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THE INCENTIVES FOR INFORMATION SHARING AND ONLINE EXPANSION STRATEGY IN MEDICAL SUPPLY CHAINS

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Abstract. Recently, online shopping for medical products has gradually normalized, promoting the acceleration of medical e-commerce. This improves the channel layout, subsequently broadening the consumer market and augmenting enterprise performance. Considering a two-stage supply chain composed of a medical manufacturer and a dealer with more accurate demand information, this paper focuses on the online channel expansion strategy with information sharing. Four distinct sales modes are developed: traditional sales, dual-channel, O2O and multi-channel. For each modality, an investigation of the information sharing motivation and impact of online expansion on enterprise profits and patient surplus is conducted. Intriguingly, a dealer may be incentivized to share information exclusively under multi-channel mode, accompanied by either a moderate level of public welfare or high online preference. Moreover, the online entry decision is independent of information sharing strategy. Specifically, O2O and multi-channel are more conducive to dealer, whereas manufacturer prefers the dual-channel. In addition, online expansion can not only prove to be a "win–win" situation for both manufacturer and dealer, but can also increase patient surplus.

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1. Introduction

In the medical industry, most medical dealers are sponsored or managed by government, making public welfare their main characteristic [1–4]. To ensure sustainability, medical service development must prioritize public welfare alongside marketization and incorporate consumer surplus [5–7]. However, recent pursuit of high profits has caused medical enterprises to deviate from their public welfare nature and inflate prices, leading to issues in the medical supply chain such as channel and pricing strategy, social welfare, etc. Consequently, practitioners in the medical industry face the challenge of determining appropriate pricing and sales strategies.

As a consequence of the public welfare, how should medical enterprises develop marketing channels that align with their values? The traditional sales mode is generally adopted by most medical manufacturers to conduct their business. It is still common for credence goods, such as medical services or health products (*e.g.*, Amway), to be sold through traditional channels in order to avoid negative impressions among consumers [8]. With the popularization of internet technology, e-commerce has developed unprecedentedly, and online shopping for medical products has become the mainstream consumption mode [9, 10]. Wang Jianlin, the chairman of Dalian

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Wanda Group, also believes that any enterprise needs to integrate online and offline resources to survive [11]. During the COVID-19 epidemic, the sale of masks on Tmall and JD.COM increased 68-fold from 167 million in January to 11.57 billion in May 2021. In addition, Ro in the US and Pharmacy2U in the UK are two well-known online medical platforms. Ro generated a revenue of \$32.5 million in Q2 2021 through selling drugs on its own platform, showing a YoY growth of approximately 80%. In contrast, Pharmacy2U achieved a revenue of £230 million in 2021 by providing patients with online drug purchasing and e-prescription services, up 30% year-on-year. E-commerce platform trust has steadily increased as well as medical e-commerce has accelerated, which is behind these alarming figures. In light of this, the O2O mode, dual-channel mode, and multi-channel mode are gradually emerging.

The O2O mode combines offline business opportunities with online to reach consumers [12, 13]. In recent years, online sales in the healthcare retail sector have developed rapidly, with many pharmacies and medical equipment retailers launching their own online sales platforms. Among them, companies such as JD Health, Bayer and Walgreens have demonstrated significant advantages and influence in online sales. With fierce market competition, manufacturers introduced direct selling channels (*i.e.*, channel invasion) to compete with dealers' offline channels, also known as dual-channel marketing [6, 14, 15]. Kefu Medical, a pioneer in establishing e-commerce channels in the medical industry, has successfully launched flagship stores of "Good Nurses" on Tmall, JD.COM, Pinduoduo, etc., generating significant revenue. Another example is that after launching the online sales platform TMH, the American equipment manufacturer Medtronic saw a 22% increase in the sales of individual otolaryngology products. Differently, the multi-channel mode is a combination of O2O and dual-channel modes, *i.e.*, manufacturers invade dealer's online and offline sales [10, 16]. The medical industry has entered a multi-channel marketing era as companies such as Olympus, Johnson & Johnson, Medtronic, GE, JD Health, Bayer and Walgreens utilize offline and online channels simultaneously. Taking the perspectives of patients, enterprises, and supply chain, the paper investigates the optimal sales mode and the influence of online expansion in comparison to traditional mode.

Despite the fact that Internet technology improves the channel layout, it increases the complexity and uncertainty of supply chains. Big data is beneficial for enterprises to better perceive and respond to changes in the environment [17–19]. Online channels can be more accurately established by supply chain members with the help of information prediction. Moreover, it has been feasible to share demand information between upstream and downstream enterprises in this new data-driven environment. Why is medical reform a worldwide problem? One of the big reasons is the serious information asymmetry. For a long time, information asymmetry has existed between manufacturers and dealers of medical products, as well as patients and medical institutions. The development of information technology such as big data is conducive to eliminating information asymmetry and establishing a new medical supply chain service mode. A survey has shown that more than 62% of the U.S. retailers reported demand information with suppliers at least every week [11, 20]. Companies such as McDonald's healthcare pharmaceuticals as well as retailers Walmart and CVS Health, American manufacturer Pfizer and pharmacy chain Walgreens, German Witt Meinung GmbH and Rossmann, all use information sharing strategies, including retailers providing better sales data and enabling manufacturers to better understand specific needs and trends. In evolving retail, sales innovation and better information sharing reshape traditional business. Under traditional sales mode, info silos and single-channel tactics hindered market responsiveness and customer experience. With the rise of dual-channel mode, enterprises need to manage and coordinate the inventory and price to avoid channel conflicts and improve overall efficiency. O2O strategies highlight integrated IT for online-offline data fusion, aiming for tailored services and supply chain gains. Multi-channel intricacies push for solid online-offline integration, using deep data for demand insight and customer pleasure. E-commerce choices and optimized sharing are now critical decisions, working together for a smooth customer experience in volatile markets.

In the intricate network of medical supply chain, information sharing and channel strategies play a pivotal role [21, 22]. Given the uniqueness of this sector, characterized by stringent regulation, life-critical emergencies, complex stakeholder structure, and tech-driven opportunities/challenges, the study of information sharing mechanisms and channel strategies holds profound implications for enhancing supply chain efficiency, reducing costs, and ensuring patient safety. Especially during global health crises such as COVID-19, the effectiveness of these strategies ensures critical medical resources and healthcare system resilience. Thus, this research targets the application and optimization of information sharing and channel strategies, offering practical guidance and theoretical insights for tackling medical supply chain challenges. Against this background, this paper will discuss the following issues:

(i) What role does the public welfare play in pricing decisions and supply chain performance of different supply chain structures? Public welfare is an important factor for the stable development of society, and enterprises can avoid risks and attract consumers by considering public welfare pricing. For example, Jiuzhoutong cooperated with small and medium-sized medical institutions, and Sinopharm Group paid attention to public welfare pricing when dealing with public health incidents, which improved its performance and image respectively. This shows that such pricing decisions are significant for enterprises and society.

(ii) Does the dealer have an incentive to share information with manufacturer? And which channel is the most effective for sharing information? The motivation for dealers to share information is to pursue economic benefits. Mindray Medical dealers use digital platforms and meetings to boost sales and profits. Effective sharing channels are based on industry needs like Yuyue medical dealers' feedback, and enterprises adjust production through channels. This shows dealer-manufacturer information sharing is significant for market demand and economic benefits.

(iii) Compared with traditional sales mode, what impact does online selling have on medical industry? In the medical field, online sales enhance medical resource accessibility for rare-disease patients to get special drugs, increase competition for more transparent prices to ease high medical costs. Ali Health uses e-commerce for resource integration and price reduction; JD Health depends on logistics and price supervision to cut purchase costs. This shows online sales positively impact the medical industry in sales, price and information dissemination.

The main findings are summarized as follows. First, the wholesale and online prices are always lower without information sharing for each sale mode. Often, the manufacturer's non-invasion results in the dealer setting a higher offline retail price after sharing information. While it is online preference and public welfare that determine offline prices in case of manufacturer invasion. Additionally, online and offline prices are adversely affected by the social welfare level, regardless of whether or not information is shared. Second, it is intuitive that the manufacturer and dealer are inconsistent in their willingness to share information. Regardless of the sales mode, the manufacturer benefits from sharing information, while the dealer differs in the sharing intentions. Especially under traditional, dual-channel and O2O modes, the dealer is more inclined to keep demand information rather than share it. Only under the multi-channel mode, the dealer is motivated to share at a medium level of public welfare or extreme online preference. Finally, the dealer has higher utility without information sharing in O2O marketing by comparing four modes. As for the dealer, the dealer is willing to enter an online channel for O2O or multi-channel retail. And it is inevitable that the manufacturer will expand its sales online regardless of information exchange. Moreover, the expansion of online channel enhances patient shopping experiences and expands the potential market, ultimately increasing the patient surplus.

The remainder of this paper is organized as follows. Section 2 reviews the literature. In Section 3, we develop four marketing modes for non-sharing and sharing. In Section 4, an optimal strategy for sharing information and expanding online channels is analyzed. Section 5 makes some extensions, *i.e.*, considering online expansion cost and partial information sharing. Finally, conclusion, managerial insights, and limitations are made in Section 6. In addition, Proofs and Some important mode results are presented in the appendices.

2. Literature review

This study is related to three streams of literature, namely, operation management of medical supply chain, the role of online selling and vertical information sharing.

2.1. Operation management of medical supply chain

Researchers have paid great attention to the operation management of medical supply chain. Many influential literatures about medical supply chain have solved the price and quality decisions [7, 21, 23], product recall decision [24, 25], network design [26–28], analysis and prediction based on big data [22, 29, 30] and other issues. Specifically, Ma *et al.* [7] considered the medical equipment industry that focuses on patients' interests, and explored the impact of patient attention levels on optimal decisions. Xie *et al.* [21] studied the emergency medical supply chain considering corporate social responsibility, and discussed the decision-making and coordination based on the principle of maximizing social welfare. McGinty *et al.* [23] aimed to summarize the previous research on the medical quality of severe mental patients in the United States, identified the potential sources of changes in nursing quality, and determined the focus of future research. Using econometrics and predictive analysis, Mukherjee and Sinha [24] investigated the reports of adverse events related to medical devices generated by users, and analyzed the judgment bias of enterprises in product recall decision. Thirumalai and Sinha [25] empirically evaluated the financial impact of medical device recall, and considered the cross section of medical device manufacturers to test the impact of company characteristics on inferior cost. Fahimnia *et al.* [26] put forward a stochastic dual-objective supply chain design mode for blood supply with minimum cost and delivery time. Hasani *et al.* [27] discussed how to maximize the after-tax profit of medical device supply chain under the uncertain decision-making environment. Nagurney and Nagurney [28] developed a manageable network mode and calculation method to design the medical nuclear supply chain. Based on the shortage of medical supplies, Bai and Song [22] studied the trade-off of medical equipment renovation strategies in different structures of block chain. Bjarnadottir *et al.* [29] used the comprehensive data set of all patients with colorectal cancer in California to generate a prediction mode, which solved some contradictions about the survival rate. Malik *et al.* [30] classified and evaluated the reported research on health care operation and data mining framework by systematically reviewing the existing knowledge system.

However, most of the literature was categorized under traditional marketing and deterministic demand. In contrast to the above literature, this paper develops a mode for comparing the profitability with different channel strategies, assuming that downstream dealers forecast market demand and decide whether to share it.

2.2. The role of online selling

Our study is closely related to literature on the role of online selling, which mostly refers to the retailers' online expansion of retailers and manufacturers' invasion. Firstly, a great deal of research has explored the influence of entity retailers' online and offline sales. For example, Gao and Su [31] studied the impact on channel selection and corporate performance of retailers' choices to customers, *i.e.*, online purchase and in-store pick-up. Then, considering three information mechanisms, they studied how retailers can effectively transmit online and offline information to consumers [32]. Ma *et al.* [12] studied the effects of consumer reference effect, channel preference and corporate altruistic behavior on corporate optimal decision-making and performance in low-carbon tourism O2O supply chain. Secondly, there have been numerous research findings about the influence of market competition intensity caused by supplier/manufacturer encroachment. In the mode of Yan *et al.* [33], they developed a two-channel mode for durable goods and explored the impact of product durability and manufacturer encroachment on enterprises. Guan *et al.* [34] reviewed the supplier's voluntary disclosure strategy under the condition that the supplier encroached the retailer. Siragusa and Tumino [35] evaluated the environmental impact of online and offline purchasing processes in grocery industry on all shopping stages. Chen *et al.* [6] investigate a manufacturer's online selling strategy choice, and discuss its impact in the presence of spillovers from online to offline sales. Thirdly, a large number of studies have appeared in recent years about manufacturers' online sales behavior through electronic retailers or platforms. Wang *et al.* [10] considered a hybrid mode for online retail supply chain, in which manufacturers sell to online retailers and intermediaries through wholesale contracts, retailers sell through intermediaries by paying commissions (agency selling), and intermediaries resell as e-retailers (reselling). Taking into account the impact of data-driven marketing (DDM), Liu *et al.* [16] established four modes to investigate the platform's preference between agency sales and resale. Wu *et al.* [36] studied the supply chain composed of manufacturer, third-party (3P) seller and electronic platform, in which 3P sellers sell products through electronic platform. Tsunoda and Zennyo [37] studied the supplier's multi-channel strategy under the uncertain demand, including the choice of online sales form and optimal pricing. It also expounds how platform information sharing can change suppliers' multi-channel management and ultimately impact retailers.

Nevertheless, most of these studies only examined the online sales of manufacturers or retailers, and seldom addressed whether expanding online will benefit enterprises or customers. Hence, by comparing the enterprise profit and patient surplus under four sales modes, the online channel expansion decision are derived from exploring the online expansion preference of enterprises and patients.

2.3. Vertical information sharing

The literature on vertical information sharing in the context of demand uncertainty is also related. There are two ways of vertical sharing in a sizeable stream of literature: top-down forward and bottom-up reverse. Firstly, in the information mode shared by upstream manufacturers, Jiang *et al.* [38] examined the equilibrium solution under the three structures: no information sharing, voluntary information sharing and mandatory information sharing. Xu *et al.* [39] investigated manufacturers' horizontal and vertical information sharing behaviors under two competitive supply chains. Jain [40] analyzed the demand information sharing collaboration between two manufacturers and a retailer, where the manufacturer owns the information and decides whether to share it. Wang *et al.* [41] established a principal-agent mode to help manufacturers design an information screening contract, and studied the private information of third-party collectors in a dual-channel closed-loop supply chain. Secondly, most of the literature on information sharing examines the unilateral information acquisition behavior of downstream enterprises. For instance, Huang *et al.* [42] discussed the influence of information sharing on inventory reduction and profit growth for supply chains with multiple suppliers. Furthermore, in the endogenous channel structure, retailers' motivation for sharing information may be higher than in an exogenous channel structure. Guan *et al.* [34] studied the demand information sharing in two competitive supply chains, and tested the value of information sharing to each supply chain through establishing a multi-stage game framework. Their results showed that information sharing in one supply chain can trigger decision adjustment in another, which may be beneficial to the first. Zhang and Zhang [11], Yang *et al.* [43] focused on the information sharing strategy and sales mode selection strategy of e-retailers. Zhao *et al.* [15] compared the pricing decisions with and without information sharing in a dual-channel supply chain composed of retail and direct sales. Zha *et al.* [44] studied the demand information sharing strategy of online platform in distribution channels. Huang *et al.* [45] studied the information sharing in an endogenous distribution channel structure, where retailers possess better demand information than manufacturers. They found under the condition of sufficient and effective investment, retailers may encourage manufacturers to invade the endogenous channel structure *via* information sharing.

The above research overwhelmingly considered the information sharing under the traditional mode and rarely combined channel strategy with information sharing. This paper investigates the dealer's motivation for information sharing under various channel strategies and its influence, including on the supply chain and patient surplus.

2.4. Summary

In this literature, three noteworthy studies are closely related to our work. First, Ma *et al.* [7] examined the impact of patient concern levels on optimal decisions in the medical equipment industry, where concerns about patient benefits are essential. Second, Zhang and Zhang [11] studied the demand sharing strategies between e-retailer and physical supplier under agency sales and resale, in which supplier sought offline expansion opportunity. As a result, the e-retailer would retain demand information in some cases and prevent supplier from entering offline channel. Finally, Yang *et al.* [43] considered the e-commerce sales mode selection in a dual-channel supply chain, and explored the sharing motivation of e-retailer and optimal sales strategy. Similar to Ma *et al.* [7], this paper also considers the introduction of public welfare into the medical supply chain. A

TABLE 1. Comparative study of relevant literature with present work.

Article	Medical supply chain	Information sharing	Online selling	Consumer surplus
Ma *et al.* [7]	✓			✓
Zhang and Zhang [11]		Vertical	✓	
Guan *et al.* [34]		Vertical	✓	✓
Wang *et al.* [10]		Vertical and horizontal	✓	
Huang *et al.* [45]		Vertical	✓	✓
Yang *et al.* [43]		Vertical	✓	
Tsunoda and Zennyo [37]		Vertical	✓	
Zha *et al.* [44]		Vertical and horizontal	✓	
Bai and Song [22]	✓	Vertical	✓	
Xie *et al.* [18]	✓			✓

TABLE 2. Four sales modes.

Sales mode	Information sharing behavior	
	No information sharing (N)	Information sharing (I)
Traditional sales mode (N)	NN	NI
Dual-channel mode (D)	DN	DI
O2O mode (O)	ON	OI
Multi-channel mode (DO)	DON	DOI

simultaneous analysis of information sharing and sales strategy is then presented in this paper as in Zhang and Zhang [11] and Yang *et al.* [43]. The difference lies in the fact that this paper emphasizes the information sharing strategy between physical dealer and manufacturer in four modes, where dealer or manufacturer may seek to expand online.

Table 1 summarizes the main differences between the modes developed in the above three research fields and those developed in this study. It is worth noting that, although many studies have explored information sharing and channel strategies, this paper studies the interaction between endogenous online expansion decision-making and information sharing incentives on medical supply chain.

