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Enhancing the Efficacy of Pharmaceutical E-Commerce Through Omni-Channel Coordination

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ABSTRACT

In the current era of e-commerce, the pharmaceutical industry has not experienced the same level of growth as regular commodities due to the high costs associated with home delivery and the perceived risks associated with purchasing drugs online. This paper proposes an omni-channel strategy to address these challenges, involving an "order online, home-delivery offline" approach between e-pharmacies and drugstores, with telemedicine serving as a coordination mechanism between e-pharmacies and hospital doctors. The proposed strategy achieves a seamless patient experience during online diagnosis. To analyze its feasibility, the paper employs optimization techniques to compare the profits of supply chain members in both omni-channel and non-omni-channel scenarios. The results demonstrate that the proposed strategy is both practical and efficient, boosting patients' trust in e-commerce and improving the profitability of the pharmaceutical industry.

KEYWORDS

Home-Delivery, Imbalanced, Omni-Channel Coordination Strategy, Pharmaceutical E-Commerce, Three-Channel

INTRODUCTION

The pharmaceutical e-commerce market in China has grown significantly with the development of mature enterprises and advanced network technologies. The market growth rate of B2C pharmaceutical e-commerce has consistently remained at over 20% annually. In 2020, China's medical e-commerce has been thriving, with a total transaction value of 28 billion dollars (Zhang, 2023). However, despite the rapid growth in sales volume, the profit margin of pharmaceutical e-commerce enterprises remains poor. The largest Chinese web portal, Sina, reported that Dingdang Express, one of China's top five pharmaceutical e-commerce enterprises, had incurred a cumulative book loss of 400 million dollars over the past 3 years and did not foresee any imminent profit turnaround. Similarly, AliHealth, another pharmaceutical e-commerce giant, reported a loss of over 30 million dollars in fiscal year 2022.

The development of pharmaceutical e-commerce is impeded by primary bottlenecks, including high home-delivery costs and low safety of purchasing drugs online. Firstly, patients expect to receive drugs immediately after placing an online order to alleviate symptoms, necessitating e-pharmaceuticals

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to provide prompt home-delivery services. Consequently, pharmaceutical e-commerce has been compressing delivery time, with some platforms, such as Dingdang Express, guaranteeing 28-minute delivery in urban areas. However, this requires the establishment of warehouses in every corner of each city and a considerable number of couriers, resulting in high drug delivery costs. Secondly, the customer service staff of pharmaceutical e-commerce platforms are not necessarily professional physicians or pharmacists but rather sales personnel with limited knowledge of drug products. This knowledge gap poses potential safety risks for patients when purchasing drugs online, resulting in a weak customer reliance on pharmaceutical e-commerce channels.

To address the high delivery costs and safety concerns associated with pharmaceutical e-commerce, an omni-channel business model has been implemented to provide consumers with a seamless shopping experience through all available channels (Brynjolfsson, 2013). Specifically, the coordination strategy that covers the entire patient journey from outpatient clinic visits to medication home-delivery is designed as follows: (1) a telemedicine platform connecting patients with a remote doctor in a hospital is launched by the e-pharmacy to improve the safety of purchasing drugs online and increase demand in the e-pharmacy channel. However, in cases where examination equipment is unavailable at home or the illness is severe, online doctors may be unable to make a diagnosis, and patients are advised to visit a hospital; and (2) An "order online, home-delivery offline" strategy involves transferring online orders to offline drugstores for home-delivery, with the e-pharmacy paying a service subsidy or fee to the offline drugstore.

In summary, the omni-channel scenario designed in this article includes coordination: the coordination between the e-pharmacy and drugstore and the coordination between the e-pharmacy and hospital. To achieve the omni-channel coordination strategy, the value ranges of the service fee and referral rate need to be determined.

This paper employs optimization techniques to conduct a comprehensive analysis of the viability of the coordination strategy under the omni-channel approach, including a comparison of the profits of supply chain members in both omni-channel and nonomni-channel (multichannel) scenarios. The primary motivation for this research is to examine the impact of omni-channel practices on the pharmaceutical supply chain and provide valuable insights for e-platforms and drugstores seeking to adapt to evolving market dynamics.

The remainder of the paper is organized as follows. The Literature Review reviews the relevant literature. Models and Assumptions presents the game-theoretical model for a multichannel scenario and omni-channel scenario, respectively, and then derives analytical optimal profits. Numerical Studies reports numerical experiments to examine the effects of the coordination mechanism and discusses the impacts of the coordination on the shareholders' profits and the retail prices of the drugs. Practical and Managerial Implications discusses the managerial implications. Conclusion draws a conclusion and makes suggestions for future research.

LITERATURE REVIEW

This paper presents an omni-channel strategy for the pharmaceutical supply chain under an e-commerce environment, and two research areas closely related to our model are reviewed. Firstly, we analyze existing literature on pharmaceutical e-commerce, followed by a review of the literature on omni-channel supply chains.

Pharmaceutical E-Commerce

Pharmaceutical e-commerce has experienced rapid development in recent years, yet there has been limited research on the pharmaceutical e-commerce market from the perspective of the supply chain. Li et al. (2019) studied the decision-making process behind the subsidy strategy used by pharmaceutical e-commerce platforms to optimize their profits and achieve sustainable development goals. Wang et al. (2015) analyzed the pricing model and influential factors of drug trade service platforms based on the two-sided market theory and discussed pricing issues in both monopoly and competition scenarios. Wu et al. (2023) investigated the impact of logistics service encounters on customer satisfaction in the context of pharmaceutical e-commerce using a structural equation model. Zhang et al. (2022) constructed an evolutionary game model for the dual-channel supply chain, analyzing the impact of stakeholder strategic choices on drug quality in different distribution channels. Luo et al. (2022) explored the impacts of different attributes of online additional reviews on the sales volume of cross-border pharmaceutical platforms and the moderating role of country-of-origin. Liu et al. (2021) proposed a prudent and iterative native Bayesian algorithm for disease prediction in telemedicine environments. Srivastava et al. (2018) discussed the creation of targeted proposals to understand customer needs in e-drug sales, the formation of strategies for working with clusters, and the development of partnerships for revenue. Chen (2018) suggested that online pharmacies enhance corporate self-discipline and establish third-party logistics to improve pharmaceutical care quality.

The aforementioned literature predominantly relies on either a single-channel or dual-channel pharmaceutical supply chain model, which fails to capture the complexities of the Chinese pharmaceutical retail market, where three distinct channels, namely, hospitals, drugstores, and e-pharmacies, hold differing market positions. Notably, hospitals, which are public institutions under government administration, possess a dominant market position. In light of this, this article posits a more realistic three-channel model that better reflects the current realities of the drug retail market. However, the inclusion of further imbalanced channels presents considerable difficulties in terms of optimizing value.

