetric information setting, with a better-informed manufacturer. We show that the upstream manufacturer who possesses superior customer's marginal utility has to upwardly distort the wholesale price to separate himself from the low type, but doing so amplifies double marginalization and hurts both parties. Furthermore, although the same lose-lose outcome can be found in Li et al. (2014), who also focus on an asymmetric information setting, in which the downstream retailer can have access to obtain superior demand forecasts, the rationale of their study is quite different from that of ours. Due to this difference, we find that encroachment will more likely result in a lose-lose outcome with a better-informed manufacturer versus a better-informed retailer. Nevertheless, we also reach the interesting and counterintuitive conclusion that a larger direct sell cost or a greater degree of information asymmetry does not necessarily hurt them; that is, both of them may benefit from a larger direct selling cost or a greater degree of information asymmetry; however, more accurate information may hurt them and inhibit the manufacturer from encroachment.

We further consider whether or not credible information sharing benefits both supply chain parties. We find that due to the signaling cost, both of them can be better off with information shar-

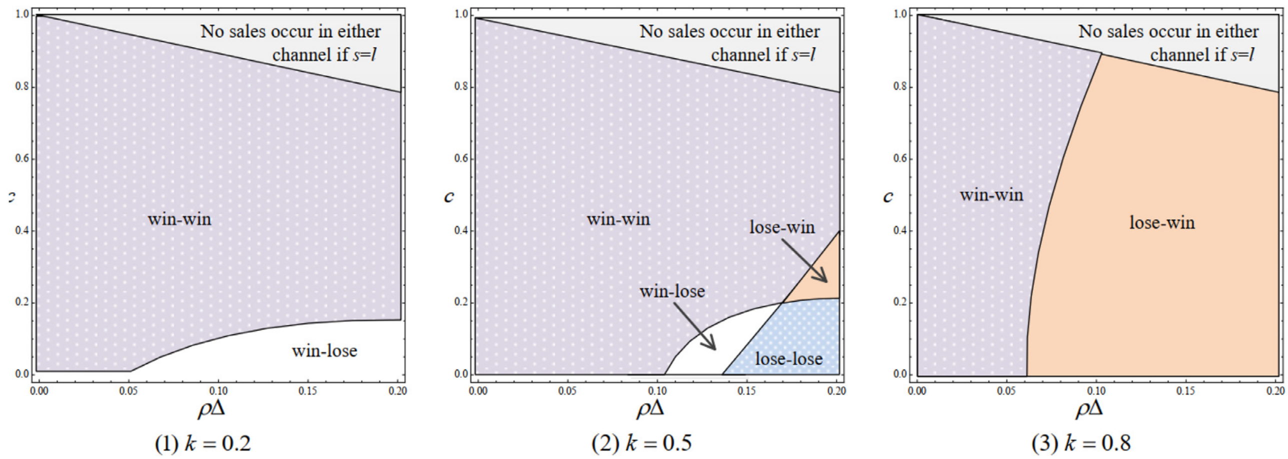

Fig. 8. The Impacts of Encroachment on the Payoffs under Price Competition.

ing, if it is costless to do so, which is different from the case with respect to retailer-side private information, in which information sharing may hurt the better-informed retailer. With respect to the price decision within a single retail channel, the uninformed retailer becomes worse off by investing in the capability to share information. We also reveal that supply chain members may become reluctant to invest in the capability of information sharing due to manufacturer encroachment.

Our model does have some limitations. First, our analysis suggests that there might be some inefficiency within the supply chain due to information asymmetry under wholesale price contract. It is worth further exploring if more complicated contracts or coordination mechanisms could improve supply chain efficiency and guarantee a win-win outcome. Second, we find that the manufacturer will mimic the high type to acquire a higher marginal profit through the retail channel if the products sold through two channels are identical. Accordingly, another promising direction for future research would be to explore the setting in which the manufacturer can distribute two products with differentiated quality levels through the two channels. The quality differentiation may change the manufacturer's mimicking behavior and, thus, affect the impact of encroachment and information sharing.

Acknowledgments

The authors are grateful to Prof. Ruud Teunter (Editor) and the four anonymous referees for their constructive comments, which helped us significantly improve this paper. The research of Y. Tong was partially supported by the National Natural Science Foundation of China (No. 71771123). The research of F. Ye was partially supported by the National Natural Science Foundation of China (No. 72071080, 71771090), and the research of Y. Li was partially supported by Guangdong Basic and Applied Basic Research Foundation, China (No. 2021A1515011884, 2019A1515011768).