3. Model

This paper considers a two-echelon medical supply chain consisting of one medical manufacturer (she, denoted as m) and one non-profit medical dealer (he, denoted as d). The supply chain implements a Stackelberg game in which the manufacturer is the decision-maker and the dealer is the follower. Both manufacturer and dealer can decide whether to expand online channel. Online sales enable the manufacturer to target consumers directly; otherwise, wholesale orders can only be placed by dealer. A dealer who enters the online channel can sell products both online and offline. Following Liu *et al.* [16], Niu *et al.* [46] and Yang *et al.* [43], there is a greater likelihood of a dealer knowing the market and having direct contact with consumers (patients). Therefore, dealer can forecast market demand for better decision-making, as well as decide whether to share private information with upstream manufacturer. To optimize decisions for information sharing and non-sharing, and explore the influence of online expansion on supply chain, four sales modes are considered: traditional sales mode, dual-channel mode, O2O mode and multi-channel mode, as shown in Table 2 and Figure 1.

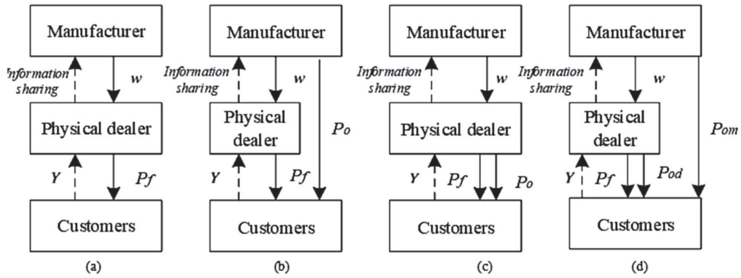

FIGURE 1. Supply chain structure diagram under four sales modes. (a) Traditional sales mode. (b) Dual-channel mode. (c) O2O mode. (d) Multi-channel mode.

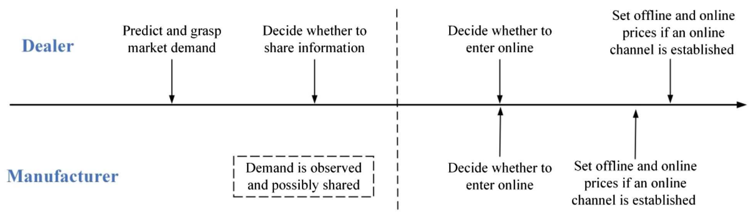

FIGURE 2. The event sequence.

To characterize the demand uncertainty, the total market size is $a = a_o + \varepsilon$, where a_o is the basic market demand known by two enterprises, and the random variable ε represents the demand fluctuation caused by the uncertainty factors, satisfying $E[\varepsilon] = 0, Var[\varepsilon] = \sigma^2$. Similar to relevant literature [47, 48], assuming that dealer obtains demand signal Y by observing market changes, which is an unbiased estimator of $\varepsilon(E[Y|\varepsilon] = \varepsilon)$. Consistent with Shin and Tunca [49], we define $t = Var(\varepsilon)|E[Var(Y|\varepsilon)]$ as information precision, where a larger t indicates a more accurate forecast. Then, considering demand forecasting function based on linear information structure [43], we can get the structure of information prediction by referring to Li [50] as follows:

$$E[\varepsilon|Y] = \frac{t}{1+t}Y \qquad E[Y^2] = \frac{1+t}{t}\sigma^2 = A.$$

Compared with enterprises aiming at profit maximization, public welfare is an essential attribute of medical dealers. Patient-oriented social sustainability and fairness are more important to end users in the medical industry. In this sense, the public welfare and profit-making requirements of medical dealers are thus compatible. Referring to literature [7, 51–53], the utility of dealer can be expressed as $v_d = \pi_d + \beta_d\mathrm{CS}$, where CS and β_d represent patient surplus and public welfare coefficient respectively, satisfying $\beta_d \in [0, 1]$. A larger β_d represents a stronger level of public welfare, whereas $\beta_d = 0$ means a fully profitable enterprise, and $\beta_d = 1$ a completely public welfare enterprise.

The event sequence is shown in Figure 2. To begin with, the dealer determines whether to fully share information with manufacturer after predicting and grasping the market demand. After the demand is observed and shared accordingly, the dealer and manufacturer decide whether to enter online simultaneously, which is known to the opposite side. Furthermore, we assume that there is no cost associated with setting up an online channel. As the market leader, the manufacturer first decides the wholesale and online prices if she expands online. After observing the manufacturer's decision, the dealer establishing an online channel decides the offline and online prices.

TABLE 3. Parameters and decision variables.

a	Total market size, $a = a_o + \varepsilon$
p_f	Unit offline retail price
p_o	Unit online retail price under traditional, dual-channel and O2O modes
p_{od}	Unit online retail price of online store channel under multi-channel mode
p_{om}	Unit online retail price of online direct sales channel under multi-channel mode
w	Unit wholesale price
θ	Purchase intention of offline stores, $\theta \in [0, a]$
α	Customer's preference coefficient for online channel (dual-channel, O2O)
α_m	Customer's preference coefficient for online direct sales channel (multi-channel), $\alpha_m \in (0, 1)$
α_d	Customer's preference coefficient for online store channel (multi-channel), $\alpha_d \in (\alpha_m, 1)$
β_d	Public welfare coefficient, $\beta_d \in [0, 1], \beta_d + \alpha_d(\alpha) < 1$.
t	Information precision
d_f	Offline market demand
d_o	Online market demand under traditional, dual-channel and O2O modes
d_{od}	Online market demand of online store channel under multi-channel mode
d_{om}	Online market demand of online direct sales channel under multi-channel mode
F	The data collection cost paid by the dealer
CS^j	Patient surplus
π_i^j	Profit of i under j mode
v_d^j	Utility of dealer concerned with public welfare, $v_d^j = \pi_d^j + \beta_d \mathrm{CS}^j$
V	The value of information sharing

To be specific, we summarize the parameters and decision variables in Table 3. Subscript $i = m, d, sc$ represents manufacturer, dealer and supply chain, respectively. Superscript $j = NN, NI, DN, DI, ON, OI, DON, DOI$ corresponds to the sales modes in Table 2.

3.1. Benchmark without online channel

The basic mode of medical product distribution relies solely on offline sales to determine consumer utility, which can be expressed as $U_f = \theta - p_f$. Assuming that θ is the purchase intention of consumers (patients) in offline stores, and evenly distributed among the consumer groups of $[0, a]$. Due to consumers' rational nature, utility maximization will always be the driving force behind purchase decisions for patients, *i.e.*, $U_{\max} = \max\{0, U_f\}$. Therefore, only when the valuation is in the range of $[p_f, a]$, would consumers decide to purchase. Then, the demand function with offline price is $d_f = a - p_f$. Referring to previous literature [54, 55], the patient surplus (*i.e.*, patient interests in our mode) is $\mathrm{CS} = \int_0^{a-p_f} (a - x - p_f)\,\mathrm{d}x = \frac{(a-p_f)^2}{2}$.

3.1.1. Mode NN

Under the mode NN, dealer strives to obtain demand information Y by investing F in data collection without sharing demand information. As the dealer cares about patients' benefits, the objective functions of the manufacturer and dealer are respectively:

$$\underset{w}{\mathrm{Max}}\, E\left(\pi_m^{NN}\right) = E(wd_f) \tag{1}$$

$$\underset{p_f}{\mathrm{Max}}\, E\left(v_d^{NN}|Y\right) = E((p_f - w)d_f - F + \beta_d \mathrm{CS}|Y). \tag{2}$$

3.1.2. Mode NI

Under the mode NI, the dealer shares information with manufacturer after obtaining demand information Y. Then, the objective functions of manufacturer and dealer are:

$$\operatorname*{Max}_{w} E\left(\pi_m^{NI}|Y\right) = E(wd|Y) \tag{3}$$

$$\operatorname*{Max}_{p_f} E\left(v_d^{NI}|Y\right) = E((p_f - w)d - F + \beta_d \mathrm{CS}|Y). \tag{4}$$

3.2. Dual-channel mode

Dual-channel marketing involves manufacturers selling directly to consumers through traditional channels that are invading. Similar to the traditional mode, the patients utility through offline channel and online channel are $U_f = \theta - p_f$ and $U_o = \alpha\theta - p_o$, where $\alpha\theta$ represents the online purchase intention of consumers. Rational consumers will make purchase decisions based on maximization of utility, *i.e.*, $U_{\max} = \max\{U_o, U_f\}$. Hence, only when θ is in the interval of $[\frac{p_f - p_o}{1-\alpha}, a]$, would patients buy from offline channel. And when $\frac{p_o}{\alpha} \le \theta < \frac{p_f - p_o}{1-\alpha}$, online channel will be favored by patients. Then, the demand functions of online and offline channels can be expressed as $d_f = a - \frac{p_f - p_o}{1-\alpha}$ and $d_o = \frac{p_f - p_o}{1-\alpha} - \frac{p_o}{\alpha}$. The retail prices available offline and online based on the demand functions are $p_f = a - d_f - \alpha d_o$ and $p_o = \alpha(a - d_f - d_o)$. Moreover, the corresponding patient surplus is $\mathrm{CS} = \int_0^{a - p_f - \alpha d_o} (a - x - \alpha d_o - p_f)\,\mathrm{d}x + \int_0^{\frac{a\alpha - \alpha d_f - p_o}{\alpha}} (a - d_f - y - \frac{p_o}{\alpha})\,\mathrm{d}y = \frac{d_o^2 + d_f^2}{2}$.

3.2.1. Mode DN

Under the mode DN, dealer will not disclose any information. Consequently, the manufacturer and dealer face the following decision-making problems:

$$\operatorname*{Max}_{w,p_o} E(\pi_m) = E(p_o d_o + w d_f) \tag{5}$$

$$\operatorname*{Max}_{p_f} E(v_d|Y) = E((p_f - w)d_f - F + \beta_d \mathrm{CS}|Y). \tag{6}$$

3.2.2. Mode DI

Under the mode DI, dealer shares the complete demand information Y with manufacturer. Then, the decision-making problems for manufacturer and dealer are:

$$\operatorname*{Max}_{w,p_o} E(\pi_m|Y) = E(p_o d_o + w d_f|Y) \tag{7}$$

$$\operatorname*{Max}_{p_f} E(v_d|Y) = E((p_f - w)d_f - F + \beta_d \mathrm{CS}|Y). \tag{8}$$

3.3. O2O mode

O2O mode allows dealer to sell medical products simultaneously offline and online. Consistent with the dual-channel mode, the demand functions and retail prices for offline and online channels are $d_f = a - \frac{p_f - p_o}{1-\alpha}$, $d_o = \frac{p_f - p_o}{1-\alpha} - \frac{p_o}{\alpha}$, $p_f = a - d_f - \alpha d_o$ and $p_o = \alpha(a - d_f - d_o)$. And the corresponding patient surplus is $\mathrm{CS} = \frac{d_o^2 + d_f^2}{2}$.

3.3.1. Mode ON

Under the mode ON, dealer will not share information after obtaining demand information Y. Therefore, the objective functions of the manufacturer and dealer are respectively:

$$\operatorname*{Max}_{w} E(\pi_m) = E(w(d_o + d_f)) \tag{9}$$

$$\operatorname*{Max}_{p_f,p_o} E(v_d|Y) = E((p_o - w)d_o + (p_f - w)d_f - F + \beta_d \mathrm{CS}|Y). \tag{10}$$

3.3.2. Mode OI

Under the mode OI, the dealer shares complete information Y with manufacturer. The objective functions of the manufacturer and dealer are as follows:

$$\operatorname*{Max}_{w} E(\pi_m|Y) = E(w(d_o + d_f)|Y) \tag{11}$$

$$\operatorname*{Max}_{p_f, p_o} E(v_d|Y) = E((p_o - w)d_o + (p_f - w)d_f - F + \beta_d \mathrm{CS}|Y). \tag{12}$$

3.4. Multi-channel mode

Multi-channel mode involves manufacturer entering dealer's dual-channel sales, meaning both manufacture and dealer sell online simultaneously. Under this mode, consumers can purchase through three channels: offline channel, online store channel and online direct sales channel. As with the dual-channel and O2O modes, the utilities obtained under three channels are $U_f = \theta - p_f$, $U_{od} = \alpha_d\theta - p_{od}$ and $U_{om} = \alpha_m\theta - p_{om}$, where α_d and α_m are preference coefficients of online store channel and online direct sales channel, respectively. Consumers make purchasing decisions according to the principle of utility maximization, which can be summarized as: when $U_f \geq \max\{U_{od}, U_{om}, 0\}$, customers purchase from a physical store; when $U_{od} \geq \max\{U_f, U_{om}, 0\}$, the customer buys through the store's online channel; when $U_{om} \geq \max\{U_f, U_{od}, 0\}$, customers opt for the online direct sales channel. The resulting demand functions are respectively:

$$\begin{cases} d_f = a - \dfrac{p_f - p_{od}}{1-\alpha_d}; \\ d_{od} = \dfrac{p_f - p_{od}}{1-\alpha_d} - \dfrac{p_{od} - p_{om}}{\alpha_d - \alpha_m}; \\ d_{om} = \dfrac{p_{od} - p_{om}}{\alpha_d - \alpha_m} - \dfrac{p_{om}}{\alpha_m}; \\ \text{s.t. } \dfrac{(1-\alpha_m)p_{od} + (\alpha_d - 1)p_{om}}{\alpha_d - \alpha_m} \leq p_f \leq a(1-\alpha_d) + p_{od}. \end{cases}$$

And the corresponding patient surplus is $\mathrm{CS} = \frac{{d_{od}}^2 + {d_{om}}^2 + d_f^2}{2}$.

3.4.1. Mode DON

The mode DON specifies that dealer information will not be shared with manufacturer, and the objective functions are respectively:

$$\operatorname*{Max}_{w,\ p_{om}} E(\pi_m) = E(w(d_{od} + d_f) + p_{om}d_{om}) \tag{13}$$

$$\operatorname*{Max}_{p_f, p_{od}} E(v_d|Y) = E((p_{od} - w)d_{od} + (p_f - w)d_f + \beta_d \mathrm{CS} - F|Y). \tag{14}$$

3.4.2. Mode DOI

Under the mode DOI, the dealer shares complete information Y with manufacturer, and the objective functions are as follows:

$$\operatorname*{Max}_{w,\ p_{om}} E(\pi_m|Y) = E(w(d_{od} + d_f) + p_{om}d_{om}|Y) \tag{15}$$

$$\operatorname*{Max}_{p_f, p_{od}} E(v_d|Y) = E((p_{od} - w)d_{od} + (p_f - w)d_f + \beta_d \mathrm{CS} - F|Y). \tag{16}$$

4. Analysis

Through backward induction, the game is solved for each mode. Due to the complexity of the results, the equilibrium results are summarized in Table A.1 in Appendix A. In this section, we first analyze the impact of public welfare level β_d on decision variables. Then, the impact of online sales on the supply chain and patients is considered to determine the best strategy for online expansion. Ultimately, a comparison of four modes is then conducted in order to determine the preferences of manufacturer, dealer and the entire supply chain regarding information sharing.

4.1. Analysis of decision variables

In this section, as a result of our comparison and analysis of wholesale and retail prices, the following propositions can be drawn.

4.1.1. Effects of public welfare level on wholesale prices

Proposition 1. *Information sharing will result in a higher wholesale price for any mode (i.e., $w^{NN} < w^{NI}$, $w^{DN} < w^{DI}$, $w^{ON} < w^{OI}$, $w^{DON} < w^{DOI}$).*

The implication behind Proposition 1 is as follows. In the absence of information asymmetry, manufacturer tends to raise wholesale price, which will capture the dealer's marginal profit, forming a double marginal effect. To reduce channel competition, the manufacturer may set higher wholesale price to stimulate dealer's online sales and avoid price wars. Nonetheless, information sharing can improve the information transparency of the whole supply chain and increase market demand, thus compensating for the increase in wholesale costs [46]. Through information sharing, manufacturers can control the balance between supply and demand, and attain a higher profit rate within the limited market capacity by setting higher wholesale prices. Therefore, the increase in wholesale price is a balanced result aimed at reducing channel conflict, controlling the balance between supply and demand, or striving for more profits.

Corollary 1. *The impact of β_d on wholesale prices shows that* (1) $\frac{\mathrm{d}w^{NN}}{\mathrm{d}\beta_d} = \frac{\mathrm{d}w^{NI}}{\mathrm{d}\beta_d} = 0$. (2) $\frac{\mathrm{d}w^{DN}}{\mathrm{d}\beta_d} = \frac{\mathrm{d}w^{DI}}{\mathrm{d}\beta_d} = 0$. (3) $\frac{\mathrm{d}w^{ON}}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}w^{OI}}{\mathrm{d}\beta_d} < 0$. (4) $\frac{\mathrm{d}w^{DON}}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}w^{DOI}}{\mathrm{d}\beta_d} < 0$.

Corollary 1 shows that under traditional and dual-channel modes, the manufacturer's decision-making is not influenced by public welfare level, regardless of whether information is shared or not. As a public welfare organization, the dealer typically does not purchase at prices oriented towards commercial interests, resulting in relatively lower requirements for wholesale prices. Instead, wholesale prices fall with improved welfare level in O2O and multi-channel modes, thereby narrowing manufacturer's profit margin as dealer expansion online. As the dealer with public welfare aims not to pursue commercial profits, he can use the influence in society to strive for more favorable price strategies, thereby reducing the wholesale price. This can increase product flow and market share, ultimately prompting manufacturer to lower wholesale price and increase social responsibility.

4.1.2. Effects of public welfare level on offline prices

Proposition 2. *The equilibrium offline prices under different sales modes satisfy the following:* (1) *Under the traditional, dual-channel and O2O modes, dealer will set a higher offline retail price with information sharing ($p_f^{NN} < p_f^{NI}, p_f^{DN} < p_f^{DI}, p_f^{ON} < p_f^{OI}$);* (2) *Under the multi-channel mode, when $\alpha_d + \beta_d < 1$, $p_f^{DON} > p_f^{DOI}$ and $p_f^{DON} < p_f^{DOI}$ otherwise.*

Based on Proposition 1, the manufacturer generally sets a higher wholesale price under information sharing, thus increasing the dealer's purchasing cost. In response, the dealer may determine a higher offline retail price for high-cost products under the traditional, dual-channel and O2O modes, thereby maximizing sales profits. In the multi-channel mode, higher public welfare results in a higher offline retail price under information sharing, satisfying constraint conditions. The reason is that dealer can take advantage of high public welfare to raise profit by improving offline price under information sharing. This may be particularly applicable to enterprises engaged in multi-industries, such as Johnson & Johnson, Philips, and GE. Additionally, dealer can balance online and offline by increasing offline price after information sharing, thereby better coordinating different channels' relationships. In general, enterprises need to consider the coordination and balance among different channels, social welfare and economic benefits when formulating pricing strategies.