Omni-Channel Supply Chain

The research on omni-channel coordination in the supply chain has yielded fruitful results. Some of the studies have applied an online-to-offline (O2O) coordination strategy on the sales side to stimulate consumer purchases. For instance, Wang et al. (2023) conducted a study on a manufacturer supplying products to two rival retailers, exploring channel payoffs under four different scenarios with social media advertising. Liu et al. (2020) demonstrated the benefits of display showroom mode for the manufacturer, retailer, and entire omni-channel supply chain. Zhang et al. (2020) developed a theoretical model to investigate consumer intershowrooming behavior and information service provision in an omni-channel supply chain. Yu et al. (2019) introduced reference dependence to examine the fairness utility functions of channel members under an O2O business model and analyzed coordination solutions. Lee et al. (2019) and Li et al. (2019) addressed competition and coordination between physical books and ebooks. Liao et al. (2019) designed revenue-sharing contracts for hotels and online travel agencies under the merchant and agency models, respectively. He et al. (2020) examined the effects of implementing a store return option on the retailer under omnichannel retailing. Kort et al. (2020) discussed revenue-sharing contracts in a dual-channel digital-product supply chain. Kim et al. (2018) analyzed retailing channel and pricing strategies, considering intracannibalization and intercompetition effects in a dual-channel supply chain.

On the other hand, there are also studies that focus on product delivery. Xu et al. (2018) built an O2O model with an online subsidy service and analyzed the impact of demand disruption on supply chain performance. Gao et al. (2016) developed a model with a retailer operating in both online and offline channels and examined the impact of the "buy online, pick up in-store" strategy on retailer operations. Finally, Jiang et al. (2020) studied the interaction between a stronger retailer and a manufacturer's strategy on pricing and service value based on the "buy online, pick up in-store" strategy.

The existing literature on an omni-channel supply chain primarily concentrates on sales- or delivery-related issues; however, this article takes a comprehensive approach that considers the entire process of medical treatment for patients, including telemedicine and medication home-delivery services. This approach is used to develop omni-channel strategies that provide patients with end-to-end medical experiences. In pursuit of this objective, a novel three-channel omni-channel model is proposed, which extends previous research on this topic and offers practical solutions to the challenges faced by e-commerce enterprises.

MODELS AND ASSUMPTIONS

This section presents two unique three-channel supply chain models, each comprising three distinct channels: drugstore, e-pharmacy, and hospital. These channels offer patients distinct attributes, as outlined in Table 1. Patients have the flexibility to choose from among these channels based on their individual preferences for purchasing medications.

From the perspective of patients, a drugstore, e-pharmacy, and hospital are all considered pharmaceutical retailers that purchase medications from wholesalers and sell them to patients. The model depicted on the left illustrates the current state of the pharmaceutical market, wherein channels operate independently and compete with each other. We refer to this model as the multichannel supply chain model (see Figure 1). In contrast, the model on the right-hand side represents the omni-channel supply chain, with an e-commerce platform at its center, connecting hospitals and physicians to provide patients with telemedicine and connecting offline drugstores to provide pharmaceutical home-delivery services to patients (see Figure 2). The emphasis should be placed on informing patients of the utmost confidentiality of their personal information when they opt for telemedicine services. This approach plays a crucial role in bolstering trust in this particular channel. Therefore, this article assumes that the e-commerce platform complies with legal regulations and can be deemed trustworthy. The following will explain the models from three aspects: wholesale prices, retail prices, and drug types.

Wholesale Prices

Considering the different market positions of retailers, we make the following assumptions: (1) Due to the centralized purchasing of drugs by large domestic comprehensive hospitals through joint procurement, hospitals have an absolute market dominance in wholesale pricing. Therefore, we assume that the wholesale price of the hospital, denoted as w, is determined by the production cost of drugs, which is an exogenous variable. (2) Given the nationwide coverage and high demand of pharmaceutical e-commerce platforms, it also possesses significant bargaining power in the drug wholesale market. Thus, we set the wholesale price of the e-pharmacy to be w as well. (3) In contrast, an individual drugstore has limited coverage areas and demands, resulting in weaker bargaining power in the drug wholesale market. Therefore, we assume that the wholesale price of the drugstore is assumed as $w + \Delta w$, where Δw is determined by the pharmaceutical manufacturer.

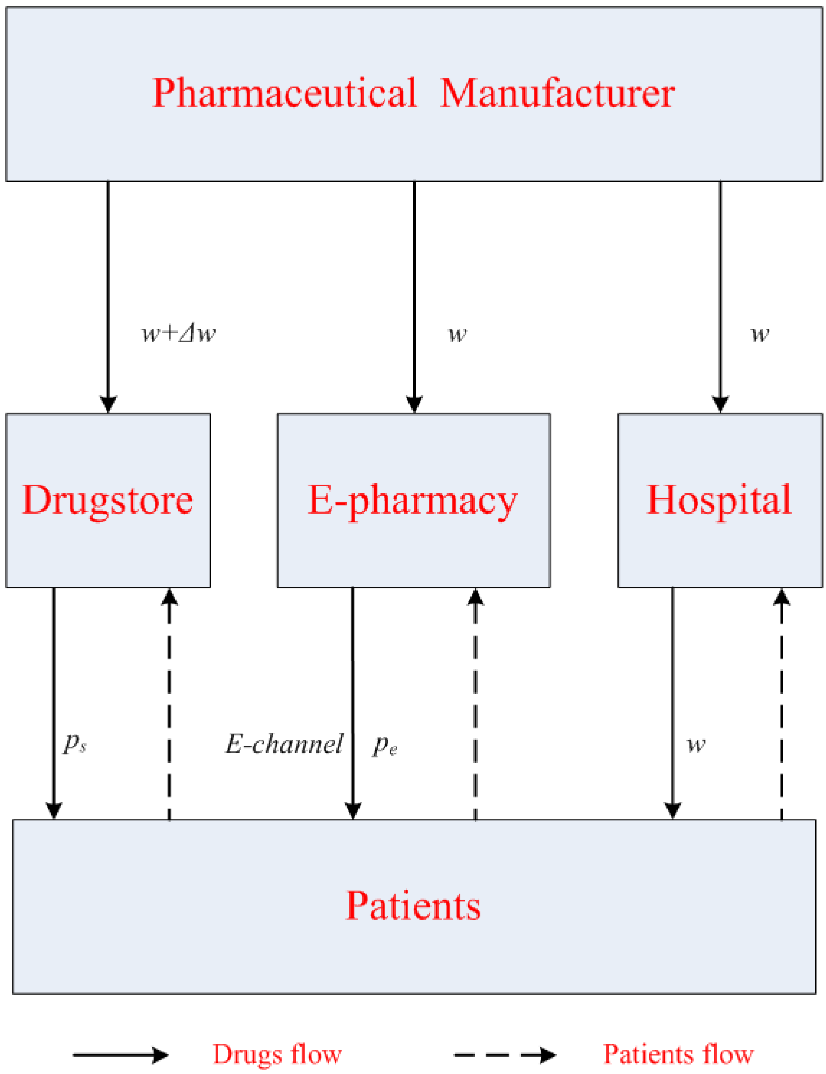
Retail Prices

The public hospital is required to sell drugs at the wholesale price w, as the Chinese government mandated that all urban public hospitals eliminate drug markups by September 2017 (Tang, 2018). Conversely, drugstores and e-pharmacies set their own retail prices, denoted as p_s and p_e, respectively, to maximize their profits.