Appendix A. Normalization of the average customer's marginal utility

Consider a more general case where $\theta_H = n + \frac{\hat{\Delta}}{2}$ and $\theta_L = n - \frac{\hat{\Delta}}{2}$ such that $\theta_H - \theta_L = \hat{\Delta}$. Then, given θ_H, the manufacturer's profit is $\pi_M = (\theta_H - \hat{q}_r - \hat{q}_m - \hat{c})\hat{q}_m + \hat{w}\hat{q}_r = (n + \frac{\hat{\Delta}}{2} - \hat{q}_r - \hat{q}_m - c)\hat{q}_r + \hat{w}\hat{q}_r = n^2[(1 - \frac{\hat{\Delta}}{2n} - \frac{\hat{q}_r}{n} - \frac{\hat{q}_m}{n} - \frac{\hat{c}}{n})\frac{\hat{q}_m}{n} + \frac{\hat{w}}{n}\frac{\hat{q}_r}{n}]$. Then, for any given $n > 0$, $\hat{\Delta} > 0$, and $\hat{c} > 0$, define $\Delta = \frac{\hat{\Delta}}{2n}$, $c = \frac{\hat{c}}{n}$, $q_r = \frac{\hat{q}_r}{n}$, $q_m = \frac{\hat{q}_m}{n}$, and $w = \frac{\hat{w}}{n}$, we have $\pi_M = n^2[(1 + \Delta - q_r - q_m - c)q_m + wq_r]$, that is, the manufacturer's profit is equal to what is assumed in the main paper times a normalizing constant n^2. Thus, the manufacturer's optimal solution is unrelated to n. Following the same method, we can show a similar result for the manufacturer's profit given θ_L, and for the retailer's profit as well. Therefore, without loss of generality, we assume $\theta_H = 1 + \Delta$ and $\theta_L = 1 - \Delta$.

Appendix B. Proofs

Proof of Proposition 1. First, we characterize the separating equilibrium. Here, the retailer's belief system is: if $w < w^{NS}$, the demand forecast is l; otherwise, the demand forecast is h. A PBE exists if the following constraints are satisfied:

$$\begin{cases} \max_w \pi_M^{NS}(w < w^{NS}|l) \geq \max_w \pi_M^{NS}(w \geq w^{NS}|l), & \text{(A1)} \\ \max_w \pi_M^{NS}(w \geq w^{NS}|h) \geq \max_w \pi_M^{NS}(w < w^{NS}|h), & \text{(A2)} \\ w^{NS} \geq 0. & \text{(A3)} \end{cases}$$

For concision, we use $\pi_M^{NS}(w < w^{NS}|l)$ to denote the l-type manufacturer's expected profit for $w < w^{NS}$ and similar notations are also given accordingly.

Since $\pi_M^{NS}(w < w^{NS}|l) = \frac{w(1-\rho\Delta-w)}{2}$ and $\pi_M^{NS}(w \geqslant w^{NS}|l) = \frac{w(1+\rho\Delta-w)}{2}$. Therefore, we need $w^{NS} \geqslant \frac{1+\rho\Delta+2\sqrt{\rho\Delta}}{2}$ to satisfy constraint (A1). Thus, the optimal wholesale price for l-type manufacturer is $w^{NS*}|l = \frac{1-\rho\Delta}{2} < w^{NS}$. Note that $\pi_M^{NS}(w < w^{NS}|h) = \frac{w(1-\rho\Delta-w)}{2}$ and $\pi_M^{NS}(w \geqslant w^{NS}|h) = \frac{w(1+\rho\Delta-w)}{2}$, and the h-type manufacturer's wholesale price is $w = \frac{1+\rho\Delta}{2}$. Since $\frac{1+\rho\Delta}{2} < \frac{1+\rho\Delta+2\sqrt{\rho\Delta}}{2}$ always holds, and the larger w^{NS} is, the smaller $\pi_M^{NS}(w \geqslant w^{NS}|h)$ will be. Therefore, we have $w^{NS*}|h = \frac{1+\rho\Delta+2\sqrt{\rho\Delta}}{2}$.

Thus, in the separating equilibrium, the manufacturer sets $w^{NS*}|l = \frac{1-\rho\Delta}{2}$ and $w^{NS*}|h = \frac{1+\rho\Delta+2\sqrt{\rho\Delta}}{2}$, respectively.

Next, we solve the pooling equilibrium. Again, we formulate the retailer's belief system: if $w \geqslant w^{NP}$, the retailer's belief is the same as the prior belief; otherwise, the retailer's belief is l. A PBE exists if the following constraints are satisfied:

$$\begin{cases} \max_w \pi_M^{NP}(w \geq w^{NP}|h) = \pi_M^{NP}(w = w^{NP}|h), & \text{(A4)} \\ \max_w \pi_M^{NP}(w \geq w^{NP}|l) = \pi_M^{NP}(w = w^{NP}|l), & \text{(A5)} \\ \max_w \pi_M^{NP}(w \geq w^{NP}|h) \geq \max_w \pi_M^{NP}(w < w^{NP}|h), & \text{(A6)} \\ \max_w \pi_M^{NP}(w \geq w^{NP}|l) \geq \max_w \pi_M^{NP}(w < w^{NP}|l), & \text{(A7)} \\ w^{NP} \geqslant 0. & \text{(A8)} \end{cases}$$

Again, we use $\pi_M^{NP}(w \geq w^{NP}|h)$ to denote the h-type manufacturer's expected profit for $w \geq w^{NP}$ and similar notations are also given accordingly.

Table A.1
The Optimal Solutions of Encroachment Setting in the Separating Equilibrium.