Corollary 2. *The impact of β_d on offline prices shows that* $\frac{\mathrm{d}p_f^{NN}}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}p_f^{NI}}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}p_f^{DN}}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}p_f^{DI}}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}p_f^{ON}}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}p_f^{OI}}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}p_f^{DON}}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}p_f^{DOI}}{\mathrm{d}\beta_d} < 0$.

Based on Corollary 2, offline prices are adversely affected by public welfare level in any mode. The dealer, a public welfare and profit-making entity, is becoming more closely affiliated with public welfare institutions as β_d increases. This, in turn, encourages consumers to choose these dealers instead of more expensive commercial institutions, which is also conducive to dealers reducing offline prices. In the dual-channel mode, competition intensifies as manufacturer sells online, resulting in more tense price wars. In this case, reducing offline prices becomes the common approach of dealer and manufacturer seeking a price advantage. In the O2O and multi-channel modes, the wholesale price decreases with public welfare, as stated in Corollary 1. In these two scenarios, the dealer becomes more convenient and fluent in sales, eventually increasing purchase volume and providing manufacturer with a channel to reduce supply costs. The above reasons urge dealer to obtain more competitive price strategies, ultimately promoting price reductions. For dealer, he can obtain more favorable price strategies and lower offline price. And manufacturer also needs to recognize the public welfare and take into account the price factors, so as to promote the competition between manufacturer and dealer.

4.1.3. Effects of public welfare level on online prices

Proposition 3. *For dual-channel, O2O and multi-channel modes, online retail price under information sharing is always higher than that under non-sharing* ($p_o^{DN} < p_o^{DI}, p_o^{ON} < p_o^{OI}, p_{om}^{DON} < p_{om}^{DOI}, p_{of}^{DON} < p_{of}^{DOI}$).

Proposition 3 reveals that public welfare level is not a factor in online pricing. Recall the results of Proposition 1. Manufacturer is induced by information sharing to raise wholesale price, exacerbating double marginalization and harming dealer. Therefore, the dealer in O2O mode tends to increase online and offline retail prices correspondingly to increase profits. With the intrusion of manufacturer, manufacturer and dealer can better understand the changes in demand after sharing information, so as to realize the complementarity between offline and online. Enterprises then should adjust to changing demand for improving sales efficiency, potentially leading to higher online prices. Besides, too much competitiveness can lead to price wars, which will affect the normal growth of corporate profits. Then, to avoid price war or competition, higher online prices will be set. Overall, higher online retail prices may be due to reasons such as avoiding price competition and maintaining supply chain balance. Enterprises need to balance profit growth with market balance when formulating pricing strategies, taking into account consumer demand, revenue growth, and supply-demand balance.

Corollary 3. *The impact of β_d on offline prices shows* $\frac{\mathrm{d}p_o^{DN}}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{d}p_o^{DI}}{\mathrm{d}\beta_d} > 0$; $\frac{\mathrm{d}p_o^{ON}}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{d}p_o^{OI}}{\mathrm{d}\beta_d} > 0$; $\frac{\mathrm{d}p_{om}^{DON}}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{d}p_{om}^{DOI}}{\mathrm{d}\beta_d} > 0$; $\frac{\mathrm{d}p_{of}^{DON}}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{d}p_{of}^{DOI}}{\mathrm{d}\beta_d} > 0$.

Corollary 3 indicates that online prices are positively correlated with the public welfare level. Based on Corollary 2, when dealer or manufacturer acts as an online provider, it can result in a decrease in offline demand and a sharing of some profits. As a result, enterprises raise online retail prices to ensure profitability. The dealer, as a public welfare institution, places more emphasis on public interest and social responsibility. This requires more funds to support the procurement and sales, which are typically transferred to online sales, resulting in higher online prices. With stronger public welfare nature, the dealer pays more attention to maintaining price differentiation, avoiding damage to public interest due to price pressures, and thereby increasing the online price. Therefore, the stronger the public welfare, the higher the products' online price may be. This increased emphasis on public welfare value and social responsibility, along with the promotion of various interests, including profit, raises the requirements for online sales prices.

4.2. Channel expansion strategy

4.2.1. Online expansion vs. no expansion

In this section, we focus on how supply chain members choose the best online expansion sales mode among different information sharing strategies. Based on a comparison of the optimal expected profits and patient surplus, the optimal online sales mode selection strategy is discussed.

Proposition 4. *For dealer's profit, in the presence of online channel, the optimal online entry decision is*

(1) *when the dealer does not share the demand information, the dealer prefers ON if* $\psi_1(\alpha, \beta_d) > 0$ *and* $\psi_2(\alpha, \beta_d) < 0$*, and DON if* $\psi_2(\alpha, \beta_d) > 0$ *and* $\psi_3(\alpha, \beta_d) > 0$*;*
(2) *when the dealer shares the demand information, the dealer prefers OI if* $\psi_2(\alpha, \beta_d) < 0$ *and* $\psi_4(\alpha, \beta_d) > 0$*, and DOI if* $\psi_2(\alpha, \beta_d) > 0$ *and* $\psi_5(\alpha, \beta_d) > 0$*.*

Proof. In Appendix B, where the values of $\Psi_1(\alpha, \beta_d) - \Psi_5(\alpha, \beta_d)$ are visible in the proof. □

Corollary 4. *The effects of* β_d *and* α *on the dealer's profit are as follows:*

(1) $\frac{\mathrm{d}\pi_d^N}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}\pi_d^D}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}\pi_d^O}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}\pi_d^{DO}}{\mathrm{d}\beta_d} < 0$*;*
(2) $\frac{\mathrm{d}\pi_d^N}{\mathrm{d}\alpha} < 0$, $\frac{\mathrm{d}\pi_d^D}{\mathrm{d}\alpha} < 0$, $\frac{\mathrm{d}\pi_d^O}{\mathrm{d}\alpha} < 0$, $\frac{\mathrm{d}\pi_d^{DO}}{\mathrm{d}\alpha} < 0$.

Proposition 4 indicates that dealer's channel strategy is related to β_d and α, wherein O2O and multi-channel modes are more conducive to dealer. As such, it is apparent that the dealer is willing to participate in an online channel, regardless of whether he divulges information. Specifically, the increase in public welfare exerts a series of negative impacts on the dealer's profit, a phenomenon primarily due to dealer with strong public welfare who typically prioritizes consumer interests, reduce offline prices, and affect profit (Cor. 2). Moreover, intensified market competition and heightened consumer price sensitivity may trigger price wars among dealers, squeezing profits. Corollary 4(2) shows that when customers' inclination to online reaches a certain stage, competition will be further intensified. To attract more customers, the dealer may need to lower prices continually. Although this can increase sales, the profit will gradually decrease over time due to the decrease in gross profit margin. Thus, dealer should maintain a balance between effective price and deterring manufacturer from entering online by retaining information based on public welfare and online acceptance.

Proposition 5. *For manufacturer's profit, in the presence of online channel, the optimal online entry decision is: with and without information sharing, the manufacturer prefers* $DI(DN)$*.*

Corollary 5. *The effects of* β_d *and* α *on the manufacturer's profit are as follows:*

(1) $\frac{\mathrm{d}\pi_m^N}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{d}\pi_m^D}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{d}\pi_m^O}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}\pi_m^{DO}}{\mathrm{d}\beta_d} < 0$*;*
(2) $\frac{\mathrm{d}\pi_m^N}{\mathrm{d}\alpha} > 0$, $\frac{\mathrm{d}\pi_m^D}{\mathrm{d}\alpha} > 0$, $\frac{\mathrm{d}\pi_m^O}{\mathrm{d}\alpha} > 0$, $\frac{\mathrm{d}\pi_m^{DO}}{\mathrm{d}\alpha} > 0$.

Proposition 5 demonstrates that irrespective of information exchange, the manufacturer always prefers dual-channel sales. Meanwhile, Corollary 5(1) highlights that under traditional and dual-channel setups, public welfare has a positive impact on the manufacturer's profit, whereas a negative effect in O2O and multi-channel models. In terms of consumer behavior, public welfare boosts consumer confidence and stimulates product demand in traditional and dual-channel models. However, in O2O and multi-channel models, consumers become more price-sensitive, intensifying price competition and compressing profit margins. The macroeconomic environment also plays a feedback role: high welfare brings a stable social backdrop, yet in O2O and multi-channel models, it is constrained by rapidly changing market expectations and supply chain complexities. Corollary 5(2) reveals that as online willingness strengthen, manufacturer can better understand customer needs and optimize pricing, thus increasing sales volume and gross margin. On one hand, digitalization breaks physical barriers, significantly expanding market reach, injecting momentum into sales growth. On the other hand, the instant feedback mechanism of online channels accelerates information flow, assisting manufacturer in responding promptly to market changes. In conclusion, customers' preference for online channels broadens market horizons, directly contributing to a significant enhancement of the manufacturer's economic benefits.

Proposition 6. *For supply chain, in the presence of online channel, the optimal online entry decision is*

(1) *without information sharing, the supply chain is better off under DON if* $\Psi_1(\alpha,\beta_d) > 0$ *and* $\Psi_2(\alpha,\beta_d) < 0$, *and DN if* $\Psi_1(\alpha,\beta_d) < 0$ *and* $\Psi_2(\alpha,\beta_d) > 0$.
(2) *with information sharing, the supply chain is better off under DOI if* $\Psi_3(\alpha,\beta_d) < 0$ *and* $\Psi_4(\alpha,\beta_d) > 0$, *and DI if* $\Psi_3(\alpha,\beta_d) > 0$ *and* $\Psi_4(\alpha,\beta_d) < 0$.

Proof. In Appendix B, where the values of $\Psi_1(\alpha,\beta_d) - \Psi_4(\alpha,\beta_d)$ are visible in the proof. □

Corollary 6. *The effects of* β_d *and*α *on the profit of supply chain are as follows:*

(1) $\frac{\mathrm{d}\pi_{sc}^N}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{d}\pi_{sc}^D}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{d}\pi_{sc}^O}{\mathrm{d}\beta_d} < 0$, $\frac{\mathrm{d}\pi_{sc}^{DO}}{\mathrm{d}\beta_d} < 0$;
(2) $\frac{\mathrm{d}\pi_{sc}^N}{\mathrm{d}\alpha} < 0$, $\frac{\mathrm{d}\pi_{sc}^D}{\mathrm{d}\alpha} > 0$, $\frac{\mathrm{d}\pi_{sc}^O}{\mathrm{d}\alpha} < 0$, $\frac{\mathrm{d}\pi_{sc}^{DO}}{\mathrm{d}\alpha} < 0$.

Proposition 6 can be summed up as the case of online channel establishments, the supply chain can be optimized under the invasion of manufacturer. Based on Corollary 6, the supply chain's revenue is a monotonic increasing function of the public welfare under traditional and dual-channel modes. While under O2O and Multi-channel modes, the increase in manufacturer's income caused by a strong welfare level cannot make up for the dealer's loss, leading to a sharp decline in supply chain income. On the one hand, the popularization of online channels has made price transparency reach an unprecedented level, and consumers have become extremely price-sensitive. In order to compete for market share, dealer often has to adopt low-price strategies, which squeezes profit margins. On the other hand, the complexity of O2O and multi-channel modes also means higher operating costs (such as technical support and data processing), which affects the overall profit level of the supply chain. Furthermore, in the dual-channel mode, customers' preference for online channels shows an obvious positive effect, which are rooted in the low-cost operation and wide-area market coverage of online channels. Combined with the improvement of marketing precision driven by data analysis capabilities, it has jointly contributed to the leap-forward growth of supply chain efficiency and substantial growth of profits. Conversely, although there is a potential increase in sales volume in the traditional, O2O and multi-channel modes, it is affected by high costs, channel frictions, high data costs and social welfare requirements, which has a restraining effect on supply chain profits. It is thus revealed that the performance of online channel preferences varies greatly under different retail models, and its impact on supply chain profits depends on whether effective integration between channels and reasonable cost control can be achieved.

Proposition 7. *For the patient surplus, in the presence of online channel, the optimal online entry decision is*

(1) *without information sharing, the patients are better off under DON if* $H_3 > 0$ *and* $H_4 < 0$, *DN if* $H_1 < 0$, *and ON if and only if* $H_2 < 0$;
(2) *with information sharing, the patients are better off under DOI if* $H_3 > 0$ *and* $H_4 < 0$, *DI if* $H_1 < 0$, *and OI if and only if* $H_2 < 0$.

Proof. In Appendix B, where the values of $H_1 - H_4$ are visible in the proof. □

Corollary 7. *The effects of* β_d *and* α *on the patient surplus are as follows:*

(1) $\frac{\mathrm{dCS}^N}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{dCS}^D}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{dCS}^O}{\mathrm{d}\beta_d} > 0$, $\frac{\mathrm{dCS}^{DO}}{\mathrm{d}\beta_d} > 0$;
(2) $\frac{\mathrm{dCS}^N}{\mathrm{d}\alpha} > 0$, $\frac{\mathrm{dCS}^D}{\mathrm{d}\alpha} > 0$, $\frac{\mathrm{dCS}^O}{\mathrm{d}\alpha} > 0$, $\frac{\mathrm{dCS}^{DO}}{\mathrm{d}\alpha} > 0$.

Table 4. Game matrix between dealer and manufacturer.

Dealer strategy	Manufacturer strategy	
	Non-invasion	Invasion
Offline	π_d^N, π_m^N	π_d^D, π_m^D
Online and offline	π_d^O, π_m^O	π_d^{DO}, π_m^{DO}

Proposition 7 indicates that expanding online channels promotes better shopping experiences and expands potential markets, ultimately increasing patient surplus. Dealer who prioritizes the concept of social responsibility may provide attractive prices due to social influence and concern for public welfare, which benefits consumers more. The primary reason is that the inherent information transparency of online channels maximizes consumers' knowledge acquisition and empowers them to make cost-effective choices. In addition, the fair market environment created by social welfare eliminates price manipulation, ensures that customers can enjoy reasonable pricing in multiple choices, and fully protects and expands customer surplus. Moreover, customers' preference for online channels has also significantly improved customer surplus, and the core motivation lies in the multi-level enhancement of consumer value: the convenience and accessibility of online channels have broken the time and space restrictions, greatly enriching customers' choice range and purchase convenience; the improvement of information symmetry is convenient for customers to compare prices and make decisions. Besides, the optimization of cost-benefit ratio benefits from the low marginal cost and economies of scale of online channels, so that customers can enjoy better services at lower prices. To sum up, both social welfare and customers' preference can systematically improve customer surplus from convenience, information transparency and cost-effectiveness, highlighting the profound impact of online channels on customer value.

4.2.2. Equilibrium strategy

In this section, based on the optimal solution and Propositions 4 and 5, the game matrix (Tab. 4) and equilibrium strategy are derived, and the impact of equilibrium strategy is assessed. Then, we can get the following propositions.

Proposition 8. *In the presence of online channel,* (1) *Under information non-sharing, when* $\Psi_1(\alpha, \beta_d) > 0$*, DON is the equilibrium strategy, and DN otherwise;* (2) *Under information sharing, when* $\Psi_2(\alpha, \beta_d) > 0$*, DOI is the equilibrium strategy, and DI otherwise;* (3) *Whether the information is shared or not, the traditional and O2O modes are never equilibrium strategies.*

As seen in Proposition 8, manufacturer always chooses channel invasion to lure more consumers online, resulting in a decrease in offline sales. While dealer should trade off dual-channel with single-channel sales based on the public welfare level and online preference. Figure 3 shows that with a higher public welfare level, dealer often adheres to traditional channel, wherein the wholesale price is higher and the demand is reduced. When manufacturer invades traditional channel, it is profitable for dealer to adopt single channel in order to recover wholesale cost. With a low public welfare level, the dealer will only introduce online channel in moderate online preference, thus easing the channel conflict and weakening the manufacturer's profit. Consequently, the dealer can earn more through small profits but quick turnover when the wholesale and retail prices are lower than those in single-channel sales. Under extreme online preference, the dealer only conducts online sales at a very low public welfare level, otherwise he will pursue single-channel sales to avoid losing profits. Note that $\Psi_1(\alpha, \beta_d) > \Psi_2(\alpha, \beta_d)$, which implies the dealer has a greater chance of entering dual-channel sales without sharing information.

Proposition 9. *The impacts of equilibrium strategy under information non-sharing and sharing on manufacturer and dealer are as follows:*

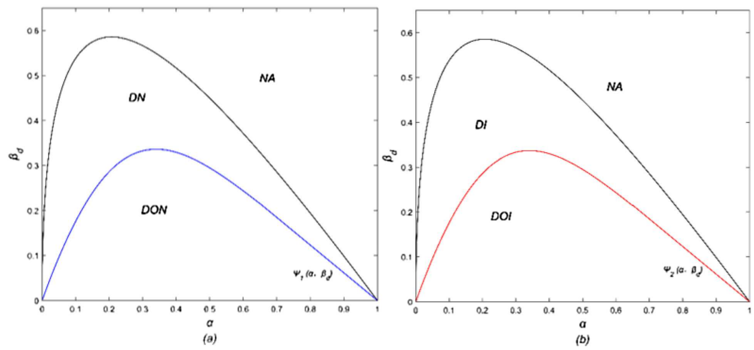

FIGURE 3. Equilibrium strategy of manufacturer and dealer without and with sharing.

