MANUFACTURER’S DECISION-MAKING AND COORDINATION STRATEGY IN AN ASYMMETRIC MULTI-CHANNEL ENVIRONMENT

Ge Yang*, Conghui Wang and Min Zhang

Abstract. This paper explores the significant impact of e-commerce and investigates manufacturers’ decision-making processes regarding the opening of e-shops and the adoption of online and offline coordination strategies to enhance profits in an e-commerce environment. A novel three-channel model with asymmetric retailers is proposed, and three scenarios are analyzed: the initial dual-channel scenario, the multi-channel scenario with e-platform, and the “Order online, Pickup offline” coordinated scenario. By comparing optimal profits across these scenarios, decision-making inequalities for manufacturers are derived. Subsequently, numerical experiments validate that manufacturers, aiming to maximize profits, opt to establish an e-commerce channel and coordinate with offline retailers. Additionally, the study emphasizes the importance of e-platforms in setting commission rates to drive increased profits. The findings offer practical implications for manufacturers to engage in interest-balanced coordination, enabling them to adapt to evolving retail dynamics in the advancing e-commerce landscape from both theoretical and practical perspectives.

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1. Introduction

With the proliferation of e-commerce, manufacturers have proactively established their own online sales channels or utilized third-party sales platforms. E-business offers companies an efficient avenue for sales and enhances operational agility. This is exemplified by the establishment of Vmall, an e-shop launched by renowned electronics manufacturer Huawei in 2012 [1]. The web connects buyers regardless of location and can reduce the cost of production and distribution of products and services. According to a report from the Ministry of Commerce of China, e-commerce transactions reached about 6.3 trillion dollars in 2021 [2].

However, the advent of e-commerce and its direct sales channel to customers has exerted a profound impact on the retail industry. In 2017, Fortune magazine reported a year of retail bankruptcies and turnarounds in the United States, marked by a surge in store closures and notable efforts by Walmart and Target to compete with Amazon [3]. E-commerce channels offer the advantage of lower retail prices attributable to asymmetric information and reduced search costs for buyers. Remarkably, the impact of e-commerce on traditional retailers has been far more pronounced than anticipated. Between 2016 and 2020, Walmart China closed 80 stores...
nationwide, with a further 10 closures in 2021 [4]. And it was reported in 2017 that the renowned Wanda Group closed 120 venues and shifted its focus towards e-commerce [5]. Large supermarkets, shopping malls, chain stores, and small retailers have all experienced significant pressure, leading to closures. As the e-commerce industry continues to emerge and grow, competition between channels has increasingly shifted towards online-to-offline (O2O) coordination.

In real-world scenarios, the O2O coordination model with asymmetric retailers has found application. For instance, pharmaceutical manufacturer Renhe Group aspired to directly sell their products to patients through e-commerce platform. However, due to significant geographical distances, the patients had to experience prolonged waiting times before receiving their medications. The patients preferred to promptly obtain their medications after placing online orders to alleviate their symptoms. Additionally, within the Chinese pharmaceutical retail market, due to the absence of the separation of prescribing and dispensing system, government-operated hospitals have emerged as the most dominant pharmaceutical retailers in the retail market, while street pharmacies operate at a disadvantage. To address patients needs, Renhe coordinated with offline pharmacies to offer a “order online, pickup offline” service [6]. The result of implementing this service is that patients in urban areas can obtain the medication within a time frame of 28 min. This coordination strategy enables fringe pharmacies to earn service commissions and enhance customer foot traffic while simultaneously reducing the delivery costs associated with pharmaceutical e-commerce, thereby improving delivery timeliness. Similarly, there is a similar sales model in the mobile phone market. On August 29, 2023, Huawei launched the “HUAWEI Mate60 Pro Pioneer Program” and made it available for purchase on its official e-commerce platform. As part of this program, users have the opportunity to acquire the Mate60 Pro device directly from designated offline partner stores [7].