Precondition	$0 < c < \frac{3(1-\rho\Delta)}{5}$	$\frac{3(1-\rho\Delta)}{5} \le c < 1-\rho\Delta$	
$w^*(w < w^{ES}\|l)$	$\frac{3(1-\rho\Delta)-c}{6}$	$\frac{\rho\Delta+3c-1}{2}$	
Precondition	$0 < c < \frac{3-5\rho\Delta}{5}$	$\frac{3-5\rho\Delta}{5} \le c < 1-\rho\Delta$	
$w^*(w \ge w^{ES}\|l)$	$\frac{3-\rho\Delta-c}{6}$	$\frac{3c+3\rho\Delta-1}{2}$	
Precondition	$0 < c < \frac{3(1+\rho\Delta)}{5}$	$\frac{3(1+\rho\Delta)}{5} \le c < 1-\rho\Delta$	
$w^*(w \ge w^{ES}\|h)$	$\frac{3(1+\rho\Delta)-c}{6}$	$\frac{3c-\rho\Delta-1}{2}$	
Precondition	$0 < c < \rho\Delta$	$\rho\Delta \le c < \frac{3+5\rho\Delta}{5}$	$\frac{3+5\rho\Delta}{5} \le c < 1-\rho\Delta$
$w^*(w < w^{ES}\|h)$	$\frac{1-\rho\Delta+c}{2}$	$\frac{3+\rho\Delta-c}{6}$	$\frac{3c-3\rho\Delta-1}{2}$

Table A.2
The Optimal Solutions of Encroachment Setting in the Pooling Equilibrium.

Precondition	$0 < c < \frac{3-4\rho\Delta}{5}$	$\frac{3-4\rho\Delta}{5} \le c < 1-\rho\Delta$	
$w^*(w \ge w^{EP}\|l)$	$\frac{3-c-2\rho\Delta}{6}$	$\frac{3c+2\rho\Delta-1}{2}$	
Precondition	$0 < c < \frac{3(1-\rho\Delta)}{5}$	$\frac{3(1-\rho\Delta)}{5} \le c < 1-\rho\Delta$	
$w^*(w < w^{EP}\|l)$	$\frac{3(1-\rho\Delta)-c}{6}$	$\frac{\rho\Delta+3c-1}{2}$	
Precondition	$0 < c < \frac{\rho\Delta}{2}$	$\frac{\rho\Delta}{2} \le c < \frac{3+4\rho\Delta}{5}$	$\frac{3+4\rho\Delta}{5} \le c < 1-\rho\Delta$
$w^*(w \ge w^{EP}\|h)$	$\frac{1+c}{2}$	$\frac{3-c+2\rho\Delta}{6}$	$\frac{3c-2\rho\Delta-1}{2}$
Precondition	$0 < c < \rho\Delta$	$\rho\Delta \le c < \frac{3+5\rho\Delta}{5}$	$\frac{3+5\rho\Delta}{5} \le c < 1-\rho\Delta$
$w^*(w < w^{EP}\|h)$	$\frac{1-\rho\Delta+c}{2}$	$\frac{3+\rho\Delta-c}{6}$	$\frac{3c-3\rho\Delta-1}{2}$

Since $\pi_M^{NP}(w \ge w^{NP}|h) = \pi_M^{NP}(w \ge w^{NP}|l) = \frac{w(1-w)}{2}$, we need $w^{NP} \ge \frac{1}{2}$ to satisfy constraints (A4) and (A5). As the larger w^{NP} is, the smaller $\max_w \pi_M^{NP}(w \ge w^{NP}|h)$ and $\max_w \pi_M^{NP}(w \ge w^{NP}|l)$ will be, and thus, the optimal pooling wholesale price is $w^{NP*} = \frac{1}{2}$. Then, we have $\pi_M^{NP}(w < w^{NP}|h) = \pi_M^{NP}(w < w^{NP}|l) = \frac{1}{8}$. Meanwhile, note that $\max_w \pi_M^{NP}(w < w^{NP}|h) = \max_w \pi_M^{NP}(w < w^{NP}|l) = \frac{(1-\rho\Delta)^2}{8}$. Clearly, constraints (A6) and (A7) always hold.

Thus, in the pooling equilibrium, the manufacturer sets $w^{NP*} = \frac{1}{2}$.

Finally, the LMSE concept is used to refine the equilibria. The h-type manufacturer's expected profit under two equilibrium outcomes are $\pi_M^{NS*}|h = \frac{(1-\rho\Delta)^2}{8}$ and $\pi_M^{NP*}|h = \frac{1}{8}$, respectively. It is easy to testify that $\pi_M^{NP*}|h > \pi_M^{NS*}|h$ always holds. Therefore, when the manufacturer does not encroach, the unique LMSE is always pooling. □

Proof of Proposition 2. First, we characterize the separating equilibrium. Here, the retailer's belief system: if $w < w^{ES}$, the market potential is l; otherwise, the market potential is h. A PBE exists if the following constraints are satisfied:

$$\begin{cases} \max_w \pi_M^{ES}(w < w^{ES}|l) \ge \max_w \pi_M^{ES}(w \ge w^{ES}|l), & \text{(A9)} \\ \max_w \pi_M^{ES}(w \ge w^{ES}|h) \ge \max_w \pi_M^{ES}(w < w^{ES}|h), & \text{(A10)} \\ w^{ES} \ge 0. & \text{(A11)} \end{cases}$$