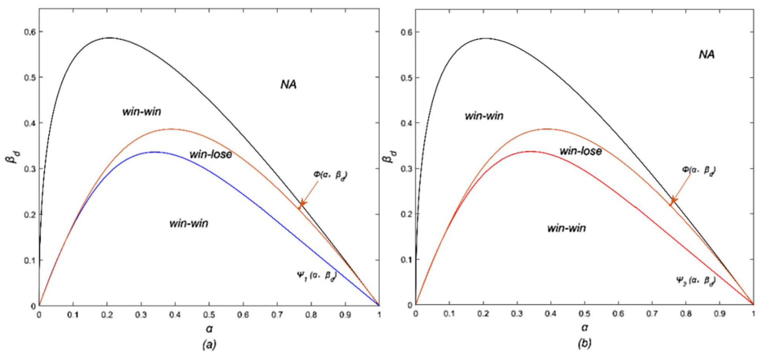

FIGURE 4. The impacts of equilibrium strategy without and with sharing.

(1) *Without information sharing, when* $\Psi_1(\alpha, \beta_d) > 0$*, the equilibrium strategy DON benefits both manufacturer and dealer; when* $\Psi_1(\alpha, \beta_d) < 0$ *and* $\Phi(\alpha, \beta_d) > 0$*, the equilibrium strategy DN is beneficial to dealer but not to manufacturer; when* $\Phi(\alpha, \beta_d) < 0$ *and* $H_1 < 0$*, the equilibrium strategy DN is beneficial to both parties.*
(2) *With information sharing, when* $\Psi_2(\alpha, \beta_d) > 0$*, the equilibrium strategy DOI benefits both manufacturer and dealer; when* $\Psi_2(\alpha, \beta_d) < 0$ *and* $\Phi(\alpha, \beta_d) > 0$*, the equilibrium strategy DI is beneficial to dealer but not to manufacturer; when* $\Phi(\alpha, \beta_d) < 0$ *and* $H_1 < 0$*, the equilibrium strategy DI is beneficial to both parties.*

Figure 4 illustrates that the equilibrium strategy may benefit manufacturer and dealer (region *win–win*), meaning that both sides achieve a win–win situation. It is inevitable that the manufacturer's profit will increase when both parties introduce online channels, even if the overall demand of dealer decreases. With the improvement of public welfare level, the manufacturer's revenue is higher under multi-channel marketing. Therefore, the equilibrium strategy is more inclined to dealer, but not to manufacturer. As manufacturer invades dealer's single-channel sales, the online market demand increases, resulting in an increase of manufacturer's profit. Despite the decline in offline demand, the dealer with higher public welfare level can still profit from higher sales price. Besides, whether or not information is shared, the Pareto region is larger with a moderate online preference, *i.e.*, the likelihood of generating higher revenues is greater.

4.3. Dealer information sharing *vs.* no sharing

4.3.1. Comparison of profit appreciation

In this section, a comparison of the profit gap between information sharing and non-sharing modes further illustrates the value of information sharing in the four sales modes. $V_x^y = E(\pi_x^{yI}) - E(\pi_x^{yN})$ means the value of information sharing, where subscript $x = d, m, sc$ represents dealer, manufacturer and supply chain, and superscript $y = N, D, O, DO$ stands for traditional mode, dual-channel, O2O and multi-channel respectively. For any mode, the dealer voluntarily shares information if and only if $V_d^y > 0$. Based on such criteria, we obtain the following proposition.

Proposition 10. *Under the traditional mode, the values of information sharing to the supply chain are as follows:* (1) $V_d^N < 0$, $\frac{\mathrm{d}V_d^N}{\mathrm{dt}} < 0$. (2) $V_m^N > 0$, $\frac{\mathrm{d}V_m^N}{\mathrm{dt}} > 0$. (3) *if* $F < \tilde{F}_1(\beta_d 0)$, $V_{sc}^N > 0$ *and* $V_{sc}^N < 0$ *otherwise; if* $\tilde{F}_1(\beta_d) > 0$, $\frac{\mathrm{d}V_{sc}^N}{\mathrm{dt}} > 0$ *and* $\frac{\mathrm{d}V_{sc}^N}{\mathrm{dt}} < 0$ *otherwise, where* $\tilde{F}_1(\beta_d) = \frac{(2\beta_d - 1)A}{4(2-\beta_d)^2}$.

Proposition 10 displays that under traditional mode, the improvement of information accuracy is not conducive to dealer, as opposed to existing literature [6,46]. In contrast, the manufacturer benefits from information sharing, along with accurate information. As seen in Proposition 1, wholesale prices under information sharing are higher than those under non-sharing. Then, the manufacturer can satisfy the market demand through pricing schemes, leading to increased selling price and profit. Although the offline retail price increases after information sharing (Prop. 2), the profit improves is insufficient to compensate for the cost loss of forecasting information, making information sharing unfavorable to dealer. Moreover, the role of information sharing in the supply chain is unclear, which depends on the information accuracy and welfare level. Especially, a better supply chain can be benefited by information sharing at a higher β_d, as well as more accurate information. The double marginal impact of higher wholesale prices may be overshadowed by a positive price increase effect. Sharing information enables manufacturer and dealer to be more accurate in making price decisions, ultimately increasing supply chain profits.

Proposition 11. *Under the dual-channel mode, the values of information sharing to the supply chain are as follows:* (1) $V_d^D < 0$, $\frac{\mathrm{d}V_d^D}{\mathrm{dt}} < 0$. (2) $V_m^O > 0$, $\frac{\mathrm{d}V_m^O}{\mathrm{dt}} > 0$. (3) *if* $F < \tilde{F}_2(\alpha, \beta_d)$, $V_{sc}^D > 0$ *and* $V_{sc}^D < 0$ *otherwise; if* $\tilde{F}_2(\alpha, \beta_d) > 0$, $\frac{\mathrm{d}V_{sc}^D}{\mathrm{dt}} > 0$ *and* $\frac{\mathrm{d}V_{sc}^D}{\mathrm{dt}} < 0$ *otherwise, where*

$$\tilde{F}_2(\alpha, \beta_d) = \frac{\begin{array}{c} A[\beta_d^4(\alpha - 1) + 3\alpha\beta_d^3(8\alpha - 1) + 4\alpha\beta_d^2(30\alpha^2 - 15\alpha + 1) \\ + 16\alpha^2\beta_d(11\alpha^2 - 14\alpha + 3) + 16\alpha^2(5\alpha - 1)(\alpha - 1)^2] \end{array}}{4(8\alpha^2 + 8\alpha\beta_d - 8\alpha + \beta_d^2)^2}.$$

Proposition 11 indicates that in dual-channel mode, sharing information is not favorable to the dealer but is beneficial to manufacturer. Firstly, manufacturer competes with dealer and improves sales performance, leading to a reduction in the sales volume and dealer's profit margin. Secondly, sharing information enables manufacturer to understand the demand better and connect directly with consumers, reducing the reliance on dealer. Higher prediction accuracy helps the manufacturer make more informed decisions and improve the profit level. Regarding supply chain profit, within the region of unique equilibrium outcomes, both information symmetry and accurate forecasting have a positive effect on it if $F < \tilde{F}_2(\alpha, \beta_d)$. However, excessive investments in big data and free-riding by the manufacturer may be detrimental to supply chain ($F > \tilde{F}_2(\alpha, \beta_d)$), leading to a decrease in overall efficiency, referred to as the "free-riding" dilemma. When $F < \tilde{F}_2(\alpha, \beta_d)$, a moderate investment can improve the profitability of the entire supply chain without asymmetric information. And the dealer with public welfare has higher market recognition and social influence, thus increasing the credibility of the supply chain. This, in turn, boosts the sales volume and profit level.

Proposition 12. *Under the O2O mode, the values of information sharing to the supply chain are as follows:* (1) $V_d^O < 0$, $\frac{\mathrm{d}V_d^O}{\mathrm{dt}} < 0$. (2) $V_m^O > 0$, $\frac{\mathrm{d}V_m^O}{\mathrm{dt}} > 0$. (3) $V_{sc}^O < 0$, $\frac{\mathrm{d}V_{sc}^O}{\mathrm{dt}} < 0$.

Proposition 6 reveals that in the O2O mode, the dealer has no incentive to share demand information, regardless of consumer surplus considerations. Note that not only is $V_d^O < 0$ but also $\frac{\mathrm{d}V_d^O}{\mathrm{d}t} < 0$, which means that the dealer should not over-invest in big data forecasting to improve accuracy. While forecasting helps dealer better understands consumer behavior, the development of online channels diverts consumer attention and purchase methods, leading to a decrease in offline store traffic. When dealing with the marketing strategies of both online and offline channels, the dealer faces corresponding problems such as increase in procurement and predict cost, decrease in offline traffic, etc. For the hitchhiker manufacturer, the information accuracy is positively correlated with the opportunity for profit improvement. As the sole wholesaler of products, the manufacturer's profit has also improved due to the higher wholesale price under information sharing, as seen in Proposition 1. Furthermore, the supply chain revenue from information sharing decreases with prediction accuracy, implying that the dealer bears a far greater burden of big data prediction cost than the manufacturer gains from information sharing.

Proposition 13. *Under the multi-channel mode, the values of information sharing to the supply chain are as follows:* (1) *if* $F < \tilde{F}_3(\alpha, \beta_d)$, *we have* $V_d^{DO} > 0$ *and* $V_d^{DO} < 0$ *otherwise; if* $\tilde{F}_3(\alpha, \beta_d) > 0$, $\frac{\mathrm{d}V_d^O}{\mathrm{d}t} > 0$ *and* $\frac{\mathrm{d}V_d^O}{\mathrm{d}t} < 0$ *otherwise.* (2) $V_m^{DO} > 0$, $\frac{\mathrm{d}V_m^{DO}}{\mathrm{d}t} > 0$. (3) *if* $F < \tilde{F}_4(\alpha, \beta_d)$, *we have* $V_{sc}^{DO} > 0$ *and* $V_{sc}^{DO} < 0$ *otherwise; if* $\tilde{F}_4(\alpha, \beta_d) > 0$, $\frac{\mathrm{d}V_{sc}^{DO}}{\mathrm{d}t} > 0$ *and* $\frac{\mathrm{d}V_{sc}^{DO}}{\mathrm{d}t} < 0$ *otherwise, where*

$$\tilde{F}_3(\alpha, \beta_d) = \frac{\left\{\begin{array}{l} -\alpha A[-2\beta_d^6 + \beta_d^5(3\alpha_d + \alpha_m - 4) - 4\beta_d^4(\alpha_d^2 - 8\alpha_\mathrm{d}\alpha_m - 10\alpha_m^2 - 6\alpha_d - 8\alpha_m - 1) \\ +32\alpha^2\beta_d^3(2\alpha_d^2 + 3\alpha_\mathrm{d}\alpha_m + 3\alpha_m^2 - 7\alpha_d - 9\alpha_m + 8) \\ +32\alpha^2\beta_d^2(3\alpha_d^2 + 4\alpha_\mathrm{d}\alpha_m + 6\alpha_m^2 - 2\alpha_d + 4\alpha_m + 3)] - 32\beta_\mathrm{d}\alpha_m^2(\alpha_d - \alpha_m)(\alpha_d - 1)^2 \end{array}\right\}}{\begin{array}{l}[-\beta_d^3 + \beta_d^2(-\alpha_d - 6\alpha_m + 1) - 8\beta_\mathrm{d}\alpha_m(\alpha_m - 1) \\ \quad + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m)]^2(4\alpha^2 - \beta_d^2 + 2\alpha\beta_d - 4\alpha + 2\beta_d)^2\end{array}}$$

$$\tilde{F}_4(\alpha, \beta_d) = \frac{\alpha A[\beta_d^3 - 2\beta_d(\alpha_d^2 - \alpha_\mathrm{d}\alpha_m + \alpha_m^2 - \alpha_d - \alpha_m + 1) + 2(\alpha_d - 1)(\alpha_m - 1)(\alpha_d - \alpha_m)]}{\begin{array}{l}[-\beta_d^3 + \beta_d^2(-\alpha_d - 6\alpha_m + 1) - 8\beta_\mathrm{d}\alpha_m(\alpha_m - 1) + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m)]^2 \\ (4\alpha^2 - \beta_d^2 + 2\alpha\beta_d - 4\alpha + 2\beta_d)^2\end{array}}.$$

Proposition 13 explains that under the multi-channel mode, excessive investment in big data will result in a decline in the dealer's profit after information sharing, also known as the "accuracy trap". Additionally, price competition in different channels puts pressure on the dealer, leading to a decrease in profit margins. A higher accuracy in forecasting enables the dealer to determine market positioning accurately when $\tilde{F}_3(\alpha, \beta_d) > 0$, strengthening the competitiveness of product differentiation, and boosting sales and profit. Consistent with Propositions 10–12, information sharing is always beneficial to the manufacturer. However, just like in the dual-channel mode, the dealer's over-investment in data prediction to improve accuracy harms the interests of the supply chain as a whole. Higher prediction accuracy leads to a higher reliance on information and feedback from the dealer. However, this reliance also means a higher competitive pressure on the dealer, posing a threat to the supply chain profit. Only when the predicted cost F is lower than a certain threshold $\tilde{F}_4(\alpha, \beta_d)$, will sharing information provide a more reliable database for the promotion of market competitiveness, improve the market adaptability of products, and thus increase the sales volume and profit.

4.3.2. Information sharing vs. no sharing

Propositions 10–13 demonstrate that information sharing is always beneficial to manufacturer, which is consistent with many literatures [6, 30, 35, 38]. In contrast, the sharing intentions of dealer differ according to four modes. In the traditional, dual-channel and O2O modes, the dealer is more inclined to keep demand information rather than share it. Nevertheless, the dealer in multi-channel mode will take the initiative to share information under certain conditions. In order to further explain the information sharing strategies numerical analysis with respect to F, β_d and α is performed as shown in Figure 5.

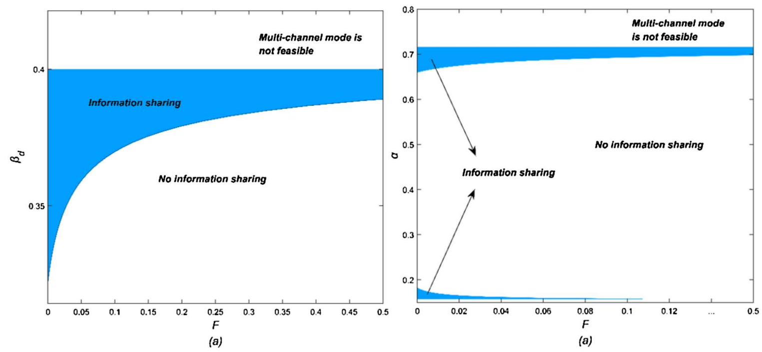

FIGURE 5. Dealer's equilibrium information sharing decision under multi-channel mode.

The findings are as follows: in the multi-channel mode, with the low public welfare, the dealer is less competitive in the market and will be in a relatively weak position. To gain more profit space, the dealer may prefer to keep demand information private. However, hiding demand information may reduce the efficiency of cooperation within the supply chain, negatively impacting the overall profitability of supply chain (Prop. 13(3)). With the increase in F, *i.e.*, the higher data collection cost, the dealer's intention to share information gradually decreases to zero. The reason lies in that with the higher investment cost, the increase in profit generated by demand prediction cannot offset the cost loss, and the dealer should not blindly invest in data forecasting. When α is sufficiently small or large, *i.e.*, the online preference is an extreme value, the dealer will share information without reservation. With the great (small) tendency of consumers to online purchase, online (offline) channel of dealer will usher in more consumers and higher sales. Forecasting and sharing can help the dealer better position products and pricing strategies, thus increasing sales and profits. These findings are in line with Proposition 13.

5. Extensions

5.1. Online expansion cost

In the basic mode, we do not consider the cost of establishing an online channel. However, in reality, it is costly to establish online channels, including recruitment of professional online customer service, channel marketing, etc. Therefore, we relax this assumption and consider that the cost of online expansion is C, which is constant. Therefore, the profits of the manufacturer and dealer are respectively expressed as:

$$\begin{aligned} E(\pi_m) &= E(p_{om}d_{om} + w(d_f + d_{od}) - C), \\ E(\pi_d) &= E((p_{od} - w)d_{od} + (p_f - w)d_f - F + \beta_d \mathrm{CS} - C). \end{aligned}$$

In the following, we discuss the online expansion conditions of supply chain members without and with information sharing respectively.

Proposition 14. *The optimal online expansion conditions of supply chain members are*

(1) *Without information sharing, the condition of manufacturer's online expansion is* $C \leq \frac{\alpha {a_0}^2(1+\alpha)(\alpha+\beta_d-1)}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2} - \frac{{a_0}^2}{4(2-\beta_d)}$, *and that of dealer is*

$$C \leq \frac{\left\{\begin{array}{l} -a_0^2(2-\beta_d)^2[\beta_d^5(10\alpha^2-12\alpha+10)-\beta_d^4(15\alpha^3-13\alpha^2-23\alpha+37) \\ -4\beta_d^3(\alpha-1)(10\alpha^3-29\alpha^2+24\alpha+11) \\ +4\beta_d^2(\alpha-1)^2(16\alpha^3+5\alpha^2-41\alpha-4)+64\alpha\beta_d(\alpha-1)^3(2\alpha^2-2\alpha-1) \\ +16\alpha^2(\alpha-1)^4(3\alpha-4)]+16A(2-\beta_d)^2(\beta_d+\alpha-1)^2[\beta_d^3(-\alpha^2-1) \\ +\beta_d^2(\alpha^3-2\alpha^2+4\alpha+1)+4\alpha\beta_d(\alpha^2-1)+4\alpha^2(\alpha-1)^2] \\ -4(1-\beta_d)(\beta_d+\alpha-1)^2(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)^2(a_0^2+4A) \end{array}\right\}}{16(2-\beta_d)^2(\beta_d+\alpha-1)^2(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)^2}$$

while that of manufacturer and dealer is the same as those under mode DN.

(2) *With information sharing, the condition of manufacturer's online expansion is* $C \leq [\frac{\alpha {a_0}^2(1+\alpha)(\alpha+\beta_d-1)}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2} - \frac{{a_0}^2}{4(2-\beta_d)}](a02+A)$, *and that of dealer is*

$$C \leq \frac{\left\{\begin{array}{l} (2-\beta_d)^2[\beta_d^4(15\alpha^3-13\alpha^2-23\alpha+37)+4\beta_d^3(\alpha-1)(10\alpha^3 \\ -29\alpha^2+24\alpha+11)-\beta_d^5(10\alpha^2-12\alpha+10) \\ -4\beta_d^2(\alpha-1)^2(16\alpha^3+5\alpha^2-41\alpha-4) \\ -16\alpha^2(\alpha-1)^4(3\alpha-4)]+64\alpha\beta_d(1-\alpha)^3(2\alpha^2-2\alpha-1) \\ -4(1-\beta_d)(\beta_d+\alpha-1)^2(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)^2 \end{array}\right\}(a_0^2+A)}{16(2-\beta_d)^2(\beta_d+\alpha-1)2(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)^2}$$

while that of manufacturer and dealer does not exist.