Currently, manufacturers face two critical decision-making questions: (1) Whether to establish a completely new e-commerce channel on top of existing retail channels? (2) Whether to engage in coordination with offline retail stores to provide consumers with more convenient delivery services? To address these questions, this paper first categorizes retailers into dominant retailers and fringe retailers based on real-world scenarios. The dominant retailers refer to large-scale retailers that possess market influence and bargaining power with the manufacturers, such as major chain supermarkets. On the other hand, the fringe retailers are smaller in scale and can only passively accept the prices set by the manufacturers, such as independent convenience stores found on the streets. Subsequently, three supply chain models (initial model, e-commerce model, coordination model) are constructed. The Stackelberg game theory is then employed to determine the optimal profits for each entity in the supply chain under different scenarios. Finally, by comparing the optimal profits, the decision-making inequalities for manufacturers are derived. Overall, the motivation for this research is to analyze the effects of e-commerce on different stakeholders and provide guidance for manufacturers looking to adapt to changing market dynamics.

The innovation of the above scheme can be attributed to two key aspects: Firstly, in order to align with the aforementioned real-life context, we have developed a complex three-channel two-echelon supply chain model characterized by an asymmetric retailers structure (dominant retailers vs. fringe retailers) and differential channels (online channel vs. offline channel). Subsequently, secondly, within this context of the three-channel model, the present study devises an O2O coordination strategy between the manufacturers and the fringe retailers, enabling expedited and cost-effective delivery of online orders, thereby effectively enhancing the profitability of the online manufacturers.

The remainder of the paper is organized as follows. Section 2 provides a literature review, and Section 3 introduces the model construction and analyzes the changes caused by e-commerce and the strategies that manufacturers can adopt. Section 4 presents the results of numerical experiments to validate the analysis. Section 5 discusses the managerial implications. Finally, Section 6 concludes the paper and outlines topics for future research.
Table 1. Impacts of e-commerce on manufacturers.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Profitable</th>
<th>Unprofitable</th>
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<tbody>
<tr>
<td>Barman et al. [12]</td>
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<td>Cai et al. [14]</td>
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<td>Chiang et al. [8]</td>
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<td>Chen et al. [11]</td>
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<td>Lu and Liu [9]</td>
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<td>Matsui et al. [10]</td>
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<td>Rofin and Mahanty [15]</td>
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<td>Ghosh et al. [17]</td>
<td>✔</td>
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<tr>
<td>Tsay and Agrawal [13]</td>
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2. Literature review

The rapid development of e-commerce in China has intensified the competition between traditional and electronic channels, leading to the transformation of many manufacturers. This literature review aims to investigate the impact of e-commerce on the decision-making processes of manufacturers.

Previous researchers have achieved fruitful research on the impact of e-commerce on manufacturers. They have witnessed both the success and failure of manufacturers with different channel strategies. From the perspective of channel competition, Chiang et al. demonstrated that adding a direct sales channel can reduce profit loss [8]. Lu et al. indicated that physical retailers might benefit from e-commerce channel entry, but the dual-channel might be unprofitable for the manufacturer [9]. Matsui et al. studied two recycling manufacturer using a dual-channel recycling strategy and found that neither company was profitable [10]. Chen et al. inferred that reselling mode will be unprofitable when the online spillover effect is significant, and the manufacturer has weak bargaining power [11]. Barman et al. highlighted that a manufacturer-led dual-channel centralized decision-making system can effectively minimize carbon emissions and enhance overall supply chain profitability [12].

However, other scholars hold the opposite view. Tsay et al. initially demonstrated that a Pareto zone exists that benefits both the manufacturer and the retailer under a manufacturer’s dual-channel strategy [13]. Cai et al. highlighted that suppliers have more negotiation power in a dual-channel supply chain [14]. From the perspective of consumer channel preferences, Rofin et al. found that manufacturers benefit from a retailer with an e-marketplace configuration when customers have a high e-channel preference [15]. Zhou et al. concluded that uncertainty in demand leads manufacturers to pay zero information rent but obtain greater profits [16]. Ghosh et al. showed that incorporating an online sales channel can be a viable option for manufacturers in a dual-channel supply chain operating under cap-and-trade regulations while considering consumers’ low carbon preferences [17]. Li et al. observed an increasing trend among manufacturers to establish online channels, while highlighting the occurrence of strategic customers who engage in the behavior of initially exploring products at brick-and-mortar stores but ultimately making their purchases through manufacturers’ e-commerce platforms [18].