Since $\pi_M^{ES}(w < w^{ES}|l) = \frac{(3c-1+\rho\Delta)^2+4cw+12w(1-\rho\Delta-w)}{16}$, $\pi_M^{ES}(w \ge w^{ES}|l) = \frac{(3c-1+3\rho\Delta)^2+4w(3-\rho\Delta+c)-12w^2}{16}$, $\pi_M^{ES}(w \ge w^{ES}|h) = \frac{(3c-1-\rho\Delta)^2-4cw+12w(1+\rho\Delta-w)}{16}$, and $\pi_M^{ES}(w < w^{ES}|l) = \frac{(3c-1-3\rho\Delta)^2+4w(3+\rho\Delta-c)-12w^2}{16}$, respectively. Therefore, the optimal solutions in the separating equilibrium are summarized in Table A.1.

In order to satisfy the constraint, we need $w^{ES} \ge \begin{cases} \frac{3-\rho\Delta-c+4\sqrt{\rho^2\Delta^2+2\rho\Delta c}}{6} & \text{if } 0 < c < \frac{3(1-\rho\Delta)}{5} \\ \frac{3-\rho\Delta-c+2\beta(\rho\Delta,c)}{6} & \text{if } \frac{3(1-\rho\Delta)}{5} \leqslant c < 1-\rho\Delta \end{cases}$. Thus, we have $w^{ES*}|l = \begin{cases} \frac{3(1-\rho\Delta)-c}{6} & \text{if } 0 < c < \frac{3(1-\rho\Delta)}{5} \\ \frac{\rho\Delta+3c-1}{2} & \text{if } \frac{3(1-\rho\Delta)}{5} \leqslant c < 1-\rho\Delta \end{cases}$. Since $w^*(w \ge w^{ES}|h) < w^{ES}$ always holds, and the larger w^{ES} is, the smaller $\pi_M^{ES}(w \ge w^{ES}|h)$ will be. Therefore, it is optimal for the H-manufacturer to set $w^{ES*}|h = \begin{cases} \frac{3-\rho\Delta-c+4\sqrt{\rho^2\Delta^2+2\rho\Delta c}}{6} & \text{if } 0 < c < \frac{3(1-\rho\Delta)}{5} \\ \frac{3-\rho\Delta-c+2\beta(\rho\Delta,c)}{6} & \text{if } \frac{3(1-\rho\Delta)}{5} \le c < 1-\rho\Delta \end{cases}$, where $\beta(\rho\Delta, c) = \sqrt{13\rho^2\Delta^2 + (3-5c)^2 - 2\rho\Delta(9-19c)}$.

Next, we solve the pooling equilibrium. Consider the retailer's belief system: if $w \geqslant w^{EP}$, the retailer's belief is the same as the prior belief; otherwise, the retailer's belief is l. A PBE exists if the following constraints are satisfied:

$$\begin{cases} \max_w \pi_M^{EP}(w \ge w^{EP}|h) = \pi_M^{EP}(w = w^{EP}|h), & \text{(A12)} \\ \max_w \pi_M^{EP}(w \ge w^{EP}|l) = \pi_M^{EP}(w = w^{EP}|l), & \text{(A13)} \\ \max_w \pi_M^{EP}(w \ge w^{EP}|h) \ge \max_w \pi_M^{EP}(w < w^{EP}|h), & \text{(A14)} \\ \max_w \pi_M^{EP}(w \ge w^{EP}|l) \ge \max_w \pi_M^{EP}(w < w^{EP}|l), & \text{(A15)} \\ w^{EP} \ge 0. & \text{(A16)} \end{cases}$$

Since $\pi_M^{EP}(w < w^{EP}|l) = \frac{(3c-1+\rho\Delta)^2+4cw+12w(1-\rho\Delta-w)}{16}$, $\pi_M^{EP}(w < w^{EP}|h) = \frac{(3c-1-3\rho\Delta)^2+4w(3+\rho\Delta-c)-12w^2}{16}$, $\pi_M^{EP}(w \ge w^{EP}|l) = \frac{(3c-1+2\rho\Delta)^2+4w(3-2\rho\Delta-c)-12w^2}{16}$, and $\pi_M^{EP}(w \ge w^{EP}|h) = \frac{(3c-1-2\rho\Delta)^2+4w(3+2\rho\Delta-c)-12w^2}{16}$. Therefore, the optimal solutions in the pooling equilibrium are summarized in Table A.2.