Proposition 14 represents the best conditions for manufacturer and dealer to expand online. The above arguments can be verified by comparing the benefits between online expansion and traditional mode, as shown in Figure 6. Figure 6a shows that in the absence of information sharing, the lower online expansion cost encourages manufacturer to enter online, *i.e.*, $C < 0.0415$. When the expansion cost exceeds this fixed value, she will give up online expansion and choose the traditional mode. For dealer, online marketing will only be abandoned when online expansion cost is relatively high ($C < 0.106$). Figure 6b indicates that under information sharing, the smaller expansion cost will encourage manufacturer to establish online channel. However, dealer will only choose online marketing at a substantial expansion cost. Moreover, the conditions for supply chain members to jointly enter online without information sharing are the same as those for dual channel, but the opposite is true under sharing.

5.2. Partial information sharing

The basic mode assumes that the dealer shares complete information without any cost to the manufacturer. It can be found that that sharing information is unfavorable for dealer under any marketing mode. Then, we assume the dealer only shares part of information and charges the variable cost $v\mu t$. μ represents the level of information sharing, which can be regarded as the amount of information required for sharing, wherein $0 \leq \mu \leq 1$. If $\mu = 0$, there is no information sharing; $\mu \in (0, 1)$, indicating partial information sharing; $\mu = 1$ means that the information is completely shared. Taking the demand information obtained by the manufacturer as y is also an unbiased estimate of ε, satisfying $E[y|\varepsilon] = \varepsilon$. v is the compensation factor, which represents the compensation provided by the manufacturer to dealer for the unit amount of information. Considering demand forecasting function based on linear information structure, we can get the structure of information prediction by referring to Li [50] as follows:

$$E[\varepsilon|y] = \frac{\tau}{1+\tau}y \qquad E[Y|y] = \frac{\mu+\mu t}{1+\mu t}y$$

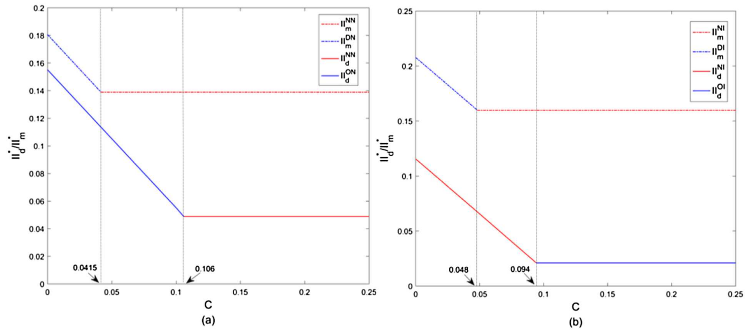

FIGURE 6. Supply chain members' preference for online expansion with respect to C.

$$E[Yy] = E[Y2] = \frac{1+t}{t}\sigma^2 \qquad E[y^2] = \frac{1+\mu t}{\mu t}\sigma^2.$$

Proposition 15. *Only under dual-channel and multi-channel can the manufacturer and dealer reach an agreement, and their profits can be increased simultaneously.*

(1) *Under dual-channel mode, the conditions of optimal information sharing strategy is*

$$\left[\frac{(\beta_d-\alpha+1)}{4} - \frac{\beta_d^3(7\alpha^2+6\alpha+1)+\beta_d^2(14\alpha^3-6\alpha^2-8\alpha)+8\alpha^2(1-\alpha)^3}{2(8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2)^2}\right]\frac{\sigma^2}{1+\mu t}$$
$$\leq v \leq \frac{\alpha\sigma^2(1+\alpha)(\alpha+\beta_d-1)}{(8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2)(1+\mu t)}.$$

(2) *Under multi-channel mode, the conditions of optimal information sharing strategy is*

$$\left\{\begin{array}{l} \dfrac{\beta_d^3-2\beta_d(\alpha_d^2-\alpha_d\alpha_m+\alpha_m^2-\alpha_d-\alpha_m+1)+2(\alpha_d-1)(\alpha_m-1)(\alpha_d-\alpha_m)}{[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]} \\ - \dfrac{\begin{array}{l} 32\alpha_m^2(\alpha_d-1)^3(3\alpha_d+\alpha_m-4)(\alpha_d-\alpha_m)^2+\beta_d^5(\alpha_d^2-8\alpha_d\alpha_m-10\alpha_m^2 \\ -6\alpha_d-8\alpha_m-1)+\beta_d^4(-\alpha_d^3+4\alpha_d^2\alpha_m-16\alpha_d\alpha_m^2-32\alpha_m{}^3-13\alpha_d^2 \\ -16\alpha_d\alpha_m+16\alpha_m^2+17\alpha_d+44\alpha_m-3)-2\beta_d^3(3\alpha_d{}^4-18\alpha_d^3\alpha_m \\ -42\alpha_d^2\alpha_m^2+32\alpha_d\alpha_m{}^3+4\alpha_m^4-2\alpha_d{}^3+22\alpha_d^2\alpha_m+100\alpha_d\alpha_m^2-40\alpha_m^3 \\ -6\alpha_d^2-38\alpha_d\alpha_m-54\alpha_m^2+6\alpha_d+34\alpha_m-1)-8\alpha_m\beta_d{}^2(29\alpha_d^3\alpha_m \\ -46\alpha_d^2\alpha_m^2+13\alpha_d\alpha_m{}^3-12\alpha_m^4-4\alpha_d{}^3-37\alpha_d^2\alpha_m+66\alpha_d\alpha_m^2+23\alpha_m{}^3 \\ +8\alpha_d^2-56\alpha_m^2-4\alpha_d+20\alpha_m)(\alpha_d-1)-32\beta_d\alpha_m^2(\alpha_d-\alpha_m)(\alpha_d-1)^2 \\ \left(2\alpha_d^2+3\alpha_d\alpha_m+3\alpha_m^2-7\alpha_d-9\alpha_m+8\right) \end{array}}{\begin{array}{c} 8(\alpha_d+\beta_d-1)[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1) \\ -8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]^2 \end{array}} \end{array}\right\}\frac{\sigma^2}{1+\mu t}$$
$$\leq v \leq \frac{\left\{\begin{array}{l} \alpha_m\sigma 2[-2\beta_d^3(\alpha_d+\alpha_m+1)+\beta_d^2(-5\alpha_d^2-2\alpha_d\alpha_m-4\alpha_m^2+6\alpha_d \\ +2\alpha_m+3)+8\beta_d(\alpha_d-1)(\alpha_d-\alpha_m^2)+4\alpha_d-12\alpha_d-\alpha_m\alpha_d+\alpha_m] \end{array}\right\}}{\left\{\begin{array}{l} 4(1+\mu t)(\alpha_d+\beta_d-1)^2[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1) \\ -8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)] \end{array}\right\}}.$$

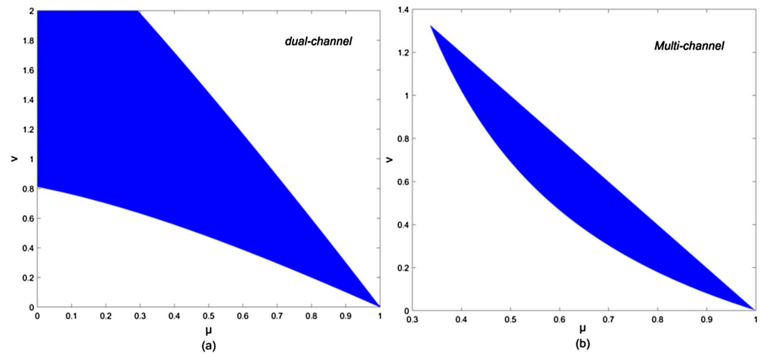

FIGURE 7. Optimal information sharing strategy with respect to v and μ.

Besides, the results under the other two modes are still robust compared with the basic mode. In the following, we illustrate the above arguments with an example analysis. The shaded part of Figure 7 shows the optimal information sharing strategy under the joint action of v and μ. On the one hand, low compensation is not enough to encourage dealer to share information. On the other hand, with the increase of information sharing level, the shadow areas gradually decrease, which means the motivation of sharing information steadily reduces.

6. Conclusion

This paper examines a medical supply chain, where the dealer predicts market demand and decides whether to share information. Dealer and manufacturer decide whether to enter online channel respectively, which can be known to the opposite side. Four sales modes with and without information sharing are developed separately: traditional sales, dual-channel, O2O and multi-channel mode. By comparing the enterprise profit and patient surplus, the equilibrium information sharing strategy and online channel expansion decision are derived.

The main findings are summarized as follows. First, wholesale and online prices are consistently lower without information sharing for each mode. Often, the manufacturer's non-invasion results in the dealer setting a higher offline price after sharing information. While it is online preference and public welfare that determine offline prices in case of manufacturer invasion. Additionally, online and offline prices are adversely affected by the social welfare level, regardless of whether or not information is shared. Second, it is intuitive that the manufacturer and dealer are inconsistent in their willingness to share information. Regardless of sales mode, the manufacturer benefits from sharing information, while the dealer differs in the sharing intentions. Especially under traditional, dual-channel and O2O modes, the dealer is more inclined to keep demand information rather than share it. Only under multi-channel mode, the dealer is motivated to share at a medium level of public welfare or extreme online preference. Third, the dealer is willing to enter an online channel for O2O or multi-channel retail. And it is inevitable that the manufacturer will expand sales online regardless of information exchange. Moreover, the expansion of online channel enhances patient shop-ping experiences and expands the potential market, ultimately increasing the patient surplus. Finally, in several cases of expansion, we have the following findings: (1) the lower online expansion cost motivates dealer to enter online marketing; (2) only under du-al-channel and multi-channel, the willingness of manufacturer and dealer to share information can be consistent under certain conditions; (3) low compensation is not enough to encourage dealer to share information.

This study is of great significance to medical enterprises that integrate social responsibility and commercial interests. Taking the medical service price reform in Xiamen (China) as an example, when the price of kidney transplantation surgery increased by 30%, the proportion of medical insurance reimbursement remained unchanged, and the burden on patients did not increase significantly. This price-adjustment strategy not only optimizes the price structure but also promotes the development of public medical institutions. Indian medical enterprises implement differential charging for patients with different incomes, achieving profitability while providing social welfare, which shows that differentiated charging achieves a win–win situation. Therefore, while pursuing commercial interests, medical enterprises should integrate social responsibility, which not only helps to enhance corporate image, but also promotes social well-being and sustainable development. Additionally, in reality, many manufacturers (*e.g.*, Johnson & Johnson, Medtronic, Philips) and dealers (*e.g.*, Rehabilitation Home, Yuyue Medical) have entered online marketing. For example, LillyDirect service platform of Eli Lilly not only improves patient convenience but may also prompt pharmaceutical enterprises to change their pricing strategies due to the reduction of intermediate links in traditional distribution. Pharmaceutical giants such as Pfizer and AbbVie have launched drug patient guidance websites and multimedia platforms, making enterprise pricing strategies more flexible and personalized. Even so, many enterprises have not yet embraced online marketing. Therefore, it is recommended that dealers carry out online sales and manufacturers expand online to intervene in traditional channels. For example, for orthopedic consumables products that cannot be sold through pharmacies, enterprises can conduct online academic and market promotion to doctors. Moreover, in view of patients' expectation of obtaining diverse channel experiences, enterprises should attach importance to the construction of multi-channels, such as purchasing some household medical products.

Although the above management insights are critical for medical enterprises to enter online, our research also has some limitations. On the one hand, online sales modes of medical industry, such as agency sales of platforms, cooperation with third-party logistics companies, have not been fully considered. Based on real cases, the future direction can be determined by identifying what kind of sales mode is suitable for different enterprises. In practice, one manufacturer may sell products through multiple dealers or multiple manufacturers *via* one dealer, which can easily expose competitors to information. Therefore, information security issues in the horizontal or vertical information sharing process can be considered in the future.

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Data availability statement

The research data associated with this article are included in the article.

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Appendix A.

TABLE A.1. Results of the mode.