From the perspective of manufacturers’ benefits, as presented in Table 1, scholars hold different views on the impact of e-commerce on channels and profit improvement. Some argue that e-commerce intensifies channel competition and does not contribute to profit enhancement, while others believe that e-commerce enhances manufacturers’ bargaining power and is beneficial to them. This article aims to comprehensively analyze the effects of e-channels on manufacturers by acknowledging the dual nature of e-commerce. Furthermore, by designing an O2O coordination strategy among channels, this article seeks to address channel conflict issues.

From a modeling perspective, the aforementioned studies are predominantly based on dual-channel models, although there have been a few emerging studies focusing on tri-channel models in recent years. For instance, Song et al. effectively divided the manufacturer’s online channel into express delivery channel and customer
pickup channel, thereby constructing a comprehensive tri-channel supply chain model [19]. In a similar vein, Chen et al. distinctively segregated the retailer’s channels into online and offline channels, resulting in the establishment of a tri-channel model [20]. Furthermore, Zhen et al. devised a pioneering first-stage tri-channel model specifically tailored for retailers, encompassing online, offline, and third-party platform channels [21]. Notably, these three articles, strictly speaking, can still be classified as dual-channel models since two out of the three channels are affiliated with the same decision-maker.

In contrast to the aforementioned studies, this present research endeavors to develop an independent three-channel supply chain model to scrutinize the decision-making challenges confronted by manufacturers. The inclusion of additional channel and decision-maker undoubtedly increases the complexity of determining optimal profits.

Furthermore, in order to maximize the profits of the manufacturer, this paper also devises coordinated strategies “Order Online, Pickup Offline” between the manufacturer and the retailer. In reality, manufacturers often choose to coordinate with fringe retailer due to abundant quantity and widespread distribution, while dominant retailers are relatively scarce and have limited coverage. In this research, to simplify the problem, we constructed a coordination model that includes only one dominant retailer and one fringe retailer. Previous studies have examined various coordination methods, with the closest resemblance to this research being the “buy-online, pick-up-in-store (BOPS)” strategy. Gallino et al. discovered that implementing the BOPS strategy led to a decrease in online sales but an increase in store sales and traffic [22]. Gao et al. suggested that revenue sharing across channels could alleviate incentive conflicts [23]. Sarkar et al. established a three-channel model (offline channel, online channel, buy-online-pick-up-in-store channel) and examined the impact of buy-online-pick-up-in-store, backorder, and on-hand inventory policies on retail profitability [24]. Saha et al. focused on offline stores participating in the BOPS service and imposed multiple inventory management policies [25]. Lu et al. aimed to establish coordinated inventory policies that effectively cater to customer demands through both offline and online BOPS channels [26]. Punj explored the influence of mobile device usage on shoppers’ search and evaluation behaviors within physical stores [27]. In a different study, He et al. developed a model to optimize channel strategies and pricing in dual channels, specifically targeting strategic customers [28]. Lastly, Kar et al. presented a production farm model for a dual-channel retailing system, consisting of both online and offline channels, and considered various factors such as advertisement, selling price, and demand elasticity [29]. Lim et al. indicated that the proposed BOPS policy increases the expected profits of a system by investing in advertising, services offered, product traceability, and product-quality maintenance [30].

While the BOPS model has been extensively explored by scholars and shares similarities with the strategy elucidated in this paper, notable distinctions also exist. Firstly, the research subjects differ. The BOPS model primarily focuses on retailers, offering different shopping channels for consumers to choose from. However, this paper predominantly centers on manufacturers who provide a singular e-channel competing with other retailers. Secondly, the implementation methods of the strategies vary. In prior studies, the BOPS model does not inherently require coordination among supply chain entities as it functions as an independent supply channel. In contrast, this paper emphasizes the importance of coordination between the e-channel and the offline channel. Therefore the current study aims to propose a coordination solution within a three-channel model, which introduces greater complexity in both model building and problem-solving.