To satisfy constraints (A12) and (A13), $w^{EP} \geqslant \begin{cases} \frac{1+c}{2} & \text{if } 0 < c < \frac{\rho\Delta}{2} \\ \frac{3+2\rho\Delta-c}{6} & \text{if } \frac{\rho\Delta}{2} \leqslant c < \frac{3-2\rho\Delta}{5} \\ \frac{3c+2\rho\Delta-1}{2} & \text{if } \frac{3-2\rho\Delta}{5} \leqslant c < 1-\rho\Delta \end{cases}$. As the larger w^{EP} is, the smaller $\max_w \pi_M^{EP}(w \ge w^{EP}|h)$ and $\max_w \pi_M^{EP}(w \ge w^{EP}|l)$ will be, and thus, the optimal pooling wholesale price is

$$w^{EP*} = \begin{cases} \frac{1+c-\rho\Delta}{2} & \text{if } 0 < c < \frac{\rho\Delta}{2}; \\ \frac{3+2\rho\Delta-c}{6} & \text{if } \frac{\rho\Delta}{2} \leqslant c < \frac{3-2\rho\Delta}{5}; \\ \frac{3c+2\rho\Delta-1}{2} & \text{if } \frac{3-2\rho\Delta}{5} \leqslant c < 1-\rho\Delta. \end{cases}$$

Meanwhile, to satisfy constraints (A14) and (A15), we need to $c_0 < c < c_5$, where $c_0 = \frac{3\rho\Delta}{4}$ and $c_5 = \frac{15-8\rho\Delta+\sqrt{\rho\Delta(60-111\rho\Delta)}}{25}$.

Thus, in the pooling equilibrium, the manufacturer sets

$$w^{EP*} = \begin{cases} \frac{3+2\rho\Delta-c}{6} & \text{if } c_0 < c < \frac{3-2\rho\Delta}{5}; \\ \frac{3c+2\rho\Delta-1}{2} & \text{if } \frac{3-2\rho\Delta}{5} \leqslant c < c_5. \end{cases}$$

Finally, the LMSE concept is used to refine the equilibria. The h-type manufacturer's expected profit under two equilibrium outcomes are

$$\pi_M^{ES*}|h = \begin{cases} \frac{3-6c+7c^2-5\rho^2\Delta^2+2\rho\Delta(3-7c+4\sqrt{\rho^2\Delta^2+2\rho\Delta c})}{12} \\ \text{if } 0 < c < \frac{3(1-\rho\Delta)}{5}; \\ \frac{12c-9c^2-3-7\rho^2\Delta^2+2\rho\Delta(6-11c+\beta(\rho\Delta,c))}{6} \\ \text{if } \frac{3(1-\rho\Delta)}{5} \leqslant c < 1-\rho\Delta. \end{cases}$$

$$\pi_M^{EP*}|h = \begin{cases} \frac{3-6c+7c^2+4\rho^2\Delta^2+\rho\Delta(6-10c)}{12} & \text{if } c_0 < c < \frac{3-2\rho\Delta}{5}; \\ \frac{c((4-3c)+\rho\Delta(3-5c)-1}{2} & \text{if } \frac{3-2\rho\Delta}{5} \leqslant c < c_5. \end{cases}$$

By comparing these profits, we can get Proposition 2. □

Proof of Proposition 3. To prove this proposition, we need to compare the profits of the manufacturer and the retailer under SD and PD at the point $c = c_1$. Then, $\pi_M^{SD*} - \pi_M^{PD*}|_{c=c_1} = -\frac{25\rho\Delta+2\sqrt{2}\rho\Delta-\rho\Delta\sqrt{9+4\sqrt{2}}}{6} < 0$ always holds. Therefore, in the direct regime, the manufacturer's profit may increase in c when the equilibria shift from SD to PD. Similarly, $\pi_R^{SD*} - \pi_R^{PD*}|_{c=c_1} = -\frac{\rho^2\Delta^2(48+8\sqrt{9+4\sqrt{2}}+11\sqrt{18+8\sqrt{2}}-24\sqrt{2})}{36} < 0$ always holds; that is, the retailer's profit may increase in c when the equilibria shift from SD to PD.

Following a similar logics, we can proof Proposition 4 and thus, we omit the straightforward algebraic steps here. $\square$

Proof of Proposition 5. By comparing π_M^{N*} and π_M^{E*}, π_R^{N*} and π_R^{E*} in different ranges of c, we can get Proposition 5. $\square$

Proof of Proposition 7. Under the No-Encroachment setting, we have $\Gamma_M^N = \frac{\rho^2\Delta^2}{8}$ and $\Gamma_R^N = \frac{\rho^2\Delta^2}{16}$, respectively. Under the Encroachment setting, we have