Table 1. Comparison of channels

	Purchase Methods	Pickup Methods	Medication Safety
Drugstore	Offline	Go to the site	Self-medication
E-pharmacy	Online	Wait at home	Self-medication
Hospital	Offline	Go to the site	Doctor guidance

Figure 1. Multichannel supply chain model

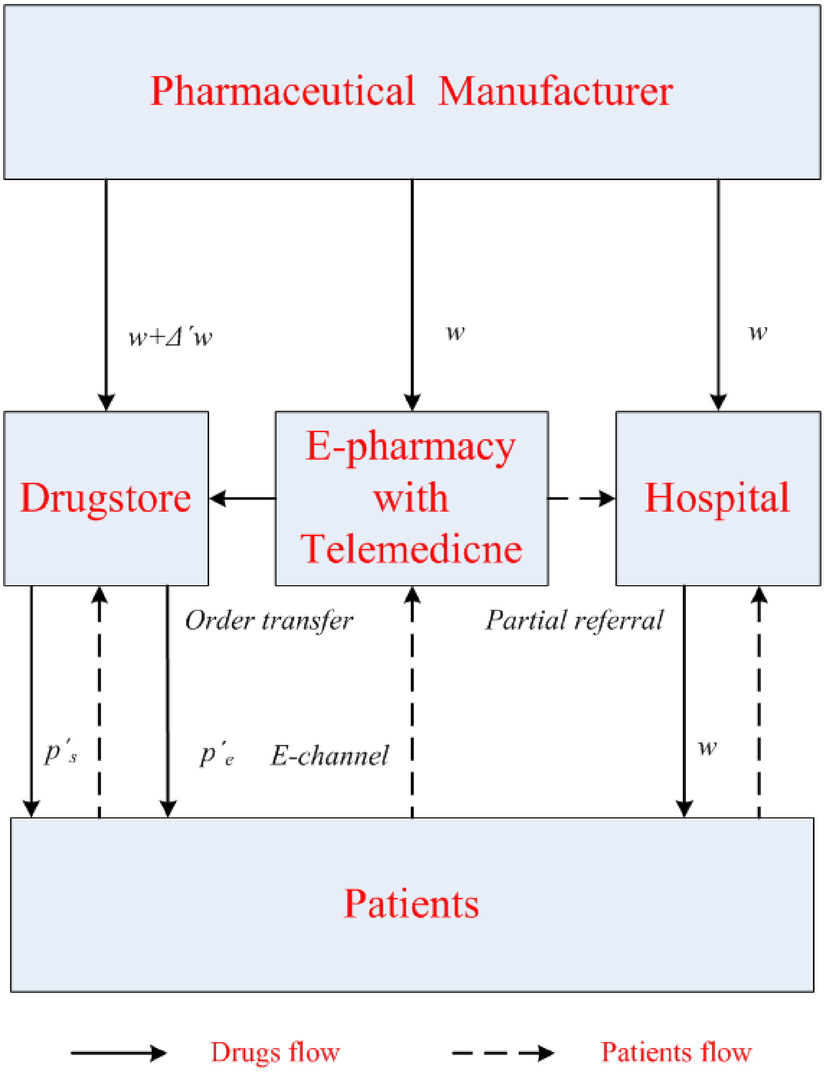


Drug Types

Patients can only purchase over-the-counter (OTC) drugs when buying medication at drugstores or e-pharmacies, which falls under self-medication. However, there are no restrictions on the types of drugs that can be purchased at hospitals. To maintain consistency in the products across the three channels, we assume that the drugs involved in this study are OTC drugs. This model is also applicable if the patient already has a prescription and is only choosing the channel through which to purchase the medication.

When constructing the mathematical model for the three-channel supply chain, we have made the following three assumptions: (1) Stable patient population. The number of patients remains stable every year, that is, the total demand for drugs from the patients remains unchanged. (2) Uniform patient distribution. The patients are evenly distributed throughout the city. (3) Impact of purchasing distance. The distance between the patient and the purchase point is assumed to influence the patient's purchasing experience, which can influence their choice of supply chain channel. Based on these

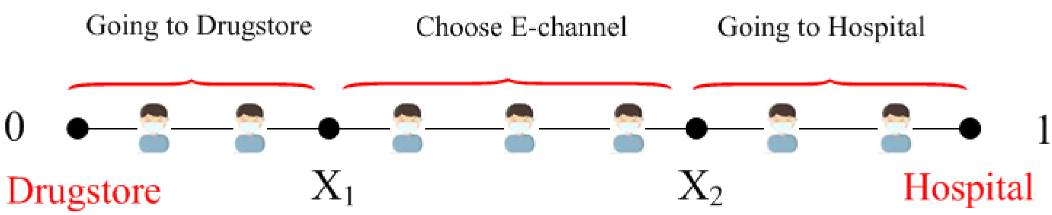
Figure 2. Omni-channel supply chain model



assumptions, we use the Hotelling model to build the models. In keeping with previous research (Larralde, 2009; Chen, 2019; Zhang, 2019; Tao, 2020), we use the Hotelling model to describe the competitive relationship between the online and offline channels. As illustrated in Figure 3, The drugstore is positioned at the initial point $x = 1$, while the hospital is situated at the terminal point $x = 0$. The patients are uniformly distributed along this interval. Each patient selects the channel that maximizes their utility for drug procurement.

In the construction of the patient utility function, three components are considered: pharmaceutical utility, distance, and expenses. Firstly, the pharmaceutical utility V is an essential component, as it ensures that the patient purchases at least one drug. Due to the lack of medical professionals, the pharmaceutical utility in drugstores and e-pharmacies is discounted as $\lambda V \left(0 < \lambda < 1\right)$, where λ denotes the effectiveness of the drugstore and e-pharmacy channels, also known as the safety of self-medication. Secondly, we assume that the generated negative utility is linearly related to the distance, as longer distances result in greater negative effects. The distance coefficient is set as a,

Figure 3. Hotelling model



which determines the extent of the negative effect. Thirdly, the expenses component comprises the sum of the retail prices of drugs and the registration fee o_h for a doctor's consultation.

By summing up the three components mentioned above, we can obtain the utility values for each channel for patients. After each patient makes their choice, the market share for each channel can be calculated accordingly. Then, using the market share model and the patient utility function of each channel, we calculate the optimal prices and maximum profits of shareholders in both the multichannel and omni-channel models. By comparing the optimal results, we can establish the decision-making conditions for omni-channel coordination.