	No information sharing	Information sharing
Traditional	$w^{NN}=\frac{a_0}{2}$ $p_f^{NN}=\frac{a_0(2\beta_d-3)+2E[\varepsilon Y](\beta_d-1)}{2(-2+\beta_d)}$ $E(v_d^{NN})=\frac{1}{8(2-\beta_d)}(a_0^2+4A)-F$ $E(\pi_m^{NN})=\frac{a_0^2}{4(2-\beta_d)}$ $\mathrm{CS}^{NN}=\frac{1}{8(2-\beta_d)^2}({a_0}^2+4A)$	$w^{NI}=\frac{a_0+E[\varepsilon Y]}{2}$ $p_f^{NI}=\frac{(a_0+E[\varepsilon Y])(2\beta_d-3)}{(2(-2+\beta_d))}$ $E(v_d^{NI})=\frac{1}{8(2-\beta_d)}(a_0^2+A)-F$ $E(\pi_m^{NI})=\frac{1}{4(2-\beta_d)}(a_0^2+A)$ $\mathrm{CS}^{NI}=\frac{1}{8(2-\beta_d)^2}(a_0^2+A)$
Dual-channel ($H_1=8\alpha^2+8\alpha\beta_d$ $-8\alpha+\beta_d^2<0$)	$w^{DN}=\frac{\alpha a_0(4-\beta_d)(\alpha+\beta_d-1)}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2}$ $p_o^{DN}=\frac{\alpha a_0(4\alpha+\beta_d)(\alpha+\beta_d-1)}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2}$ $p_f^{DN}=-\frac{a_0(2\alpha^3+2\alpha^2\beta_d-8\alpha^2-6\alpha\beta_d-\beta_d^2+6\alpha)}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2}+\frac{(1-\alpha)E(\varepsilon\mid Y)}{2}$ $E(v_d^{DN})=\frac{a_0^2[\beta_d^3(7\alpha^2+6\alpha+1)+\beta_d^2(14\alpha 3-6\alpha^2-8\alpha)+8\alpha^2(1-\alpha)^3]}{2(8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2)^2}+\frac{A(\beta_d-\alpha+1)}{4}-F$ $E(\pi_m^{DN})=\frac{\alpha {a_0}^2(1+\alpha)(\alpha+\beta_d-1)}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2}$ $\mathrm{CS}^{DN}=\frac{a_0^2[\beta_d^2(5\alpha^2+4\alpha+1)+\beta_d(12\alpha 3-8\alpha^2-4\alpha)+8\alpha^2(1-\alpha)^2]}{2(8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2)^2}+\frac{A}{4}$	$w^{DI}=\frac{\alpha(a_0+E(\varepsilon\mid Y)(4-\beta_d)(\alpha+\beta_d-1))}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2}$ $p_o^{DI}=\frac{\alpha(a_0+E(\varepsilon\mid Y))(4\alpha+\beta_d)(\alpha+\beta_d-1)}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2}$ $p_f^{DI}=-\frac{(a_0+E(\varepsilon\mid Y)(2\alpha^3+2\alpha^2\beta_d-8\alpha^2-6\alpha\beta_d-\beta_d^2+6\alpha))}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2}$ $E(v_d^{DI})=\frac{\beta_d^3(7\alpha^2+6\alpha+1)+\beta_d^2(14\alpha^3-6\alpha^2-8\alpha)+8\alpha^2(1-\alpha)^3}{2(8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2)^2}({a_0}^2+A)-F$ $E(\pi_m^{DI})=\frac{\alpha(1+\alpha)(\alpha+\beta_d-1)}{8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2}({a_0}^2+A)$ $\mathrm{CS}^{DI}=\frac{\beta_d^2(5\alpha^2+4\alpha+1)+\beta_d(12\alpha^3-8\alpha^2-4\alpha)+8\alpha^2(1-\alpha)^2}{2(8\alpha^2+8\alpha\beta_d-8\alpha+\beta_d^2)^2}({a_0}^2+A)$
O2O ($H_2=4\alpha^2-\beta_d^2$ $+2\alpha\beta_d-4\alpha+2\beta_d<0$)	$w^{ON}=\frac{a_0(2\alpha^2-2\alpha+\beta_d\alpha+\beta_d)}{4(\beta_d-1+\alpha)}$ $p_o^{ON}=\frac{a_0\alpha(6\alpha^2+3\beta_d\alpha-2\beta_d^2-6\alpha+3\beta_d)+2\alpha E[\varepsilon\mid Y](\beta_d-1+\alpha)(2\alpha-\beta_d)}{2(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)}$ $p_f^{ON}=\frac{\left\{\begin{matrix}a_0[4\beta_d^3+3\beta_d^2(\alpha^2-2\alpha-3)-4\beta_d(5\alpha^2-4\alpha-1)-4\alpha(\alpha+2)(\alpha-1)^2]\\+E[\varepsilon\mid Y][4\beta_d^3+\beta_d^2(1+\alpha)(4\alpha-8)+4\beta_d(\alpha-1)(\alpha^2-4\alpha-1)-8\alpha(\alpha-1)^2]\end{matrix}\right\}}{4(1-\beta_d-\alpha)(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)}$ $E(v_d^{ON})=\frac{\left\{\begin{matrix}a_0^2[\beta_d^2(5\alpha^2-6\alpha+5)+\beta_d(-4\alpha^3+8\alpha^2+4\alpha-8)\\-4\alpha(3\alpha-4)(\alpha-1)^2]+8A(\beta_d+\alpha-1)(\alpha^2\beta_d+2\alpha^2-2\alpha+\beta_d)\end{matrix}\right\}}{16(\beta_d+\alpha-1)(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)}-F$ $E(\pi_m^{ON})=\frac{{a_0}^2(2\alpha^2+\alpha\beta_d-2\alpha+\beta_d)^2}{8(\beta_d-1+\alpha)(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)}$ $\mathrm{CS}^{ON}=\frac{\left\{\begin{matrix}a_0^2[40\alpha^2(\alpha-1)^4+\beta_d^4(5\alpha^2-6\alpha+5)-2\beta_d^3(\alpha^2-1)(3\alpha-7)\\-2\beta_d^2(\alpha-1)^2(\alpha^2-26\alpha-5)+8\alpha\beta_d(\alpha-1)^3(6\alpha+5)]\\+8A(\beta_d+\alpha-1)^2[\beta_d^2(\alpha^2+1)+4\alpha\beta_d(\alpha^2-1)+4\alpha^2(\alpha-1)^2]\end{matrix}\right\}}{16(\beta_d+\alpha-1)^2(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)^2}$	$w^{OI}=\frac{(a_0+E[\varepsilon\mid Y])(2\alpha^2-2\alpha+\beta_d\alpha+\beta_d)}{4(\beta_d-1+\alpha)}$ $p_o^{OI}=\frac{\alpha(a_0+E[\varepsilon\mid Y])(6\alpha^2+3\beta_d\alpha-2\beta_d^2-6\alpha+3\beta_d)}{2(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)}$ $p_f^{OI}=\frac{(a_0+E[\varepsilon\mid Y])[-4\beta_d^3+\beta_d^2(-3\alpha^2+6\alpha+9)+4\beta_d(5\alpha^2-4\alpha-1)+4\alpha(\alpha+2)(\alpha-1)2]}{4(\beta_d+\alpha-1)(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)}$ $E(v_d^{OI})=-\frac{\left\{\begin{matrix}\beta_d^2(-5\alpha^2+6\alpha-5)+\beta_d(4\alpha^3-8\alpha^2\\-4\alpha-8)+4\alpha(3\alpha-4)(\alpha-1)^2\end{matrix}\right\}(a_0^2+A)}{16(\beta_d+\alpha-1)(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)}-F$ $E(\pi_m^{OI})=\frac{(2\alpha^2+\alpha\beta_d-2\alpha+\beta_d)^2}{8(\beta_d-1+\alpha)(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)}({a_0}^2+A)$ $\mathrm{CS}^{OI}=\frac{\left\{\begin{matrix}40\alpha^2(\alpha-1)^4+\beta_d^4(5\alpha^2-6\alpha+5)-2\beta_d^3(\alpha^2-1)(3\alpha-7)\\-2\beta_d^2(\alpha-1)^2(\alpha^2-26\alpha-5)+8\alpha\beta_d(\alpha-1)^3(6\alpha+5)\end{matrix}\right\}({a_0}^2+A)}{16(\beta_d+\alpha-1)^2(4\alpha^2-4\alpha+2\beta_d\alpha+2\beta_d-\beta_d^2)^2}$
Multi-channel ($H_3=3\beta_d^2+4\beta_d(\alpha_m-1)$ $+4(1-\alpha_d)(\alpha_d-\alpha_m)>0$; $H_4=-\beta_d^3+\beta_d^2$ $(-\alpha_d-6\alpha_m+1)$ $-8\beta_d\alpha_m(\alpha_m-1)$ $+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)<0$)	$w^{DON}=\frac{\left\{\begin{matrix}a_0\alpha_m[\beta_d^4+\beta_d^3-3\alpha_d+2\alpha_m-5+\beta_d^2(-9\alpha_d^2+12\alpha_d-8\alpha_m+5)\\+2\beta_d(\alpha_d-1)(\alpha_d^2-5\alpha_d\alpha_m+7\alpha_d-3\alpha_m)+8\alpha_d(\alpha_d-\alpha_m)(\alpha_d-1)^2]\end{matrix}\right\}}{2(\alpha_d+\beta_d-1)[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}$ $p_{om}^{DON}=\frac{\left\{\begin{matrix}a_0\alpha_m[-2\beta_d^3+\beta_d^2(-\alpha_d-8\alpha_m+3)+\beta_d(2\alpha_d^2-2\alpha_d\alpha_m\\-8\alpha_m^2-2\alpha_d+10\alpha_m)+8\alpha_m(\alpha_d-\alpha_m)(\alpha_d-1)]\end{matrix}\right\}}{2[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}$ $p_{of}^{DON}=\frac{\left\{\begin{matrix}a_0[-2\alpha_d\beta_d^3+\beta_d^2(-2\alpha_d^2-9\alpha_d\alpha_m+2\alpha_m^2+2\alpha_d+\alpha_m)+2\alpha_m\beta_d(\alpha_d^2\\-7\alpha_d\alpha_m+2\alpha_m^2+5\alpha_d-\alpha_m)+4\alpha_m(3\alpha_d-\alpha_m)(\alpha_d-1)(\alpha_d-\alpha_m)]\end{matrix}\right\}}{2[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}+\frac{(\alpha_d-\alpha_m)(\alpha_d+\beta_d-1)(2\alpha_d-2\alpha_m-\beta_d)E[\varepsilon\mid Y]}{-3\beta_d^2-4\beta_d(\alpha_m-1)+4(\alpha_d-1)(\alpha_d-\alpha_m)}$ $p_f^{DON}=\frac{\left\{\begin{matrix}a_0[-2\beta_d^4+\beta_d^3(-\alpha_d^2+2\alpha_d\alpha_m+2\alpha_m^2-2\alpha_d-10\alpha_m+3)+\beta_d^2(-\alpha_d^3-\alpha_d^2\alpha_m\\+2\alpha_d\alpha_m^2+4\alpha_m^3+\alpha_d^2-6\alpha_d\alpha_m-18\alpha_m^2+\alpha_d+19\alpha_m-1)-8\alpha_m\beta_d(\alpha_d-1)\\(\alpha_d\alpha_m-\alpha_m^2-2\alpha_d+3\alpha_m-1)+4\alpha_m(\alpha_d-\alpha_m)(\alpha_d-1)^2(\alpha_d-\alpha_m+2)\end{matrix}\right\}}{2(\alpha_d+\beta_d-1)[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}-\frac{[\beta_d^2(-\alpha_d-\alpha_m+2)+2\beta_d(2\alpha_m-\alpha_m^2-1)+2(\alpha_m-1)\alpha_d-\alpha_m\alpha_d-1]E[\varepsilon\mid Y]}{-3\beta_d^2-4\beta_d(\alpha_m-1)+4(\alpha_d-1)(\alpha_d-\alpha_m)}$ $E\left(V_d^{DON}\right)=\frac{\left\{\begin{matrix}{a_0}^2[32\alpha_m^2(\alpha_d-1)^3(3\alpha_d+\alpha_m-4)(\alpha_d-\alpha_m)^2+\beta_d^5(\alpha_d^2-8\alpha_d\alpha_m-10\alpha_m^2-6\alpha_d-8\alpha_m-1)\\+\beta_d^4(-\alpha_d^3+4\alpha_d^2\alpha_m-16\alpha_d\alpha_m^2-32{\alpha_m}^3-13\alpha_d^2-16\alpha_d\alpha_m+16\alpha_m^2+17\alpha_d+44\alpha_m-3)-\\2\beta_d^3(3{\alpha_d}^4-18\alpha_d^3\alpha_m-42\alpha_d^2\alpha_m^2+32\alpha_d{\alpha_m}^3+4\alpha_m^4-2{\alpha_d}^3+22\alpha_d^2\alpha_m+100\alpha_d\alpha_m^2\\-40{\alpha_m}^3-6\alpha_d^2-38\alpha_d\alpha_m-54\alpha_m^2+6\alpha_d+34\alpha_m-1)-8\alpha_m{\beta_d}^2(29\alpha_d^3\alpha_m-46\alpha_d^2\alpha_m^2\\+13\alpha_d{\alpha_m}^3-12\alpha_m^4-4{\alpha_d}^3-37\alpha_d^2\alpha_m+66\alpha_d\alpha_m^2+23{\alpha_m}^3+8\alpha_d^2-56\alpha_m^2-4\alpha_d+20\alpha_m)\\(\alpha_d-1)-32\beta_d\alpha_m^2(\alpha_d-\alpha_m)(\alpha_d-1)^2(2\alpha_d^2+3\alpha_d\alpha_m+3\alpha_m^2-7\alpha_d-9\alpha_m+8)\end{matrix}\right\}}{8(\alpha_d+\beta_d-1)[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]^2}+\frac{A[\beta_d^3-2\beta_d(\alpha_d^2-\alpha_d\alpha_m+\alpha_m^2-\alpha_d-\alpha_m+1)+2(\alpha_d-1)(\alpha_m-1)(\alpha_d-\alpha_m)]}{-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)}$ $E(\pi_m^{DON})=\frac{\left\{\begin{matrix}[-2\beta_d^3(\alpha_d+\alpha_m+1)+\beta_d^2(-5\alpha_d^2-2\alpha_d\alpha_m-4\alpha_m^2+6\alpha_d+2\alpha_m+3)\\+8\beta_d(\alpha_d-1)(\alpha_d-\alpha_m^2)+4\alpha_d-12\alpha_d-\alpha_m\alpha_d+\alpha_m]\alpha_m a_0^2\end{matrix}\right\}}{4(\alpha_d+\beta_d-1)^2[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}$ $\mathrm{CS}^{DON}=\frac{\left\{\begin{matrix}[\beta_d^6(3\alpha_d^2+4\alpha_d\alpha_m+6\alpha_m^2-2\alpha_d+4\alpha_m+3)+\beta_d^5(10\alpha_d^3+32\alpha_d^2\alpha_m+12\alpha_d\alpha_m^2+24\alpha_m^3\\-10\alpha_d^2-56\alpha_d\alpha_m-20\alpha_m^2+6\alpha_d+8\alpha_m-6)+\beta_d^4(15\alpha_d^4+16\alpha_d^3\alpha_m+84\alpha_d^2\alpha_m^2+56\alpha_d\alpha_m^3\\+24\alpha_m^4-24\alpha_d^3-128\alpha_d^2\alpha_m-160\alpha_d\alpha_m^2-104\alpha_m^3+6\alpha_d^2+144\alpha_d\alpha_m+100\alpha_m^2-32\alpha_m+3)\\+4\beta_d^3(\alpha_d-1)(3\alpha_d^4-17\alpha_d^3\alpha_m+22\alpha_d^2\alpha_m^2+24\alpha_d\alpha_m^3+24\alpha_m^4-5\alpha_d^3+5\alpha_d^2\alpha_m-44\alpha_d\alpha_m^2\\-72\alpha_m^3+\alpha_d^2+17\alpha_d\alpha_m+46\alpha_m^2+\alpha_d-5\alpha_m)+4\beta_d^2\alpha_d-12(\alpha_d^4-18\alpha_d^3\alpha_m-\alpha_d^2\alpha_m^2\alpha_m\\-12\alpha_d\alpha_m^3+54\alpha_m^4-2\alpha_d^3+20\alpha_d^2+30\alpha_d\alpha_m^2-96\alpha_m^3+\alpha_d^2-2\alpha_d\alpha_m+25\alpha_m^2)-16\alpha_m\beta_d\\(\alpha_d-1)^3(\alpha_d-\alpha_m)(\alpha_d^2-4\alpha_d\alpha_m+15\alpha_m^2-11\alpha_m)+96\alpha_m^2\alpha_d-14\alpha_d-\alpha_m^2]a_0^2\end{matrix}\right\}}{8\alpha_d+\beta_d-14-\beta_d^3+\beta_d^2-\alpha_d-6\alpha_m+1-8\beta_d\alpha_m\alpha_m-1+8\alpha_m\alpha_d-1\alpha_d-\alpha_m^2}+\frac{\begin{matrix}A[3\beta_d^5+8\beta_d^4(\alpha_m-1)-6\beta_d^3(\alpha_d^2-\alpha_d\alpha_m+\alpha_m^2+\alpha_d-3\alpha_m+1)\\-12\beta_d^2\alpha_d-\alpha_m(\alpha_d-1)(\alpha_m-1)+8\beta_d\alpha_d-12\alpha_d-\alpha_m^2]\end{matrix}}{2(4\alpha_d^2-4\alpha_d\alpha_m-3\beta_d^2-4\alpha_d+4\alpha_m+4\beta_d)^2}$	$w^{DOI}=\frac{\left\{\begin{matrix}\alpha_m(a_0+E[\varepsilon\mid Y])[\beta_d^4+\beta_d^3(-3\alpha_d+2\alpha_m-5)+\beta_d^2(-9\alpha_d^2+12\alpha_d-8\alpha_m+5)\\+2\beta_d(\alpha_d-1)(\alpha_d^2-5\alpha_d\alpha_m+7\alpha_d-3\alpha_m)+8\alpha_d(\alpha_d-\alpha_m)(\alpha_d-1)^2]\end{matrix}\right\}}{2(\alpha_d+\beta_d-1)[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}$ $p_{om}^{DOI}=\frac{\left\{\begin{matrix}\alpha_m(a_0+E[\varepsilon\mid Y])[-2\beta_d^3+\beta_d^2(-\alpha_d-8\alpha_m+3)+\beta_d(2\alpha_d^2\\-2\alpha_d\alpha_m-8\alpha_m^2-2\alpha_d+10\alpha_m)+8\alpha_m(\alpha_d-\alpha_m)(\alpha_d-1)]\end{matrix}\right\}}{2[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}$ $p_{of}^{DOI}=\frac{\left\{\begin{matrix}(a_0+E[\varepsilon\mid Y])[-2\alpha_d\beta_d^3+\beta_d^2(-2\alpha_d^2-9\alpha_d\alpha_m+2\alpha_m^2+2\alpha_d+\alpha_m)+2\alpha_m\beta_d\\(\alpha_d^2-7\alpha_d\alpha_m+2\alpha_m^2+5\alpha_d-\alpha_m)+4\alpha_m(3\alpha_d-\alpha_m)(\alpha_d-1)(\alpha_d-\alpha_m)]\end{matrix}\right\}}{2[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}$ $p_f^{DOI}=\frac{\left\{\begin{matrix}(a_0+E[\varepsilon\mid Y])-2\beta_d^4+\beta_d^3(-\alpha_d^2+2\alpha_d\alpha_m+2\alpha_m^2-2\alpha_d-10\alpha_m+3)+\beta_d^2(-\alpha_d^3\\-\alpha_d^2\alpha_m 2\alpha_d\alpha_m^2+4\alpha_m^3+\alpha_d^2-6\alpha_d\alpha_m-18\alpha_m^2+\alpha_d+19\alpha_m-1)-8\alpha_m\beta_d\\(\alpha_d-1)\alpha_d\alpha_m-\alpha_m^2-2\alpha_d+3\alpha_m-1+4\alpha_m\alpha_d-\alpha_m\alpha_d-12\alpha_d-\alpha_m+2\end{matrix}\right\}}{2\alpha_d+\beta_d-1[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}$ $E\left(V_d^{DOI}\right)=\frac{\left\{\begin{matrix}({a_0}^2+A)[32{\alpha_m}^2(\alpha_d-1)^3(3\alpha_d+\alpha_m-4)(\alpha_d-\alpha_m)^2+{\beta_d}^5({\alpha_d}^2-8\alpha_d\alpha_m-10{\alpha_m}^2-6\alpha_d-8\alpha_m-1)\\+{\beta_d}^4(-{\alpha_d}^3+4{\alpha_d}^2\alpha_m-16\alpha_d{\alpha_m}^2-32{\alpha_m}^3-13{\alpha_d}^2-16\alpha_d\alpha_m+16{\alpha_m}^2+17\alpha_d+44\alpha_m-3)-\\2{\beta_d}^3(3{\alpha_d}^4-18{\alpha_d}^3\alpha_m-42{\alpha_d}^2{\alpha_m}^2+32\alpha_d{\alpha_m}^3+4{\alpha_m}^4-2{\alpha_d}^3+22{\alpha_d}^2\alpha_m+100\alpha_d{\alpha_m}^2)\\-40{\alpha_m}^3-6{\alpha_d}^2-38\alpha_d\alpha_m-54{\alpha_m}^2+6\alpha_d+34\alpha_m-1)-8\alpha_m{\beta_d}^2(29{\alpha_d}^3\alpha_m-46{\alpha_d}^2{\alpha_m}^2\\+13\alpha_d{\alpha_m}^3-12{\alpha_m}^4-4{\alpha_d}^3-37{\alpha_d}^2\alpha_m+66\alpha_d{\alpha_m}^2+23{\alpha_m}^3+8{\alpha_d}^2-56{\alpha_m}^2-4\alpha_d+20\alpha_m)\\(\alpha_d-1)-32\beta_d{\alpha_m}^2(\alpha_d-\alpha_m)(\alpha_d-1)^2(2{\alpha_d}^2+3\alpha_d\alpha_m+3{\alpha_m}^2-7\alpha_d-9\alpha_m+8)\end{matrix}\right\}}{8(\alpha_d+\beta_d-1)[-{\beta_d}^3+{\beta_d}^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]^2}$ $E(\pi_m^{DOI})=\frac{\left\{\begin{matrix}\alpha_m[-2\beta_d^3(\alpha_d+\alpha_m+1)+\beta_d^2(-5\alpha_d^2-2\alpha_d\alpha_m-4\alpha_m^2+6\alpha_d+2\alpha_m+3)\\+8\beta_d(\alpha_d-1)(\alpha_d-\alpha_m^2)+4\alpha_d-12\alpha_d-\alpha_m\alpha_d+\alpha_m](a_0^2+A)\end{matrix}\right\}}{4(\alpha_d+\beta_d-1)^2[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]}$ $\mathrm{CS}^{DOI}=\frac{\left\{\begin{matrix}[\beta_d^6(3\alpha_d^2+4\alpha_d\alpha_m+6\alpha_m^2-2\alpha_d+4\alpha_m+3)+\beta_d^5(10\alpha_d^3+32\alpha_d^2\alpha_m+12\alpha_d\alpha_m^2+24\alpha_m^3\\-10\alpha_d^2-56\alpha_d\alpha_m-20\alpha_m^2+6\alpha_d+8\alpha_m-6)+\beta_d^4(15\alpha_d^4+16\alpha_d^3\alpha_m+84\alpha_d^2\alpha_m^2+56\alpha_d\alpha_m^3\\+24\alpha_m^4-24\alpha_d^3-128\alpha_d^2\alpha_m-160\alpha_d\alpha_m^2-104\alpha_m^3+6\alpha_d^2+144\alpha_d\alpha_m+100\alpha_m^2-32\alpha_m+3)\\+4\beta_d^3(\alpha_d-1)(3\alpha_d^4-17\alpha_d^3\alpha_m+22\alpha_d^2\alpha_m^2+24\alpha_d\alpha_m^3+24\alpha_m^4-5\alpha_d^3+5\alpha_d^2\alpha_m-44\alpha_d\alpha_m^2\\-72\alpha_m^3+\alpha_d^2+17\alpha_d\alpha_m+46\alpha_m^2+\alpha_d-5\alpha_m)+4\beta_d^2\alpha_d-12(\alpha_d^4-18\alpha_d^3\alpha_m-\alpha_d^2\alpha_m^2\alpha_m\\-12\alpha_d\alpha_m^3+54\alpha_m^4-2\alpha_d^3+20\alpha_d^2+30\alpha_d\alpha_m^2-96\alpha_m^3+\alpha_d^2-2\alpha_d\alpha_m+25\alpha_m^2)-16\alpha_m\beta_d\\(\alpha_d-1)^3(\alpha_d-\alpha_m)(\alpha_d^2-4\alpha_d\alpha_m+15\alpha_m^2-11\alpha_m)+96\alpha_m^2\alpha_d-14\alpha_d-\alpha_m^2](a_0^2+A)\end{matrix}\right\}}{8(\alpha_d+\beta_d-1)^4[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]^2}$

Notes. H_1-H_4 are the values of Hessian matrix when verifying the equilibrium results.