$$(\Gamma_M^E, \Gamma_R^E) = \begin{cases} \left(\frac{\rho\Delta(\rho\Delta+c-\sqrt{\rho^2\Delta^2+2\rho\Delta c})}{3}, \frac{2[(\rho\Delta+c)\sqrt{\rho^2\Delta^2+2\rho\Delta c}-\rho^2\Delta^2-2\rho\Delta c]}{9}\right) & \text{if } 0 < c < \min(c_1, c_2); \\ \left(\frac{\rho^2\Delta^2}{12}, \frac{\rho\Delta(4c-\rho\Delta)}{18}\right) & \text{if } c_1 \le c < c_2; \\ \left(\frac{6\rho\Delta(3-5c)-(3-5c)^2-7\rho^2\Delta^2}{24}, \frac{9-\rho\Delta(18-7\rho\Delta+26c)-18c+5c^2}{36}\right) & \text{if } \max(c_2, c_3) \le c < c_4; \\ \left(\frac{17\rho^2\Delta^2-2\rho\Delta[9-19c+2\beta(\rho\Delta,c)]+(3-5c)^2}{24}, \frac{4c^2[2\rho\Delta-\beta(\rho\Delta,c)]}{36}\right) & \text{if } c_2 \le c < c_3 or c_5 \le c < \frac{3(1+\rho\Delta)}{5}; \\ \left(\frac{(3-3\rho\Delta-5c)^2}{24}, \frac{(3-3\rho\Delta-c)(3\rho\Delta+5c-3)}{36}\right) & \text{if } c_4 \le c < \min(c_5, \frac{3(1+\rho\Delta)}{5}); \\ \left(\frac{\rho\Delta(5c-3)}{12}, \rho\Delta(1-c)\right) & \text{if } \frac{3(1+\rho\Delta)}{5} \le c < c_5; \\ \left(\frac{\rho\Delta[2\rho\Delta+17c-9-\beta(\rho\Delta,c)]}{6}, \frac{18[\rho^2\Delta^2+(1-c)^2]-9(1-\rho\Delta-c)^2-[2\rho\Delta-\beta(\rho\Delta,c)]^2}{36}\right) & \text{if } \max(c_5, \frac{3(1+\rho\Delta)}{5}) \le c < 1-\rho\Delta. \end{cases}$$

Therefore, it can be easily find that $\Gamma_M^N > 0$, $\Gamma_R^N > 0$, $\Gamma_M^E > 0$, and $\Gamma_R^E > 0$ always holds when $F = 0$. $\square$

Proof of Proposition 8. In the No-Encroachment setting, the manufacturer will share information if $F < \frac{\rho^2\Delta^2}{8}$, and the retailer will share information if $F < \frac{\rho^2\Delta^2}{16}$. Then, by comparing $\Gamma_M^N > F$ given $F < \frac{\rho^2\Delta^2}{8}$, $\Gamma_R^N > F$ given $F < \frac{\rho^2\Delta^2}{16}$, we can get Proposition 8. $\square$

Proof of Proposition 9. Following a same logic, we can derive the optimal solutions under the No-Encroachment and Encroachment settings. We omit the straightforward algebraic step while only present the optimal solutions.

Under the No-Encroachment setting, the manufacturer will always pool at $w^{N*} = \frac{1-\rho\Delta+2r\rho\Delta}{2}$, leading to $\pi_M^{N*} = \frac{(1-\rho\Delta+2r\rho\Delta)^2}{8}$ and $\pi_R^{N*} = \frac{(1-\rho\Delta+2r\rho\Delta)^2}{16}$, respectively. Then, the profits of both the manufacturer and the retailer are increasing to r; that is, $\frac{\partial\pi_M^{N*}}{\partial r} > 0$ and $\frac{\partial\pi_R^{N*}}{\partial r} > 0$ always hold.

Under the Encroachment setting, then a unique LMSE exists that is characterized by one of the following cases.

(a) When $\rho\Delta \in [0, 1/5)$ and $c \in (0, \min(\tilde{c}_1, \tilde{c}_2))$, there is a separating equilibrium with direct selling where the optimal separating wholesale prices are $w^*|l = \frac{3(1-\rho\Delta)-c}{6}$ and $w^*|h = \frac{3-\rho\Delta-c+4\sqrt{\rho^2\Delta^2+2\rho\Delta c}}{6}$;

(b) When $\rho\Delta \in [0, \min(\Delta_2, 1/5))$ and $c \in [\tilde{c}_1, \tilde{c}_3)$, there is a pooling equilibrium with direct selling where the optimal pooling wholesale price is $w^* = \frac{3+\rho\Delta(1+2r)-c}{6}$;

(c) When $\rho\Delta \in [0, \min(\Delta_3, 1/5))$ and $c \in [\max(\tilde{c}_3, \tilde{c}_4), \tilde{c}_5)$, there is a pooling equilibrium with a threat of direct selling where the optimal pooling wholesale price is $w^* = \frac{\rho\Delta(1+2r)+3c-1}{2}$;

(d) Otherwise, there is a separating equilibrium with a threat of direct selling where the optimal separating wholesale prices are $w^*|l = \frac{3c+\rho\Delta-1}{2}$ and $w^*|h = \frac{3-\rho\Delta-c+2\beta(\rho\Delta,c)}{6}$;