Multichannel Supply Chain

As depicted in Figure 1, the channels operate independently of each other under the multichannel scenario. Considering pharmaceutical utility, distance, and expenses in each channel, the patient utilities for the three channels are denoted as $\lambda V - ax - p_s$, $\lambda V - p_e$, and $V - a(1-x) - w - o_h$, respectively. Thus, the patient's decision expression is determined by:

$$Max[\lambda V - ax - p_s, \lambda V - p_e, V - a(1-x) - w - o_h] \quad (1)$$

By identifying the points where patient utility is equal, we can establish equations that define market boundaries.

$$\lambda V - ax_1 - p_s = \lambda V - p_e \quad (2)$$

$$\lambda V - p_e = V - a(1-x_2) - w - o_h \quad (3)$$

Here, x_1 and x_2 represent the patient's location with equal utility, where $0 < x_1 < x_2 < 1$ (Figure 3).

By solving the equations, we have $x_1 = \dfrac{p_e - p_s}{a}, x_2 = 1 + \dfrac{o_h - p_e + w - V(1-\lambda)}{a}$.

Without loss of generality, let the manufacturer's unit cost of production be zero. Then, the profit of the drugstore π_s, the profit of the manufacturer π_m, and the profit of the e-pharmacy π_e are specified by

$$\pi_s = (p_s - w - \Delta w)x_1 \quad (4)$$

$$\pi_m = (w + \Delta w)x_1 + w(1 - x_1) \quad (5)$$

$$\pi_e = (p_e - w - c_e)(x_2 - x_1) \quad (6)$$

where c_e denotes the costs incurred by an e-pharmacy in facilitating home-delivery services, specifically encompassing the expenses associated with transporting medications from their warehousing facilities to the residences of individual patients.

In the proposed decision-making process, the manufacturer takes the lead in determining the wholesale price difference Δw . Then, the drugstore and e-pharmacy independently establish their own optimal retail prices (p_s and p_e , respectively) based on the manufacturer's decision.

By substituting x_1 and x_2 into equations (4) and (6), we get π_s and π_e .

$$\pi_s = \frac{\left(p_e - p_s\right)\left(p_s - w - \Delta w\right)}{a} \tag{7}$$

$$\pi_e = \left(p_e - w - c_e\right)\left(\frac{a + o_h - 2p_e + p_s - V + \lambda V + w}{a}\right) \tag{8}$$

Equations (7) and (8) indicate that π_s and π_e are both convex functions with respect to p_s and p_e , respectively. Both profits have maximum values.

Based on the principles of Stackelberg game theory and profit maximization, we can calculate the optimal retail prices p_s and p_e by $\frac{\partial \pi_s}{\partial p_s} = 0$ and $\frac{\partial \pi_e}{\partial p_e} = 0$. The values of p_s and p_e are then substituted into equation (5), we get π_m .

$$\pi_m = \frac{\left(2c_e + o_h - V + \lambda V - 3\Delta w\right)\Delta w + a\left(7w + \Delta w\right)}{7a} \tag{9}$$

Clearly, π_m has a maximum value, as it is a convex function with respect to Δw . The optimal wholesale price Δw is obtained by $\frac{\partial \pi_m}{\partial \Delta w} = 0$. Thus, the optimal prices in the multichannel model are obtained as follows:

$$p_s = \frac{5a + 10c_e + 5o_h - 5V\left(1 - \lambda\right)}{21} + w \tag{10}$$

$$p_e = \frac{13a + 26c_e + 13o_h - 13V\left(1 - \lambda\right)}{42} + w \tag{11}$$

$$\Delta w = \frac{a + 2c_e + o_h - V\left(1 - \lambda\right)}{6} \tag{12}$$

It is important to note that the optimal prices must satisfy the condition of $0 < x_1 < x_2 < 1$. Failure to meet this condition suggests the elimination of one of the channels due to price competition, making the abovementioned optimal prices nonexistent. Substituting equations (10)–(12) into equations (4)–(6), the optimal profits are obtained:

$$\pi_s = \frac{\left[a + 2c_e + o_h - V\left(1 - \lambda\right)\right]^2}{196a} \tag{13}$$

$$\pi_m = \frac{\left[a + 2c_e + o_h - V\left(1-\lambda\right)\right]^2}{84a} + w \tag{14}$$

$$\pi_e = \frac{\left[13a - 16c_e + 13o_h - 13V\left(1-\lambda\right)\right]^2}{882a} \tag{15}$$

Omni-Channel Supply Chain

The omni-channel supply chain is the integration of telemedicine coordination and home-delivery coordination. Specifically:

(1) Telemedicine coordination. As illustrated in Figure 2, the channel coordination between the e-pharmacy and hospital doctor effectively enhances the medication safety of the e-pharmacy channel; however, patients are required to bear the cost of outpatient fees o_h. Due to the limitations of telemedicine, some patients may be advised to undergo referral and seek reevaluation at the hospital. In our hypothesis, we assume a referral rate of δ and $0 \le \delta \le 1$.
(2) Home-delivery coordination. In order to achieve cost-effective drug delivery, the e-pharmacy adopts a strategy of transferring online orders to offline drugstores for home delivery. In this context, we assume that the e-pharmacy compensates the drugstore by paying a service fee, denoted as f. This service fee has the potential to reduce the home-delivery cost of the e-pharmacy while simultaneously increasing the profit of the drugstore. By introducing this service fee, we aim to increase profits for both parties, and its range will be discussed in detail in next section.

Additionally, to ensure clarity and avoid confusion, we denote the omni-channel model using a superscript ‘. The patient’s decision expression is determined by:

$$Max[\lambda V - ax' - p'_s, V - p'_e - o_h, V - a\left(1-x'\right) - w - o_h] \tag{16}$$

By utilizing the patient utility function of each channel, we can establish equations that define the market boundaries.

$$\lambda V - ax'_1 - p'_s = V - p'_e - o_h \tag{17}$$

$$V - p'_e - o_h = V - a\left(1 - x'_2\right) - w - o_h \tag{18}$$

We get the boundary points $x'_1 = \frac{o_h + p'_e - p'_s - V\left(1-\lambda\right)}{a}$, $x'_2 = 1 + \frac{w - p'_e}{a}$.

With the service fee f, the profits’ expressions under an omni-channel coordination scenario are given as follows:

$$\pi'_s = \left(p'_s - w - \Delta' w\right)x'_1 + \left(f - c'_e\right)\left(1-\delta\right)\left(x'_2 - x'_1\right) \tag{19}$$

$$\pi'_m = \left(w + \Delta' w\right)x'_1 + w\left(1 - x'_1\right) \tag{20}$$

$$\pi'_e = \left(p'_e - w - f\right)\left(1-\delta\right)\left(x'_2 - x'_1\right) \tag{21}$$

where c'_e represents the home-delivery cost of a nearby drugstore, also $c'_e < c_e$.