In summary, this article presents three main contributions that differentiate it from previous research: (1) the development of a three-channel model to analyze multi-channel competition and coordination between two retailers with asymmetric market power, (2) the design of a coordination strategy where the manufacturer unites the fringe retailer to implement the “Order Online, Pickup Offline” approach. This strategy involves the retailer participating in a direct channel, which differs from previous coordination solutions, and (3) the identification of conditions under which coordination is more likely to occur and the benefits of coordination for the manufacturer.
MANUFACTURER'S DECISION-MAKING AND COORDINATION STRATEGY

Table 2. Summary of notations.

<table>
<thead>
<tr>
<th>Notations</th>
<th>Descriptions</th>
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<tbody>
<tr>
<td>$w$</td>
<td>Wholesale price</td>
</tr>
<tr>
<td>$c_e$</td>
<td>Express cost</td>
</tr>
<tr>
<td>$V$</td>
<td>Product utility</td>
</tr>
<tr>
<td>$x$</td>
<td>Patients location</td>
</tr>
<tr>
<td>$t$</td>
<td>Distance coefficient</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Commission rate of e-platform</td>
</tr>
<tr>
<td>$D$</td>
<td>Market share</td>
</tr>
<tr>
<td>$\pi$</td>
<td>Profits of function</td>
</tr>
<tr>
<td>$r_e$</td>
<td>Revenue of e-platform</td>
</tr>
</tbody>
</table>

Table 3. Summary of variables.

<table>
<thead>
<tr>
<th>Decision variables</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta w$</td>
<td>Price differentiation of wholesale price</td>
</tr>
<tr>
<td>$p_e$</td>
<td>Retail price of e-channel</td>
</tr>
<tr>
<td>$p_s$</td>
<td>Retail price of fringe retailer</td>
</tr>
<tr>
<td>$p_l$</td>
<td>Retail price of dominant retailer</td>
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</table>

3. Models

To address the two questions faced by manufacturers mentioned in the background introduction, we will construct three models: (1) the initial dual-channel model, where a remote manufacturer does not participate in the local retail market (Fig. 1); (2) the e-commerce multi-channel model, where the manufacturer directly sells products to consumers through a 3rd party e-platform but requires a remote express system for online orders (Fig. 2); and (3) “Order Online, Pickup Offline” coordination model, where the manufacturer coordinates with a fringe retailer, and consumers pickup the products at the fringe retailer’s location. By comparing the manufacturer’s profits between the first and second scenarios, a decision inequality is obtained regarding whether the manufacturer should establish an online purchasing channel. Similarly, by comparing the optimal profits of manufacturer and fringe retailer in the second and third scenarios, we can derive a set of decision inequalities regarding whether both parties should accept the coordination strategy. Before modeling, relevant parameters and decision variables are listed in Tables 2 and 3.

As depicted in the below figures, the manufacturer supplies goods to the dominant retailer and the fringe retailer at wholesale prices $w$ and $\Delta w + w$, respectively. The wholesale price $w$ is determined by the dominant retailer due to their stronger bargaining power with the manufacturer, making it an exogenous variable. For example, in the United States, retail chains such as Costco and Sam’s Club dominate of the sales in the wholesale club sector. As a result, they possess absolute market influence and bargaining power in supplier selection and wholesale price negotiations.

Both the manufacturer and retailers aim to maximize their individual profits and make their own decisions accordingly. The decision process is as follows: the manufacturer, as the leader, determines the price differentiation of wholesale price to the fringe retailer $\Delta w$ and retail price of e-channel $p_e$. The fringe retailer and the dominant retailer, as followers, then set their optimal retail prices $p_s$, $p_l$.