where $\Delta_1 = \frac{6[10-15r+16r^2-5r^3-10(1-r)\sqrt{1-r}]}{245-r(16-5r)(30-10-16r+5r^2)}$, $\Delta_2 = \frac{3r^2}{10-20r+16r^2-3r^3}$, $\Delta_3 = \frac{3r^2[5-(10-3r)\sqrt{r(1-r)}]}{50-2r(1-r)(10-3r)^2}$, $\tilde{c}_1 = \begin{cases} \frac{\rho\Delta(1-r)(2-r+r^2+2\sqrt{1-r})}{2r^2} & \text{if } 0 < \rho\Delta < \min(\Delta_1, \frac{1}{5}) \\ \tilde{c}_6 & \text{if } \min(\Delta_1, \frac{1}{5}) \le \rho\Delta < \min(\Delta_2, \frac{1}{5}) \end{cases}$, $\tilde{c}_2 = \frac{3(1-\rho\Delta)}{5}$, $\tilde{c}_3 = \frac{3-(1+2r)\rho\Delta}{5}$, $\tilde{c}_4 = \frac{4\rho\Delta+6r-10r\rho\Delta-3r^2(1-\rho\Delta)}{10r-3r^2}$, $\tilde{c}_5 = \frac{15-5\rho\Delta-6r\rho\Delta+2\sqrt{3r\rho\Delta(10-20\rho\Delta+3r\rho\Delta)}}{25}$, and $\tilde{c}_6$ is the second smallest solution to $(3-5c)^2 - \rho\Delta[18 - 30c + 4\beta(\rho\Delta, c) - 8rc] + \rho^2\Delta^2(21 - 8r + 4r^2) = 0$.

Inserting the optimal wholesale prices into the profits of the manufacturer and the retailer, and then, by taking the partial derivative of the profits with respective to r, it can be verified that $\frac{\partial\pi_M^{E*}}{\partial r} > 0$ always holds, while $\frac{\partial\pi_R^{E*}}{\partial r}$ may be larger than (less than or equal to) zero. $\square$

Proof of Proposition 11. Again, following a same logic, we can derive the optimal solutions under the Encroachment settings. We omit the straightforward algebraic step while only present the optimal solutions as: When $c \in (0, \rho\Delta)$, there is a separating equilibrium with direct selling where the optimal separating wholesale prices are $w^*|l = \frac{5(1-\rho\Delta)-c}{10}$ and $w^*|h = \frac{5+3\rho\Delta-c+12\sqrt{\rho^2\Delta^2+\rho\Delta c}}{10}$; When $c \in [\rho\Delta, \frac{15-19\rho\Delta}{21})$, there is a pooling equilibrium with direct selling where the optimal pooling wholesale price is $w^* = \frac{5+\rho\Delta-c}{10}$; When $c \in [\frac{15-19\rho\Delta}{21}, \tilde{c}_7)$, there is a pooling equilibrium with a threat of direct selling where the optimal pooling wholesale price is $w^* = 2\rho\Delta + 2c - 1$; When $c \in [\tilde{c}_7, 1-\rho\Delta)$, there is a separating equilibrium with a threat of direct selling where the optimal separating wholesale prices are $w^*|l = \rho\Delta + 2c - 1$ and $w^*|h = \frac{5+3\rho\Delta-c+3\sqrt{41\rho^2\Delta^2+(5-7c)^2-\rho\Delta(50-86c)}}{10}$, where $\tilde{c}_7 = \begin{cases} \frac{69+13\rho\Delta}{93} & \text{if } 0 < \rho\Delta < \frac{9}{373} \\ \frac{105-121\rho\Delta+2\sqrt{630\rho\Delta-2085\rho^2\Delta^2}}{147} & \text{if } \frac{9}{373} \leqslant \rho\Delta < \frac{1}{5} \end{cases}$. Finally, by comparing the profits under the No-Encroachment and Encroachment settings, we can get Proposition 11. $\square$

References

Arya, A., Mittendorf, B., & Sappington, D. E. (2007). The bright side of supplier encroachment. *Marketing Science, 26*(5), 651–659.

Cao, H., Guan, X., Fan, T., & Zhou, L. (2020). The acquisition of quality information in a supply chain with voluntary vs. mandatory disclosure. *Production and Operations Management, 29*(3), 595–616.

Chiang, W.-y. K., Chhajed, D., & Hess, J. D. (2003). Direct marketing, indirect profits: A strategic analysis of dual-channel supply-chain design. *Management Science, 49*(1), 1–20.

Gal-Or, E., Geylani, T., & Dukes, A. J. (2008). Information sharing in a channel with partially informed retailers. *Marketing Science, 27*(4), 642–658.

Gao, L., Guo, L., & Orsdemir, A. (2021). Dual channel distribution: The case for cost information asymmetry. *Production and Operations Management, 30*(2), 494–521.

Guan, X., & Chen, Y.-J. (2017). The interplay between information acquisition and quality disclosure. *Production and Operations Management, 26*(3), 389–408.

Guan, X., Liu, B., Chen, Y.-J., & Wang, H. (2020). Inducing supply chain transparency through supplier encroachment. *Production and Operations Management, 29*(3), 725–749.

Guan, X., Mantrala, M., & Bian, Y. (2019). Strategic information management in a distribution channel. *Journal of Retailing, 95*(1), 42–56.

Guo, L. (2009). The benefits of downstream information acquisition. *Marketing Science, 28*(3), 457–471.

Guo, L., & Iyer, G. (2010). Information acquisition and sharing in a vertical relationship. *Marketing Science, 29*(3), 483–506.