By using the same decision-making process as the multichannel model, we can derive the optimal prices for each channel.

$$p_s^{'} = \frac{5a - 6c_e^{'}\left(1-\delta\right) + f\left(16-6\delta\right) + 15o_h - 15V\left(1-\lambda\right)}{21} + w \tag{22}$$

$$p_e^{'} = \frac{13a - 3c_e^{'}\left(1-\delta\right) + f\left(29-3\delta\right) - 3o_h + 3V\left(1-\lambda\right)}{42} + w \tag{23}$$

$$\Delta^{'} w = \frac{a + 3c_e^{'}\left(1-\delta\right) - f\left(1-3\delta\right) + 3o_h - 3V\left(1-\lambda\right)}{6} \tag{24}$$

Due to $0 \leq \delta \leq 1$, that is,

$$\frac{\partial p_s^{'}}{\partial f} = \frac{16-6\delta}{21} > 0 \tag{25}$$

$$\frac{\partial p_e^{'}}{\partial f} = \frac{29-3\delta}{42} > 0 \tag{26}$$

The inequalities (25) and (26) indicate that an increase in the service fee f results in an increase in the optimal retail prices $p_s^{'}$ and $p_e^{'}$. Based on this observation, we can conclude that in the omni-channel supply chain model, a lower service fee is more beneficial for patients.

By substituting the optimal variables into equations (19)–(21), following a similar approach employed in the previous section, an analysis of the results confirms the presence of a peak value. Consequently, the expressions for optimal profits are obtained:

$$\pi_s^{'} = \frac{\begin{gathered} 3a^2 - 15c_e^{'2}\left(1-\delta\right)^2 - 403f^2\left(1-\delta\right) - 15f^2\delta^2 + 12fo_h\left(2+\delta\right) + 27o_h^2 \\ -12fV\left(2+\delta-2\lambda V-\delta\lambda V\right) - 54o_h V\left(1-\lambda\right) + 27V^2\left(1-\lambda\right)^2 \\ +2c_e^2\left(1-\delta\right)\left[5f\left(43-3\delta\right) - 6o_h V\left(1-\lambda\right)\right] \\ -2a\left[194c_e^{'}\left(1-\delta\right) - f\left(200-194\delta\right) - 9o_h + 9V\left(1-\lambda\right)\right] \end{gathered}}{588a} \tag{27}$$

$$\pi_e^{'} = \frac{\left(1-\delta\right)\left[13a - 3c_e^{'}\left(1-\delta\right) - f\left(13+3\delta\right) - 3o_h + 3V\left(1-\lambda\right)\right]^2}{882a} \tag{28}$$

$$\pi_m^{'} = \frac{\begin{gathered} \left[a^2 - 3c_e^{'}\left(1-\delta\right) + f\left(1-3\delta\right) - 3o_h + 3V\left(1-\lambda\right)\right]^2 \\ +a\left[6c_e^{'}\left(1-\delta\right) - 2f\left(1-3\delta\right) + 6o_h - 6V\left(1-\lambda\right)\right] \end{gathered}}{84a} + w \tag{29}$$

In the forthcoming section, the analysis will compare the optimal values between the two scenarios to evaluate the conditions required for implementing the coordination strategy.

Coordination Strategy Decisions

In this section, two coordination decision-making scenarios are discussed. (1) In the telemedicine coordination decision, the doctor is willing to adopt the coordination strategy, as it leads to an increased patient volume. However, the e-pharmacy needs to take its profit into account since, although this coordination can enhance the safety of telemedicine, it may result in some online patients being referred to hospitals; and (2) in the home-delivery coordination decision, both the e-pharmacy and drugstore evaluate their profits from a channel competition perspective. In summary, the feasibility of implementing the omni-channel coordination scheme depends on whether the e-pharmacy and drugstore experience a profit increase. The differences in optimal profits are expressed analytically as follows:

Firstly, let us discuss the feasible range of the service fee f for the "order online, home-delivery offline" strategy. According to Table 2, the decision inequalities for the omni-channel coordination can be determined by:

$$\Delta\pi_e > 0 ,\ \Delta\pi_s > 0 \tag{28}$$

By solving these two inequality equations, the upper and lower bounds for the service fee f can be obtained (represented by $f^{\min}$ and $f^{\max}$, respectively) . Additionally, other constraint inequalities have been introduced. To ensure that all parameters are positive, we have:

$$0 < x_1 < x_2 < 1 ,\ 0 < x_1' < x_2' < 1 \tag{29}$$

And no-arbitrage conditions:

$$p_e > w + \Delta w ,\ p_e' > w + \Delta' w \tag{30}$$

Thus, $f^{\min}$ and $f^{\max}$ must satisfy the inequality equations (29) and (30). Failure to meet these conditions implies that the service fee is nonexistent, and therefore, the coordination cannot be

Table 2. Comparison of Optimal Profits

Symbol	Analytic expression
$\Delta\pi_e$	$\dfrac{(1-\delta)\left[13a - 3c_e'(1-\delta) - f(13+3\delta) - 3o_h + 3V(1-\lambda)\right]^2 - \left[13a - 16c_e + 13o_h - 13V(1-\lambda)\right]^2}{882a}$
$\Delta\pi_s$	$\dfrac{\begin{array}{l} 3a^2 - 15c_e'^2(1-\delta)^2 - 403f^2(1-\delta) - 15f^2\delta^2 + 12fo_h(2+\delta) + 27o_h^2 \\ -12fV(2+\delta-2\lambda V-\delta\lambda V) - 54o_hV(1-\lambda) + 27V^2(1-\lambda)^2 \\ +2c_e^2(1-\delta)\left[5f(43-3\delta) - 6o_hV(1-\lambda)\right] \\ -2a\left[194c_e'(1-\delta) - f(200-194\delta) - 9o_h + 9V(1-\lambda)\right] \\ -3\left[a + 2c_e + o_h - V(1-\lambda)\right]^2 \end{array}}{588a}$
$\Delta\pi_m$	$-\dfrac{\left[2c_e - 3c_e'(1-\delta) + f(1-3\delta) - 2o_h + 2V(1-\lambda)\right]\left[2a + 2c_e + 3c_e'(1-\delta) - f(1-3\delta) + 4o_h - 2V(1-\lambda)\right]}{84a}$

realized. Assuming that the aforementioned inequality equations hold, the coordination strategy can be accepted by the drugstore and e-pharmacy if $f^{\min} < f^{\max}$. The excessive number of parameters and the involvement of quadratic inequalities make the expression for f highly intricate. Therefore, we will continue to discuss it through numerical studies.

Next, we analyze the conditions for the introduction of telemedicine by examining the impact of the referral rate δ on the profitability of the e-pharmacy channel. By solving inequality $\Delta\pi_e > 0$, we can determine the upper limit of the referral rate $\delta^{\max}$ that the e-pharmacy can tolerate. It is evident that a high value of δ would result in the e-pharmacy being unable to generate more profits, thereby indicating that the telemedicine coordination is not a feasible option. In the upcoming section, we will conduct numerical studies to further investigate the viable range of the service fee and maximum referral rate.