When formulating the mathematical model for the three scenarios, we have made the following three assumptions: (1) Stable customer population: the total demand remains constant each year, i.e., the total demand for drugs from patients remains unchanged. (2) Uniform customer distribution: customers are evenly spread across
the road. (3) Channel selection mechanism based on consumer utility: Assuming consumers are rational, they compare the utilities offered by different channels and subsequently make their purchasing channel choices. Based on these assumptions, we utilize the Hotelling model (or customer utility functions) to depict the competitive relationship between the online and offline channels. Consistent with previous studies [12, 31, 32], as illustrated in Figure 3, the fringe retailer is positioned at the initial point $x = 0$, while the dominant retailer is located at the terminal point $x = 1$. Customers are uniformly distributed along this interval, and each patient selects the channel that maximizes their shopping utility.

In the construction of the customer utility function, three components are considered: product utility, distance, and expenses. Firstly, the product utility $V$ is an essential component, as it ensures that the customers buy at least one item. The Second factor that affects customer utility is the distance between customers and retailers,
which brings negative utility that includes transportation cost, time cost, fatigue, and so on. The greater the
distance, the greater the negative effect. Assuming that the negative utility generated is linear with the distance,
we set the distance coefficient as $t$. Thirdly, the expenses refers to the retail prices paid for purchasing goods.
By aggregating the three aforementioned components, we can derive the utility values for each channel for
customers. Once each customer has made their choice, the corresponding market share for each channel can be
calculated. Utilizing the market share model and the customer utility function for each channel, we can determine
the optimal prices and maximum profits for shareholders in the three scenarios. Through a comparison of the
optimal outcomes, we can establish the decision-making conditions for the manufacturer.

Furthermore, we introduce other market parameters: $x_s$, $x_l$ denotes the boundary points of market share,
while $D_s$, $D_l$, $D_e$ represents the respective shares. Similarly, $\pi_s$, $\pi_l$, $\pi_m$ represents the profits of the fringe
retailer, dominant retailer, and manufacturer, respectively. The revenue of the e-platform is denoted by $r_e$. The
e-platform generates revenue by imposing commission charges on online merchants, and the commission rate $\lambda$
is determined by the e-platform itself. For instance, Tmall, the world’s largest e-platform, uses a commission
rate of $\lambda = 5\%$ for clothes and $\lambda = 2\%$ for electronic products, with all rates being less than 5\% [33].

3.1. Dual-channel model

In this section, a dual-channel model based on customer utility theory is constructed. The customers’ decision
expression is determined by the following equation:

$$\text{max}[V - tx - p_s, V - t(1 - x) - p_l].$$

(1)

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

$$V - tx - p_s = V - t(1 - x) - p_l.$$  

(2)

Therefore

$$x = \frac{p_l - p_s}{2t} + \frac{1}{2}.$$  

(3)

Due to the upcoming comparison of optimal profits among the three scenarios, we omit fixed costs such as
rent, warehousing, and labor for retailers [18]. Instead, we directly represent the unit profit of retailers directly
as the difference between their sales price and wholesale price. At this stage, the customer demand for each
channel is well-defined. Therefore, the expressions for the profits of dominant and fringe retailers are as follows:

$$\pi_l = (p_l - w)(1 - x)$$  

(4)

$$\pi_s = (p_s - w - \Delta w)x.$$  

(5)

Then the cut-off point is substituted into the profits, according to Nash equilibrium $\frac{\partial \pi_l}{\partial p_l} = 0$, $\frac{\partial \pi_s}{\partial p_s} = 0$, the
expressions of optimal retail prices are obtained:

$$p_l = t + w + \frac{\Delta w}{3}$$  

(6)

$$p_s = t + w + \frac{2}{3} \Delta w.$$  

(7)

At this moment, by substituting $p_l$ and $p_s$ into equation (3), the expression for $x$, which represents the market
share of the fringe retailer $D_l$, can be obtained. The market share of the dominant retailer $D_s$ can be derived
by subtracting $1 - x$. Therefore the expressions of the market demand of the dominant retailer’s channel and
the fringe retailer’s channel are obtained as follows:

$$D_l = \frac{\Delta w}{6t} + \frac{1}{2}, D_s = -\frac{\Delta w}{6t} + \frac{1}{2}.$$  