Guo, L., Li, T., & Zhang, H. (2014). Strategic information sharing in competing channels. *Production and Operations Management, 23*(10), 1719–1731.

Ha, A., Long, X., & Nasiry, J. (2016). Quality in supply chain encroachment. *Manufacturing & Service Operations Management, 18*(2), 280–298.

Ha, A. Y., Tian, Q., & Tong, S. (2017). Information sharing in competing supply chains with production cost reduction. *Manufacturing & Service Operations Management, 19*(2), 246–262.
Hsiao, L., & Chen, Y.-J. (2014). Strategic motive for introducing internet channels in a supply chain. *Production and Operations Management, 23*(1), 36–47.
Huang, S., Guan, X., & Chen, Y.-J. (2018). Retailer information sharing with supplier encroachment. *Production and Operations Management, 27*(6), 1133–1147.
Iyer, G., Narasimhan, C., & Niraj, R. (2007). Information and inventory in distribution channels. *Management Science, 53*(10), 1551–1561.
Jiang, B., Tian, L., Xu, Y., & Zhang, F. (2016). To share or not to share: Demand forecast sharing in a distribution channel. *Marketing Science, 35*(5), 800–809.
Jiang, B., & Yang, B. (2019). Quality and pricing decisions in a market with consumer information sharing. *Management Science, 65*(1), 272–285.
Li, Z., Gilbert, S. M., & Lai, G. (2014). Supplier encroachment under asymmetric information. *Management Science, 60*(2), 449–462.
Li, Z., Gilbert, S. M., & Lai, G. (2015). Supplier encroachment as an enhancement or a hindrance to nonlinear pricing. *Production and Operations Management, 24*(1), 89–109.
Liu, B., Guan, X., & Wang, Y. (2021a). Supplier encroachment with multiple retailers. *Production and Operations Management, 30*(10), 3523–3539.
Liu, M., Dan, B., Zhang, S., & Ma, S. (2021b). Information sharing in an e-tailing supply chain for fresh produce with freshness-keeping effort and value-added service. *European Journal of Operational Research, 290*(2), 572–584.
Mailath, G. J., Okuno-Fujiwara, M., & Postlewaite, A. (1993). Belief-based refinements in signalling games. *Journal of Economic Theory, 60*(2), 241–276.
Matsui, K. (2020). Optimal bargaining timing of a wholesale price for a manufacturer with a retailer in a dual-channel supply chain. *European Journal of Operational Research, 287*(1), 225–236.
Mohr, J. J., & Sohi, R. S. (1995). Communication flows in distribution channels: Impact on assessments of communication quality and satisfaction. *Journal of Retailing, 71*(4), 393–415.
Nasser, S., & Turcic, D. (2019). Temporary contract adjustment to a retailer with a private demand forecast. *Management Science, 65*(1), 209–229.
Singh, N., & Vives, X. (1984). Price and quantity competition in a differentiated duopoly. *The Rand Journal of Economics, 15*(4), 546–554.
Tian, L., & Jiang, B. (2017). Comment on "Strategic information management under leakage in a supply chain". *Management Science, 63*(12), 4258–4260.
Tsay, A. A., & Agrawal, N. (2004). Channel conflict and coordination in the e-commerce age. *Production and Operations Management, 13*(1), 93–110.
Wang, N., & Li, Z. (2021). Supplier encroachment with a dual-purpose retailer. *Production and Operations Management, 30*(8), 2672–2688.
Yang, H., Luo, J., & Zhang, Q. (2018). Supplier encroachment under nonlinear pricing with imperfect substitutes: Bargaining power versus revenue-sharing. *European Journal of Operational Research, 267*(3), 1089–1101.
Yoon, D.-H. (2016). Supplier encroachment and investment spillovers. *Production and Operations Management, 25*(11), 1839–1854.
Zhang, J., Li, S., Zhang, S., & Dai, R. (2019a). Manufacturer encroachment with quality decision under asymmetric demand information. *European Journal of Operational Research, 273*(1), 217–236.
Zhang, S., Dan, B., & Zhou, M. (2019b). After-sale service deployment and information sharing in a supply chain under demand uncertainty. *European Journal of Operational Research, 279*(2), 351–363.
Zhang, S., Wei, L., & Zhang, J. (2022). Demand forecast sharing for a dominant retailer with supplier encroachment and quality decisions. *European Journal of Operational Research, 301*(1), 39–50.
Zhang, T., Feng, X., & Wang, N. (2021a). Manufacturer encroachment and product assortment under vertical differentiation. *European Journal of Operational Research, 293*(1), 120–132.
Zhang, Y., & Hezarkhani, B. (2021). Competition in dual-channel supply chains: The manufacturers' channel selection. *European Journal of Operational Research, 291*(1), 244–262.
Zhang, Z., Song, H., Shi, V., & Yang, S. (2021b). Quality differentiation in a dual-channel supply chain. *European Journal of Operational Research, 290*(3), 1000–1013.
Zhou, J., Zhao, R., & Wang, W. (2019). Pricing decision of a manufacturer in a dual-channel supply chain with asymmetric information. *European Journal of Operational Research, 278*(3), 809–820.