NUMERICAL STUDIES

Within this section, we will utilize real-world data to determine the feasible range of the service fee f and analyze its influence on the profits of the different stakeholders involved in the supply chain, and subsequently examine the impacts of the safety of self-medication λ and referral rate δ on the decision-making process for the omni-channel strategy.

The parameter settings are as follows: as the drugs involved in this article are used to treat common illnesses, the wholesale price is set at $w = 100$; based on the price list published by the Beijing Price Bureau (Chen, 2017). The outpatient fee is set at $o_h = 50$; as the self-treatment accuracy for common illnesses ranges from 70% to 90% (Hughes, 2001). We assume the safety of self-medication $\lambda = 80\%$;given the doctors' tendency to err on the side of caution, a referral rate δ of 40% is established. Considering the income level of the city, the distance coefficient is set as $a = 40$; and the home-delivery costs under different scenarios are assumed as $c_e = 30$ and $c_e^{'} = 5$, respectively. Finally, the pharmaceutical utility $V = 200$ is sufficiently large to ensure that a channel is chosen. To clearly illustrate the trend of profit changes and the range of the service fee f, we vary the value of f within the range of $\left[5,25\right]$.

The profits obtained under the multichannel model serve as the reference point and remain unaffected by the service fee f. As depicted in Figure 4, the profit of drugstore $\pi_s^{'}$ exhibits an increasing trend with an increase in service fee f. To guarantee $\Delta\pi_s > 0$, the minimum value of service fee is set at $f = 7$. On the contrary, Figure 5 illustrates a decreasing trend in the profit of e-pharmacy $\pi_e^{'}$ with an increase in service fee f. To guarantee $\Delta\pi_e > 0$, the maximum value of service fee is bounded from above at $f = 18.5$. Therefore, the "order online, home-delivery offline" strategy can be deemed feasible for both a drugstore and e-pharmacy when the service fee f is determined within the range of $\left(7,18.5\right)$. This range provides accurate reference data for pricing decisions, thus avoiding blind pricing. Subsequently, the impacts of service fee f on retail prices will be further investigated.

In the omni-channel scenario, it can be observed that both $p_s^{'}$ and $p_e^{'}$ increase with increasing f, indicating a positive impact of the service fee on the retail prices. Comparing with the retail prices under the multichannel scenario, from Figure 6 and Figure 7, we obtain that $p_e^{'} < p_e$ and $p_s^{'} < p_s$ when $f < 16$. Therefore, when the service fee f is relatively low, the omni-channel coordination strategy can lead to a reduction in retail prices, which ultimately benefits the patients.

Finally, we set $f = 12$ to examine the impacts of self-medication λ and referral rate δ on omni-channel strategy decisions. Here, we vary $\delta \in \left[0,1\right]$ and $\lambda \in \left[0.7,1\right]$, respectively.

Figure 4. Profit of drugstore with service fee

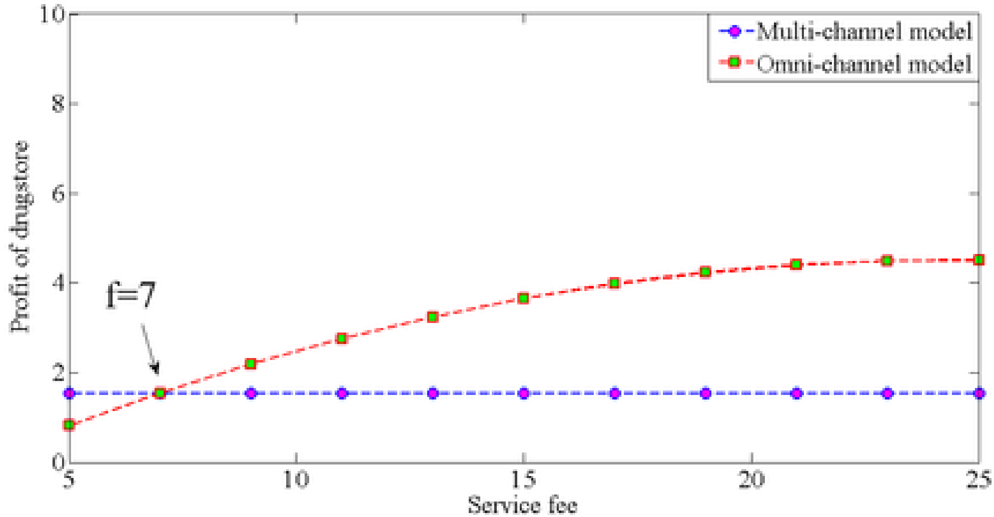
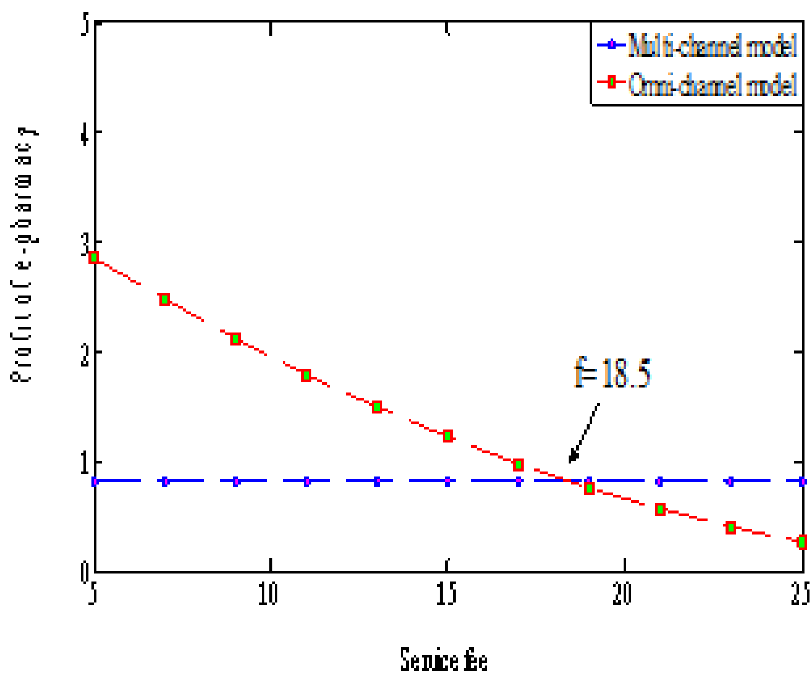


Figure 5. Profit of e-pharmacy with service fee



The profit chart in the omni-channel model is positioned above that of the multichannel model, indicating the effectiveness of the omni-channel strategy. Based on the results shown in Figure 8, under the omni-channel scenario, the drugstore experiences an increase in profit as the referral rate δ decreases and safety of self-medication λ increases. In contrast, Figure 9 shows that the profit of