Appendix B.

Proof of Appendix A – Traditional sales mode. Firstly, taking the first and second derivatives of equation (2) with respect to d_f, we have $\frac{\mathrm{d}E(v_d|Y)}{\mathrm{d}p_f} = a - 2p_f + w - \beta_d(a - p_f)$ and $\frac{\mathrm{d}^2E(v_d|Y)}{\mathrm{d}{p_f}^2} = -2 + \beta_d < 0$. Then, we can obtain $E(v_d)$ is concave in p_f. And the optimal offline price can be solved from the first-order condition that $p_f = \frac{(a0+E[\varepsilon|Y])(\beta_d-1)-w}{-2+\beta_d}$. Then, we bring the values of p_f into equation (1), and take the first and second derivatives of equation (1) with respect to w. It can be found that $\frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}w^2} = \frac{2}{-2+\beta_d} < 0$ and $w^{NN} = \frac{a_0}{2}$. Then substituting w^{NN} into dealer's best response, ${p_f}^{NN} = \frac{a_0(2\beta_d-3)+2E[\varepsilon|Y](\beta_d-1)}{2(\beta_d-2)}$. Bringing the optimal solution into equations (1) and (2), the optimal utility and profits can be obtained. Hence, the proof is complete. Similarly, the optimal solution under NI model can be obtained. □

Proof of Appendix A – Dual-channel mode. According to the reverse logistics solution method, firstly, taking the second derivative of equation (6) with respect to p_f, we can get $\frac{\mathrm{d}^2E(v_d|Y)}{\mathrm{d}{p_f}^2} = \frac{2(\beta_d-1+\alpha)}{(1-\alpha)^2}$. If $\beta_d - 1 + \alpha < 0$, $E(v_d)$ is concave in p_f and the optimal offline price can be solved that $p_f = \frac{a(1-\alpha)}{2} - \frac{\alpha w(1-\alpha)-p_o(\alpha^2+\alpha\beta_d+\beta_d-\alpha)}{2\alpha(\alpha+\beta_d-1)}$. Then, we bring the values of p_f into equation (5), and take the first and second derivatives of equation (5) with respect to w and p_o. Then the Hessian matrix is $H = \begin{bmatrix} \frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}{p_o}^2} & \frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}p_o\mathrm{d}w} \\ \frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}w\mathrm{d}p_o} & \frac{\mathrm{d}^2E(v_m)}{\mathrm{d}w^2} \end{bmatrix} = -\frac{8\alpha^2+8\alpha\beta_d-8\alpha+{\beta_d}^2}{4\alpha^2(\alpha+\beta_d-1)^2}$. Note that if $H_1 = 8\alpha^2 + 8\alpha\beta_d - 8\alpha + {\beta_d}^2 < 0$, then $\beta_d - 1 + \alpha < 0$ and $E(\pi_m)$ is joint concave in w and p_o. We can derive that $p_o^{DN} = \frac{\alpha a_0(4\alpha+\beta_d)(\alpha+\beta_d-1)}{8\alpha^2+8\alpha\beta_d-8\alpha+{\beta_d}^2}$ and $w^{DN} = \frac{\alpha a_0(4-\beta_d)(\alpha+\beta_d-1)}{8\alpha^2+8\alpha\beta_d-8\alpha+{\beta_d}^2}$. Substituting p_o^{DN} and w^{DN} into dealer's best response, $p_f^{DN} = -\frac{a_0(2\alpha^3+2\alpha^2\beta_d-8\alpha^2-6\alpha\beta_d-{\beta_d}^2+6\alpha)}{8\alpha^2+8\alpha\beta_d-8\alpha+{\beta_d}^2} + \frac{(1-\alpha)E(\varepsilon|Y)}{2}$ can be derived. Finally, we can get the optimal utility and profits as shown in Table A.1. The proofs in model DI is omitted due to similarity. □

Proof of Appendix A – O2O mode. According to the reverse logistics solution method, firstly, taking the second derivative of equation (10) with respect to p_f and p_o, we can get $\frac{\mathrm{d}^2E(v_d|Y)}{\mathrm{d}{p_f}^2} = \frac{2(\beta_d-1+\alpha)}{(1-\alpha)^2}$ and $H = -\frac{4\alpha^2-{\beta_d}^2+2\alpha\beta_d-4\alpha+2\beta_d}{\alpha^2(\alpha-1)^2}$. If $\beta_d - 1 + \alpha < 0$ and $H_2 = 4\alpha^2 - {\beta_d}^2 + 2\alpha\beta_d - 4\alpha + 2\beta_d < 0$, the Hessian matrix of $E(v_d)$ is a negative definite for p_f and p_o. Then, we bring the values of p_f and p_o into equation (9), and take the first and second derivatives of equation (9) with respect to w. It can be found that $\frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}w^2} = \frac{4(\alpha+\beta_d-1)}{4\alpha-2\beta_d-2\alpha\beta_d+{\beta_d}^2-4\alpha^2} < 0$, and the optimal wholesale price is $w^{ON} = \frac{a_0(2\alpha^2-2\alpha+\beta_d\alpha+\beta_d)}{4(\beta_d-1+\alpha)}$. We can derive

$$p_o^{ON} = \frac{a_0\alpha(6\alpha^2 + 3\beta_\mathrm{d}\alpha - 2\beta_d^2 - 6\alpha + 3\beta_d) + 2\alpha E[\varepsilon|Y](\beta_d - 1 + \alpha)(2\alpha - \beta_d)}{2(4\alpha^2 - 4\alpha + 2\beta_\mathrm{d}\alpha + 2\beta_d - \beta_d^2)}$$

and

$$p_f^{ON} = \frac{\begin{array}{c} a_0[4\beta_d^3 + 3\beta_d^2(\alpha^2 - 2\alpha - 3) - 4\beta_d(5\alpha^2 - 4\alpha - 1) - 4\alpha(\alpha + 2)(\alpha - 1)^2] \\ + E[\varepsilon|Y][4\beta_d^3 + \beta_d^2(1 + \alpha)(4\alpha - 8) + 4\beta_d(\alpha - 1)(\alpha^2 - 4\alpha - 1) - 8\alpha(\alpha - 1)^2] \end{array}}{4(1 - \beta_d - \alpha)(4\alpha^2 - 4\alpha + 2\beta_\mathrm{d}\alpha + 2\beta_d - \beta_d^2)}.$$

Similarly, the optimal solution under OI model can be obtained. □

Proof of Appendix A – Multi-channel mode. Firstly, taking the second derivative of equation (14) with respect to p_f and p_{od}, we can get $\frac{\mathrm{d}^2E(v_d|Y)}{\mathrm{d}{p_f}^2} = \frac{2\beta_d-2(1-\alpha_d)}{(1-\alpha_d)^2}$, $H = \begin{bmatrix} \frac{\mathrm{d}^2E(v_d)}{\mathrm{d}{p_f}^2} & \frac{\mathrm{d}^2E(v_d)}{\mathrm{d}p_f\mathrm{d}p_{od}} \\ \frac{\mathrm{d}^2E(v_d)}{\mathrm{d}p_{od}\mathrm{d}p_f} & \frac{\mathrm{d}^2E(v_d)}{\mathrm{d}{p_{od}}^2} \end{bmatrix} = \frac{3{\beta_d}^2+4\beta_d(\alpha_m-1)+4(1-\alpha_d)(\alpha_d-\alpha_m)}{(\alpha_d-1)^2(\alpha_d-\alpha_m)^2}$. If $\beta_d - 1 + \alpha_d < 0$ and $H_3 = 3{\beta_d}^2 + 4\beta_d(\alpha_m - 1) + 4(1 - \alpha_d)(\alpha_d - \alpha_m) > 0$, $E(v_d)$ is a negative definite for p_f and p_{od}. Then, we bring the values of p_f and p_{od} into equation (13), and take the first and second derivatives of equation (13) with respect to w and p_{om}. It can be found that $\frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}w^2} = -\frac{4\alpha_m(\alpha_d+\beta_d-1)}{\alpha_m(-3{\beta_d}^2-4\beta_d(\alpha_m-1)+4(\alpha_d-1)(\alpha_d-\alpha_m))} < 0$ and $H = \begin{bmatrix} \frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}w^2} & \frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}w\mathrm{d}p_{om}} \\ \frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}p_{om}\mathrm{d}w} & \frac{\mathrm{d}^2E(\pi_m)}{\mathrm{d}{p_{om}}^2} \end{bmatrix} = \frac{4(\alpha_d+\beta_d-1)(-{\beta_d}^3+{\beta_d}^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m))}{{\alpha_m}^2(-3{\beta_d}^2-4\beta_d(\alpha_m-1)+4(\alpha_d-1)(\alpha_d-\alpha_m))^2}$. If $H_4 = -{\beta_d}^3 + {\beta_d}^2(-\alpha_d - 6\alpha_m + 1) - 8\beta_\mathrm{d}\alpha_m(\alpha_m - 1) + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m) < 0$, $E(\pi_m)$ is a negative definite for w and p_{om}, and the optimal solutions are

$$w = \frac{\left\{\begin{aligned} & a_0\alpha_m[\beta_d^4 + \beta_d^3(-3\alpha_d + 2\alpha_m - 5) + \beta_d^2(-9\alpha_d^2 + 12\alpha_d - 8\alpha_m + 5) \\ & + 2\beta_d(\alpha_d - 1)(\alpha_d^2 - 5\alpha_\mathrm{d}\alpha_m + 7\alpha_d - 3\alpha_m) + 8\alpha_d(\alpha_d - \alpha_m)(\alpha_d - 1)^2] \end{aligned}\right\}}{2(\alpha_d + \beta_d - 1)\left[\begin{aligned} & -\beta_d^3 + \beta_d^2(-\alpha_d - 6\alpha_m + 1) \\ & - 8\beta_\mathrm{d}\alpha_m(\alpha_m - 1) + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m) \end{aligned}\right]},$$

$$p_{om} = \frac{\left\{\begin{aligned} & a_0\alpha_m[-2\beta_d^3 + \beta_d^2(-\alpha_d - 8\alpha_m + 3) + \beta_d(2\alpha_d^2 \\ & - 2\alpha_\mathrm{d}\alpha_m - 8\alpha_m 2 - 2\alpha_d + 10\alpha_m) + 8\alpha_m(\alpha_d - \alpha_m)(\alpha_d - 1)] \end{aligned}\right\}}{2[-\beta_d^3 + \beta_d^2(-\alpha_d - 6\alpha_m + 1) - 8\beta_\mathrm{d}\alpha_m(\alpha_m - 1) + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m)]}.$$

Then, we can get

$$p_{of}^{DON} = \frac{\left\{\begin{aligned} & a_0[-2\alpha_\mathrm{d}\underline{1}eta_d^3 + \beta_d^2(-2\alpha_d^2 - 9\alpha_\mathrm{d}\alpha_m + 2\alpha_m 2 + 2\alpha_d + \alpha_m) + 2\alpha_m\beta_d(\alpha_d^2 \\ & - 7\alpha_\mathrm{d}\alpha_m + 2\alpha_m 2 + 5\alpha_d - \alpha_m) + 4\alpha_m(3\alpha_d - \alpha_m)(\alpha_d - 1)(\alpha_d - \alpha_m)] \end{aligned}\right\}}{2[-\beta_d^3 + \beta_d^2(-\alpha_d - 6\alpha_m + 1) - 8\beta_\mathrm{d}\alpha_m(\alpha_m - 1) + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m)]} + \frac{(\alpha_d - \alpha_m)(\alpha_d + \beta_d - 1)(2\alpha_d - 2\alpha_m - \beta_d)E[\varepsilon|Y]}{-3\beta_d^2 - 4\beta_d(\alpha_m - 1) + 4(\alpha_d - 1)(\alpha_d - \alpha_m)}$$

and

$$p_f^{DON} = \frac{\left\{\begin{aligned} & a_0[-2{\beta_d}^4 + {\beta_d}^3\left(-{\alpha_d}^2 + 2\alpha_\mathrm{d}\alpha_m + 2{\alpha_m}^2 - 2\alpha_d - 10\alpha_m + 3\right) + {\beta_d}^2(-{\alpha_d}^3 \\ & - {\alpha_d}^2\alpha_m + 2\alpha_d{\alpha_m}^2 + 4{\alpha_m}^3 + {\alpha_d}^2 - 6\alpha_\mathrm{d}\alpha_m - 18{\alpha_m}^2 + \alpha_d + 19\alpha_m - 1) \\ & - 8\alpha_m\beta_d(\alpha_d - 1)\left(\alpha_\mathrm{d}\alpha_m - {\alpha_m}^2 - 2\alpha_d + 3\alpha_m - 1\right) + 4\alpha_m(\alpha_d - \alpha_m)(\alpha_d - 1)^2 \\ & (\alpha_d - \alpha_m + 2) \end{aligned}\right\}}{2(\alpha_d + \beta_d - 1)\left[\begin{aligned} & -{\beta_d}^3 + {\beta_d}^2(-\alpha_d - 6\alpha_m + 1) \\ & - 8\beta_\mathrm{d}\alpha_m(\alpha_m - 1) + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m) \end{aligned}\right]} - \frac{[\beta_d^2(-\alpha_d - \alpha_m + 2) + 2\beta_d(2\alpha_m - \alpha_m^2 - 1) + 2(\alpha_m - 1)(\alpha_d - \alpha_m)(\alpha_d - 1)]E[\varepsilon|Y]}{-3\beta_d^2 - 4\beta_d(\alpha_m - 1) + 4(\alpha_d - 1)(\alpha_d - \alpha_m)}.$$

Similarly, the optimal solution under DOI model can be obtained. □

Proof of Propositions 1–3. From Table A.1, by comparing the optimal wholesale price under information sharing with that under non-sharing in each sales mode, we can get $w^{NI} - w^{NN} = \frac{E[\varepsilon|Y]}{2}$, $w^{DI} - w^{DN} = \frac{E(\varepsilon|Y)}{2}$, $w^{OI} - w^{ON} = \frac{E[\varepsilon|Y](2\alpha 2 - 2\alpha + \beta_\mathrm{d}\alpha + \beta_d)}{4(\beta_d - 1 + \alpha)}$ and $w^{DOI} - w^{DON} = \frac{\alpha E[\varepsilon|Y](2\alpha^2 + \beta_d^2 + 3\alpha\beta_d - 2\alpha - \beta_d)}{4\alpha^2 + \beta_d^2 + 6\alpha\beta_d - 4\alpha - 2\beta_d}$. According to assumptions of $H_1 = 2\alpha^2 - 2\alpha + \beta_\mathrm{d}\alpha + \beta_d < 0$ and $H_2 = 4\alpha - 2\alpha\beta_d - 2\beta_d + {\beta_d}^2 - 4\alpha^2 > 0$, we can have $w^{NN} < w^{NI}$, $w^{DN} < w^{DI}$, $w^{ON} < w^{OI}$ and $w^{DON} < w^{DOI}$. Similarly, the comparison results of offline prices (online prices) between information sharing and non-sharing in each mode can be proved. □