Figure 6. Retail price of drugstore with service Fee

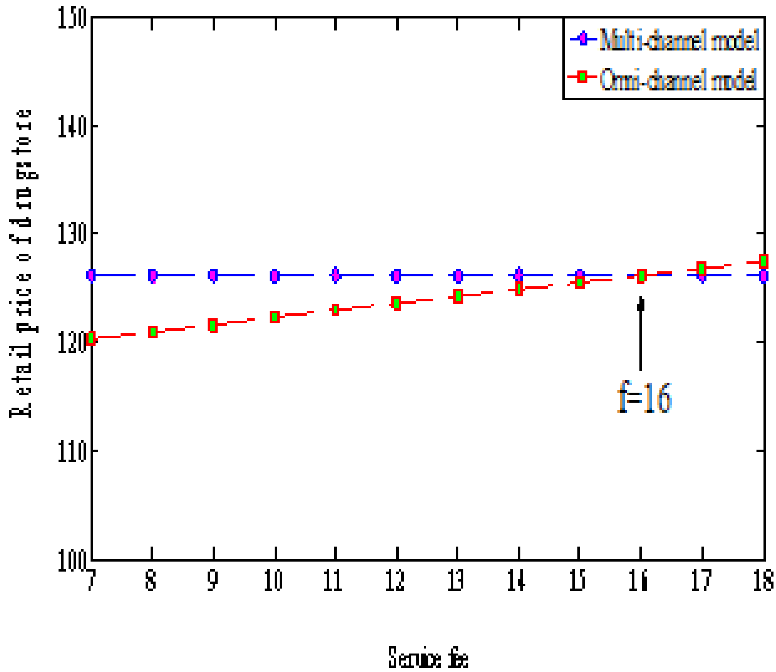


Figure 7. Retail price of e-pharmacy with service fee

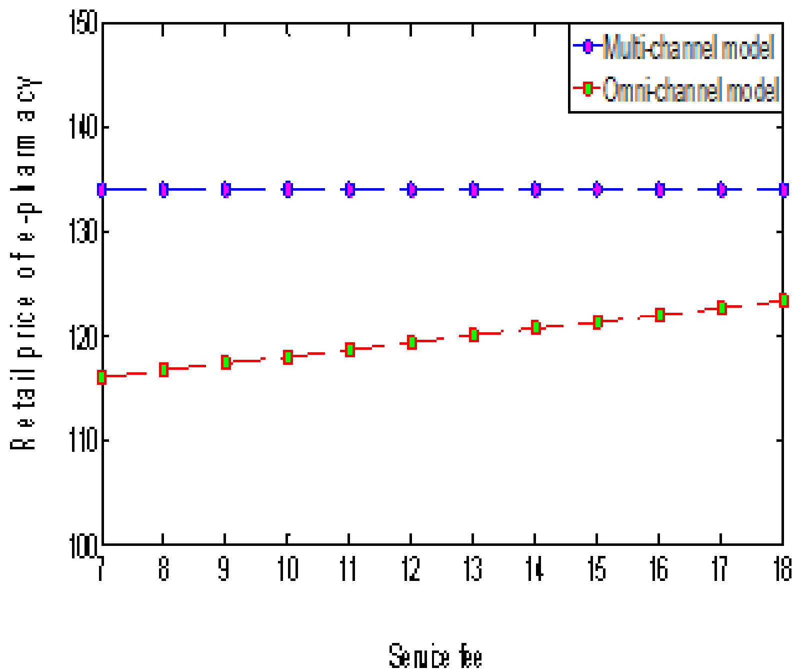


Figure 8. Profit of drugstore with δ and λ

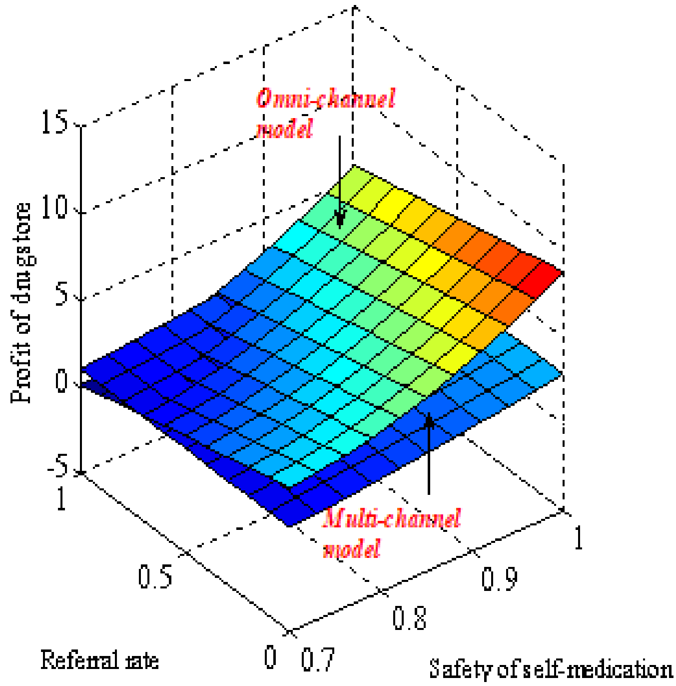
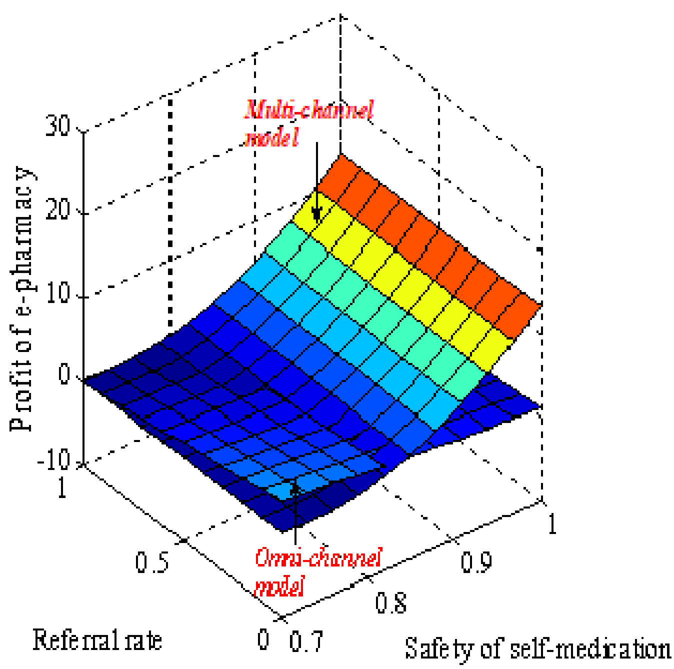


Figure 9. Profit of e-pharmacy with δ and λ



the e-pharmacy decreases with increasing λ. Taking into account the preferences of both sides, the omni-channel strategy is more likely to be accepted by both an e-pharmacy and a drugstore when the referral rate δ and safety of self-medication λ are relatively low. The low δ and λ imply that patients may be unable to perform an accurate assessment of their medical condition. However, with the aid of telemedicine, doctors can easily make an accurate diagnosis. In reality, drugs used for common illnesses, such as fever, as well as drugs for chronic diseases, such as hypertension and diabetes, are categorized under this class of drugs. Therefore, for an e-pharmacy, selling this category of drugs is highly suitable for adopting the omni-channel strategy to generate higher profits.

PRACTICAL AND MANAGERIAL IMPLICATIONS

The findings and analysis presented in this paper have several practical and managerial implications for the pharmaceutical e-commerce industry and supply chain stakeholders. This section highlights the key implications derived from the research.

Practical Implications

(1) Enhanced safety measures. The introduction of telemedicine platforms connecting patients with remote hospital doctors can improve the safety of purchasing drugs online. This enables patients to receive professional guidance and advice from healthcare professionals. By the end of 2022, doctors from 2,700 hospitals in China were providing remote healthcare services, serving over 25.9 million patients annually. Therefore, the transformation of pharmaceutical e-commerce is imperative, shifting from a singular drug retail business model to a comprehensive operational model that combines drug sales with service provision. Additionally, it is important to note that certain emergency conditions or illnesses requiring further examination may not be suitable for online diagnosis. In such cases, the e-pharmacy should inform patients in advance through data analysis.

(2) Seamless shopping experience. The "order online, home-delivery offline" strategy allows online orders to be fulfilled through offline drugstores. This coordination ensures prompt and reliable home-delivery services, bridging the gap between online and offline channels. The e-pharmacy can subsidize the offline drugstores with lower costs, facilitating efficient fulfillment and customer satisfaction. This program effectively addresses the challenge of limited healthcare access faced by patients who are constrained from seeking medical attention due to their inability to travel. This is the primary advantage of pharmaceutical e-commerce, as demonstrated by the slogan "Buy medicine without leaving home" on the homepage of the AliHealth app. Therefore, enhancing the patient's medication purchasing experience is key to strengthening their reliance on e-commerce channels.

(3) Strategic selection of drugs. The e-pharmacy and drugstore should strategically choose the types of drugs they offer for sale. This paper provides a numerical analysis to identify the types of drugs that are suitable for the online implementation of an omni-channel strategy. For example, pharmaceuticals used in the treatment of chronic cardiovascular and cerebrovascular diseases are well-suited for online sales due to factors such as long-term patient medication requirements, higher frequency of online purchases, as well as the relatively stable consumer behavior. The findings have significant implications for the operation of the e-pharmacy.

Managerial Implications

(1) Channels coordination strategy. The adoption of an omni-channel strategy can confer benefits upon a brick-and-mortar drugstore, hospital doctor, and e-pharmacy in the pharmaceutical supply chain by fostering coordination and mitigating competition between disparate channels.

This strategy entails the integration of the three channels of the pharmaceutical supply chain into a cohesive system that furnishes patients with a seamless medical experience. Furthermore, the applicability of the "online order, home-delivery offline" strategy can be extended to time-sensitive goods that require short lead time as long as an appropriate service fee is calculated.

(2) Determination of service fee and referral rate. The value ranges of the service fee and referral rate play a significant role in the omni-channel coordination strategy. Managers should carefully analyze the cost-benefit trade-offs associated with these parameters to strike a balance between customer satisfaction, operational costs, and profitability. In real-world scenarios, there may be additional cost factors that managers need to incorporate into the model presented in this paper to make decisions more precise and accurate.

(3) Optimization of supply chain performance. From the perspective of the pharmaceutical retail industry, the integration of O2O has emerged as a major trend in its development. To align with this trend, this paper combined the advantages of various channels and provided a comprehensive operational plan for the pharmaceutical industry, which can facilitate cost reduction and efficiency improvement in the pharmaceutical supply chain. By comparing the performance of supply chain members in both the omni-channel and nonomni-channel scenarios, managers can identify areas for improvement, enhance operational efficiency, and maximize overall profitability.

Ultimately, the coordination of the three channels can engender a more customer-centric and lucrative model that caters to the evolving requirements of customers and adjusts to the dynamic landscape of the e-commerce sector.

CONCLUSION

In the era of e-commerce, the development of pharmaceutical e-commerce has not progressed as successfully as that of conventional products. This study aimed to address two primary challenges faced by the pharmaceutical e-commerce market: high home-delivery costs and safety concerns associated with purchasing drugs online. We proposed an omni-channel coordination strategy that involved telemedicine and redirecting online orders to offline drugstores for home delivery, hypothesizing that it could overcome these challenges. It is noteworthy that our study considers the entire process of patient drug procurement and medication, providing strategic references for end-to-end suppliers in the general merchandises.

To test our hypothesis, we developed models for an imbalanced three-channel supply chain under both nonomni-channel and omni-channel scenarios. The three-channel model, which is based on the imbalanced characteristics of retailers, exhibits significant differences from the dual-channel model constructed by previous researchers. This model serves as the foundation for the design of omni-channel coordination strategy and represents a major academic contribution of this study. Then we formulated profit functions and derived analytical expressions to optimize profits and retail prices for each channel member. By comparing the optimal results between scenarios, we determined the feasible range of service fees that the e-pharmacy could pay to incentivize omni-channel coordination with the drugstore. On the other hand, the telemedicine platform provided by the e-pharmacy facilitates patients in procuring drugs under the guidance of hospital doctors, thereby significantly improving the safety of drugs procurement. Therefore, from a theoretical perspective, the omni-channel coordination strategy can address the bottlenecks encountered in the development of pharmaceutical e-commerce.

Through numerical studies, we found that under appropriate conditions, the omni-channel strategy indeed led to higher profits for channel members and lower retail drug prices for patients, thus supporting our hypothesis. These conditions included a moderate service fee, low self-medication accuracy, low referral rate, and drugs requiring professional diagnosis and guidance. Based on the case analysis, we have identified drug categories that can generate higher profits for e-pharmacies under the omni-channel model. However, the real-world scenarios are much more complex, and managers can adjust the patient utility function based on the design concepts presented in this paper and the actual situation of the enterprise to obtain the optimal service fee value. In future research, we also plan to verify our conclusions using operational data from a specific e-commerce enterprise.

In summary, our findings highlight that adopting an omni-channel coordination strategy is a superior approach to managing supply chains compared to the traditional multichannel model. This study offers guidance for planning effective supply chain strategies and developing coordination mechanisms that can drive better outcomes in the pharmaceutical e-commerce industry.

Several fascinating topics remain for further investigation. With the continuous advancement of artificial intelligence technology, the telemedicine platforms will become increasingly proficient at providing accurate and personalized diagnoses. However, the large-scale artificial intelligence models require massive amounts of high-quality data, which may be difficult to obtain given patients' concerns about personal information leakage and hospitals' concerns about losing customers. In the future, coordinated omni-channel strategies could be driven by data sharing rather than the economic benefits proposed in this article. Therefore, exploring how e-platforms, patients, and hospitals can coordinate to share data and mutually benefit from each other is of great value.

CONFLICT OF INTEREST

The authors of this publication declare there are no competing interests.

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