Proof of Proposition 4. By comparing the optimal profit of the dealer with and without information sharing in the four modes, we can obtain $E(\pi_d^{DN}) < E(\pi_d^{NN})$ and $E(\pi_d^{DI}) < E(\pi_d^{NI})$. Then, we can obtain

$$E(\pi_d^{ON}) - E(\pi_d^{NN}) = \frac{-a_0^2(2 - \beta_d)^2 L_1 + 4(\beta_d + \alpha - 1)^2[(\beta_d - 1)a_0^2 H_3^2 + 4L_2]}{16(2 - \beta_d)^2(\beta_d + \alpha - 1)^2(4\alpha^2 - 4\alpha + 2\beta_\mathrm{d}\alpha + 2\beta_d - \beta_d^2)^2},$$

$$E(\pi_d^{DON}) - E(\pi_d^{ON}) = \frac{16L_4{a_0}^2(1 - \alpha - \beta_d)^3 + L_1{a_0}^2(4\alpha^2 + {\beta_d}^2 + 6\alpha\beta_d - 4\alpha - 2\beta_d)^2}{16(\beta_d + \alpha_d - 1)^2(4\alpha^2 - 4\alpha + 2\beta_\mathrm{d}\alpha + 2\beta_d - {\beta_d}^2)^2(4\alpha^2 + {\beta_d}^2 + 6\alpha\beta_d - 4\alpha - 2\beta_d)^2},$$

$$E(\pi_d^{DON}) - E(\pi_d^{NN}) = \frac{\begin{aligned} & 4L_4a_0^2(1 - \alpha_d - \beta_d)(2 - \beta_d)^2 + (4\alpha^2 + \beta_d^2 + 6\alpha\beta_d - 4\alpha - 2\beta_d)^2 \\ & [(\beta_d - 1)a_0^2H_2^2 + 4L_3] \end{aligned}}{\begin{aligned} & 4[-\beta_d^3 + \beta_d^2(-\alpha_d - 6\alpha_m + 1) - 8\beta_\mathrm{d}\alpha_m(\alpha_m - 1) + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m)]^2 \\ & (4\alpha^2 - \beta_d^2 + 2\alpha\beta_d - 4\alpha + 2\beta_d)^2 \end{aligned}},$$

$$E(\pi_d^{OI}) - E(\pi_d^{NI}) = \frac{(a_0^2+A)[-L_1(2-\beta_d)2 + 4H_2^2(\beta_d+\alpha-1)^2(\beta_d-1)]}{16(2-\beta_d)^2(\beta_d+\alpha-1)^2(4\alpha^2-4\alpha+2\beta_\mathrm{d}\alpha+2\beta_d-\beta_d^2)^2},$$

$$E(\pi_d^{DOI}) - E(\pi_d^{OI}) = \frac{(a_0^2+A)[16L_4(1-\alpha-\beta_d)3 + L_1(4\alpha^2+\beta_d^2+6\alpha\beta_d-4\alpha-2\beta_d)^2]}{16(\beta_d+\alpha_d-1)^2(4\alpha^2-4\alpha+2\beta_\mathrm{d}\alpha+2\beta_d-\beta_d^2)^2(4\alpha^2+\beta_d^2+6\alpha\beta_d-4\alpha-2\beta_d)^2},$$

$$E(\pi_d^{DOI}) - E(\pi_d^{NI}) = \frac{(a_0^2+A)[4L_4(2-\beta_d)^2(1-\alpha_d-\beta_d) + H_2^2(\beta_d-1)(4\alpha^2+\beta_d^2+6\alpha\beta_d-4\alpha-2\beta_d)^2]}{4[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_\mathrm{d}\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]^2 \\ (4\alpha^2-\beta_d^2+2\alpha\beta_d-4\alpha+2\beta_d)^2}$$

where

$$\begin{aligned}
L_1 &= {\beta_d}^5(10\alpha^2-12\alpha+10) - {\beta_d}^4(15\alpha^3-13\alpha^2-23\alpha+37) - 4{\beta_d}^3(\alpha-1)(10\alpha^3-29\alpha^2+24\alpha+11)\\
&\quad + 4{\beta_d}^2(\alpha-1)^2(16\alpha^3+5\alpha^2-41\alpha-4) + 64\alpha\beta_d(\alpha-1)^3(2\alpha^2-2\alpha-1) + 16\alpha^2(\alpha-1)^4(3\alpha-4),\\
L_2 &= 64\alpha^4(\alpha-1)^4 + {\beta_d}^6(\alpha-1)^2 + 4{\beta_d}^5(\alpha-1)(\alpha^3-2\alpha^2+3\alpha-1) - 4{\beta_d}^4(\alpha-1)(6\alpha^3-5\alpha^2-3\alpha+1)\\
&\quad - 16\alpha^2{\beta_d}^3(\alpha-1)(\alpha^2-8\alpha+4) + 16\alpha^2{\beta_d}^2(\alpha-1)^2(9\alpha^2+4\alpha-2) + 192\alpha^4\beta_d(\alpha-1)^3,\\
L_3 &= A\alpha^2{\beta_d}^2(\alpha{\beta_d}^2-{\beta_d}^3+4\alpha^2+2{\beta_d}^2-4\alpha),\\
L_4 &= {\beta_d}^3 - 2\beta_d\left({\alpha_d}^2-\alpha_\mathrm{d}\alpha_m+{\alpha_m}^2-\alpha_d-\alpha_m+1\right) + 2(\alpha_d-1)(\alpha_m-1)(\alpha_d-\alpha_m).
\end{aligned}$$

Suppose that

$$\begin{aligned}
\psi_1(\alpha,\beta_d) &= -{a_0}^2(2-\beta_d)^2L_1 + 4(\beta_d+\alpha-1)^2[(\beta_d-1){a_0}^2{H_2}^2+4L_2],\\
\psi_2(\alpha,\beta_d) &= 16L_4(1-\alpha-\beta_d)^3 + L_1(4\alpha^2+{\beta_d}^2+6\alpha\beta_d-4\alpha-2\beta_d)^2,\\
\psi_3(\alpha,\beta_d) &= 4L_4{a_0}^2(1-\alpha-\beta_d)(2-\beta_d)^2 + (4\alpha^2+{\beta_d}^2+6\alpha\beta_d-4\alpha-2\beta_d)^2[(\beta_d-1){a_0}^2{H_3}^2+4L_3],\\
\psi_4(\alpha,\beta_d) &= -L_1(2-\beta_d)^2 + 4{H_3}^2(\beta_d+\alpha-1)^2(\beta_d-1),\\
\psi_5(\alpha,\beta_d) &= 4L_4(2-\beta_d)^2(1-\alpha_d-\beta_d) + {H_2}^2(\beta_d-1)(4\alpha^2+{\beta_d}^2+6\alpha\beta_d-4\alpha-2\beta_d)^2.
\end{aligned}$$

Obviously, without information sharing, $E(\pi_d^{ON}) > E(\pi_d^{NN})$ and $E(\pi_d^{DON}) < E(\pi_d^{ON})$ if $\psi_1(\alpha,\beta_d) > 0$ and $\psi_2(\alpha,\beta_d) < 0$, *i.e.*, ON is the best mode. $E(\pi_d^{DON}) > E(\pi_d^{ON})$ and $E(\pi_d^{DON}) > E(\pi_d^{NN})$ if $\psi_2(\alpha,\beta_d) > 0$ and $\psi_3(\alpha,\beta_d) > 0$, *i.e.*, DON is the optimal mode. Similarly, the dealer prefers OI if $\psi_2(\alpha,\beta_d) < 0$ and $\psi_4(\alpha,\beta_d) > 0$, and DOI if $\psi_2(\alpha,\beta_d) > 0$ and $\psi_5(\alpha,\beta_d) > 0$. We can easily prove the above results with the software Maple. □

Proof of Proposition 5. Similar to the proof of Proposition 4, by comparing the optimal profit of the manufacturer with and without information sharing in the four modes, we can obtain $E\left(\pi_m^{DN}\right) > E\left(\pi_m^{NN}\right) > E\left(\pi_m^{DON}\right) > E(\pi_m^{ON})$ and $E(\pi_m^{DI}) > E(\pi_m^{NI}) > E(\pi_m^{DOI}) > E(\pi_m^{OI})$. We get that the manufacturer prefers dual-channel mode. □

Proof of Proposition 6. Similar to the proof of Proposition 4, by comparing the optimal profit of the supply chain with and without information sharing, we can obtain $E(\pi_{sc}^{DON}) > E(\pi_{sc}^{ON})$ and $E(\pi_{sc}^{DOI}) > E(\pi_{sc}^{OI})$. Hence, we only need to compare the profits of the three sales modes (*i.e.*, traditional sales mode, dual-channel mode, multi-channel mode), and we can get

$$E(\pi_{sc}^{DON}) - E(\pi_{sc}^{NN}) = \frac{4L_4a_0^2(2-\beta_d)^2(\alpha+\beta_d-1) + (4\alpha^2+\beta_d^2+6\alpha\beta_d-4\alpha-2\beta_d)^2[a_0^2H_2^2(2\beta_d-3)+4L_3]}{4[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_\mathrm{d}\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]^2 \\ (4\alpha^2-\beta_d^2+2\alpha\beta_d-4\alpha+2\beta_d)^2},$$

$$E(\pi_{sc}^{DN}) - E(\pi_{sc}^{NN}) = \frac{4L_4\alpha{a_0}^2(2-\beta_d)^2 + {a_0}^2(2\beta_d-3) - A(\alpha{\beta_d}^2-4\alpha\beta_d-{\beta_d}^2+4\alpha)}{4(2-\beta_d)^2(\alpha-2+\beta_d)^2 \\ \left[-{\beta_d}^3+{\beta_d}^2(-\alpha_d-6\alpha_m+1)-8\beta_\mathrm{d}\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)\right]^2},$$

$$E(\pi_{sc}^{DI}) - E(\pi_{sc}^{NI}) = \frac{(a_0^2+A)[4L_4\alpha(2-\beta_d)^2+(2\beta_d-3)H_1^2]}{4(2-\beta_d)^2(\alpha-2+\beta_d)^2 \\ [-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_\mathrm{d}\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]^2},$$

$$E(\pi_{sc}^{DOI}) - E(\pi_{sc}^{NI}) = \frac{(a_0^2 + A)[4L_4(2-\beta_d)^2(\alpha+\beta_d-1) + H_2^2(2\beta_d-3)(4\alpha^2+\beta_d^2+6\alpha\beta_d-4\alpha-2\beta_d)^2]}{4[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]^2 (4\alpha^2-\beta_d^2+2\alpha\beta_d-4\alpha+2\beta_d)^2}.$$

Suppose that

$$\Psi_1(\alpha,\beta_d) = 4L_5{a_0}^2(2-\beta_d)^2(\alpha+\beta_d-1) + (4\alpha^2+{\beta_d}^2+6\alpha\beta_d-4\alpha-2\beta_d)^2[{a_0}^2{H_2}^2(2\beta_d-3)+4L_3],$$
$$\Psi_2(\alpha,\beta_d) = 4L_4\alpha{a_0}^2(2-\beta_d)^2 + {a_0}^2(2\beta_d-3) - A(\alpha{\beta_d}^2-4\alpha\beta_d-{\beta_d}^2+4\alpha),$$
$$\Psi_3(\alpha,\beta_d) = 4L_4\alpha(2-\beta_d)^2 + (2\beta_d-3){H_1}^2,$$
$$\Psi_4(\alpha,\beta_d) = 4L_5(2-\beta_d)^2(\alpha+\beta_d-1) + {H_2}^2(2\beta_d-3)(4\alpha^2+{\beta_d}^2+6\alpha\beta_d-4\alpha-2\beta_d)^2.$$

We can derive that under information non-sharing, DON is the optimal mode if $\Psi_1(\alpha,\beta_d) > 0$ and $\Psi_2(\alpha,\beta_d) < 0$, and DN if $\Psi_1(\alpha,\beta_d) < 0$ and $\Psi_2(\alpha,\beta_d) > 0$. And under information sharing, DOI if $\Psi_3(\alpha,\beta_d) < 0$ and $\Psi_4(\alpha,\beta_d) > 0$, and DI if $\Psi_3(\alpha,\beta_d) > 0$ and $\Psi_4(\alpha,\beta_d) < 0$. □

Proof of Proposition 7. Similar to the proof of Proposition 4, by comparing the patient surplus with and without information sharing, we can get the result consistent with Proposition 8. That is, in the case of $H_1 = 2\alpha^2 - 2\alpha + \beta_d\alpha + \beta_d < 0$, we have $\mathrm{CS}^{ON} > \mathrm{CS}^{NN}$, $\mathrm{CS}^{ON} > \mathrm{CS}^{DN}$, $\mathrm{CS}^{ON} > \mathrm{CS}^{DON}$ and $\mathrm{CS}^{OI} > \mathrm{CS}^{NI}$, $\mathrm{CS}^{OI} > \mathrm{CS}^{DI}$, $\mathrm{CS}^{OI} > \mathrm{CS}^{DOI}$. In the case of $H_2 = -{\beta_d}^3 + {\beta_d}^2(-\alpha_d - 6\alpha_m + 1) - 8\beta_d\alpha_m(\alpha_m - 1) + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m) > 0$, $\mathrm{CS}^{DON} > \mathrm{CS}^{NN}$, $\mathrm{CS}^{DON} > \mathrm{CS}^{DN}$, $\mathrm{CS}^{DOI} > \mathrm{CS}^{NI}$, $\mathrm{CS}^{DOI} > \mathrm{CS}^{DI}$. In addition, in the case of $H_1 = 2\alpha^2 - 2\alpha + \beta_d\alpha + \beta_d > 0$ and $H_2 = -{\beta_d}^3 + {\beta_d}^2(-\alpha_d - 6\alpha_m + 1) - 8\beta_d\alpha_m(\alpha_m - 1) + 8\alpha_m(\alpha_d - 1)(\alpha_d - \alpha_m) < 0$, we get $\mathrm{CS}^{DN} > \mathrm{CS}^{NN}$ and $\mathrm{CS}^{DI} > \mathrm{CS}^{NI}$. Hence, the proof is complete. □

Proof of Propositions 8 and 9. As can be seen from the game matrix in Table 3, if D is an equilibrium strategy, then $II_m^D > II_m^N$ and $II_d^D > II_d^{DO}$. Combined with Proposition 10, we can get $E(\pi_m^{DN}) > E(\pi_m^{NN})$ and $E(\pi_m^{DI}) > E(\pi_m^{NI})$. Then, by comparing the optimal profit of dealer under dual-channel and multi-channel modes, we can obtain

$$E(\pi_d^{DON}) - E(\pi_d^{DN}) = \frac{2{a_0}^2(1-\alpha-\beta_d)L_4 - 2(L_5+\alpha{a_0}^2L_6{H_2}^2)(4\alpha^2+{\beta_d}^2+6\alpha\beta_d-4\alpha-2\beta_d)^2}{2(4\alpha^2+{\beta_d}^2+6\alpha\beta_d-4\alpha-2\beta_d)^2\left[-{\beta_d}^3+{\beta_d}^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)\right]^2},$$

$$E(\pi_d^{DOI}) - E(\pi_d^{DI}) = \frac{(a_0^2+A)[L_4(1-\alpha-\beta_d) - \alpha H_2^2L_5(4\alpha^2+\beta_d^2+6\alpha\beta_d-4\alpha-2\beta_d)^2]}{(4\alpha^2+\beta_d^2+6\alpha\beta_d-4\alpha-2\beta_d)^2[-\beta_d^3+\beta_d^2(-\alpha_d-6\alpha_m+1)-8\beta_d\alpha_m(\alpha_m-1)+8\alpha_m(\alpha_d-1)(\alpha_d-\alpha_m)]^2},$$

where $L_5 = A[-{\beta_d}^3(\alpha^2+1) + {\beta_d}^2(\alpha^3-2\alpha^2+4\alpha+1) + 4\alpha\beta_d(\alpha^2-1) + 4\alpha^2(\alpha-1)^2]$, $L_6 = (2\alpha+\beta_d-2)[{\beta_d}^2(\alpha+1) + \beta_d(\alpha-\alpha^2) - 2\alpha(1-\alpha)^2]$. Suppose that $\Psi_1(\alpha,\beta_d) = 2{a_0}^2(1-\alpha-\beta_d)L_4 - 2(L_5+\alpha{a_0}^2L_6{H_2}^2)(4\alpha^2+{\beta_d}^2+6\alpha\beta_d-4\alpha-2\beta_d)^2$, $\Psi_2(\alpha,\beta_d) = L_4(1-\alpha-\beta_d) - \alpha{H_2}^2L_5(4\alpha^2+{\beta_d}^2+6\alpha\beta_d-4\alpha-2\beta_d)^2$. When $\Psi_1(\alpha,\beta_d) > 0(\Psi_2(\alpha,\beta_d) > 0)$, we can derive that $E(\pi_d^{DON}) > E(\pi_d^{DN})(E(\pi_d^{DOI}) > E(\pi_d^{DI}))$, where the assumption holds, *i.e.*, D is the equilibrium strategy. Moreover, we can easily use the software Maple to get $w^{DO} < w^D$, ${p_o}^{DO} < {p_o}^D$, ${p_f}^{DO} < {p_f}^D$ in the region $\Psi_1(\alpha,\beta_d) > 0(\Psi_2(\alpha,\beta_d) > 0)$, and $w^{DO} > w^D, {p_o}^{DO} > {p_o}^D$, ${p_f}^{DO} > {p_f}^D$ otherwise. Similarly, it can be proved that N, O and DO are equilibrium strategies. Finally, combining with Proposition 6, the win–win region in Proposition 9 can be easily obtained. □

Proof of Propositions 10–13. Based on the optimal profits as shown in Table A.1, we get $V_d^N = E(\pi_d^{NI}) - E(\pi_d^{NN}) = -\frac{1-\beta_d}{4(2-\beta_d)^2}\frac{3t}{1+t}\sigma^2 - F$, $V_m^N = E(\pi_m^{NI}) - E(\pi_m^{NN}) = \frac{1}{4(2-\beta_d)}\frac{t\sigma^2}{1+t}$ and $V_{sc}^N = E(\pi_{sc}^{NI}) - E(\pi_{sc}^{NN}) = \frac{2\beta_d-1}{4(2-\beta_d)^2}\frac{t}{1+t}\sigma^2 - F$. With $\beta_d < 1$, we get $V_{vd}^N < 0$, $V_d^N < 0$ and $V_m^N > 0$. Let $\tilde{F}_1(\beta_d) = \frac{2\beta_d-1}{4(2-\beta_d)^2}\frac{t}{1+t}\sigma^2$, if $F < \tilde{F}_1(\beta_d)$, $V_{sc}^N > 0$ and $V_{sc}^N < 0$ otherwise. Regarding the impact of information accuracy t, we have $\frac{\mathrm{d}V_d^N}{\mathrm{d}t} = -\frac{3\sigma^2(1-\beta_d)}{4(2-\beta_d)^2(1+t)^2}$, $\frac{\mathrm{d}V_m^N}{\mathrm{d}t} = \frac{\sigma^2}{4(2-\beta_d)(1+t)^2}$ and $\frac{\mathrm{d}V_{sc}^N}{\mathrm{d}t} = \frac{\sigma^2(2\beta_d-1)}{4(2-\beta_d)^2(1+t)^2}$. With restrictive conditions, we have $\frac{\mathrm{d}V_d^N}{\mathrm{d}t} < 0$ and $\frac{\mathrm{d}V_m^N}{\mathrm{d}t} > 0$. And if $\tilde{F}_1(\beta_d) > 0$, $\frac{\mathrm{d}V_{sc}^N}{\mathrm{d}t} > 0$ and $\frac{\mathrm{d}V_{sc}^N}{\mathrm{d}t} < 0$ otherwise. Similarly, the proof of information value analysis under the other three modes (*i.e.*, dual-channel mode, O2O mode, multi-channel mode) can also be obtained. □