(8)
Since all products in the entire supply chain are produced by the single manufacturer, the production, setup, and holding costs are equal in all three scenarios. These costs are offset when comparing the manufacturer’s profits, so this paper avoided this portion of the costs. Moreover, we assumed that the manufacturer and retailer are geographically distant, not in the same province or region, and the transportation costs are borne by the manufacturer. In the aforementioned three scenarios, the transportation process requires one vehicle and one person, with the same distance traveled and time consumed, resulting in the same transportation costs for the manufacturer. Similarly, this transportation cost from manufacturer to retailer will be offset in the profits comparison. Therefore, we represent the manufacturer’s profit by aggregating its revenue across all channels. The formula for calculating the manufacturer’s profit, which is formed by the sum of profits from dual channels, is obtained as follows:

\[
\pi_m = w\left(\frac{\Delta w}{6t} + \frac{1}{2}\right) + (w + \Delta w)\left(-\frac{\Delta w}{6t} + \frac{1}{2}\right).
\]  

To maximize profit \(\frac{\partial \pi_m}{\partial \Delta w} = 0\), the optimal wholesale price is obtained by:

\[
\Delta w = \frac{3t}{2}.
\]

By substituting the expression for into the aforementioned optimal value expressions for retail prices, profits, and market shares, respectively. So far, all optimal values are obtained as follows:

\[
\begin{align*}
p_l &= \frac{3t}{2} + w, \quad p_s = 2t + w, \quad D_l = \frac{3}{4}, \quad D_s = \frac{1}{4}, \\
\pi_l &= \frac{9t}{8}, \quad \pi_s = \frac{t}{8}, \quad \pi_m = \frac{3t}{8} + w, \quad x = \frac{3}{4}.
\end{align*}
\]

The optimal results indicate that: (1) \(p_s > p_l\) and the difference in retail prices can be explained by \(\Delta p_{s-l} = \frac{t}{2}\), which is only related to the unit transportation cost, and (2) the dominant retailer always earns higher profits than the fringe retailer.

### 3.2. Multi-channel model

In this section, the manufacturer opens an e-shop on a 3rd e-platform denoted by a superscript. Customers will see two prices: the commodity price, which is paid to the e-shop, and the express cost, which is paid to a home-delivery company. The express cost is denoted by \(c'_e\). Normally, the express cost \(c'_e\) is around 15 CNY (Chinese Yuan). Thus the customers decision expression is determined by:

\[
\max[V - tx'_s - p'_s, V - t(1 - x'_l) - p'_l, V - c'_e - p'_e].
\]  

To determine the cut-off point of customers utility, we set:

\[
\begin{cases}
V - tx'_s - p'_s = V - c'_e - p'_e \\
V - t(1 - x'_l) - p'_l = V - c'_e - p'_e.
\end{cases}
\]

The solutions of in differential points are obtained:

\[
x'_s = \frac{c'_e + p'_e - p'_s}{t}, \quad x'_l = 1 - \frac{c'_e + p'_e - p'_l}{t}.
\]

The boundary points of market share must satisfy the following inequality:

\[
0 < x'_s < x'_l < 1.
\]
Using the same method to obtain the optimal retail prices:

\[ p'_i = \frac{c'_e + p'_e + w}{2} \]  \hspace{1cm} (12)

\[ p'_s = \frac{c'_e + p'_e + w + \Delta'w}{2}. \]  \hspace{1cm} (13)

And The profit of the manufacturer is written as follows:

\[ \pi'_m = (1 - \lambda)p'_e \left( 1 + \frac{2w + \Delta'w - 2p'_e - 2c'_e}{2t} \right) + (w + \Delta') \left( \frac{c'_e + p'_e - w - \Delta'w}{2t} \right) + w \left( \frac{c'_e + p'_e - w}{2t} \right). \]  \hspace{1cm} (14)

According to no-arbitrage conditions:

\[ \begin{cases} 
  p'_e > w \\
  p'_e > w + \Delta'. 
\end{cases} \]  \hspace{1cm} (15)

The revenue of the e-platform is determined by:

\[ r'_e = \lambda p'_e \left( 1 + \frac{2w + \Delta'w - 2p'_e}{2t} \right). \]  \hspace{1cm} (16)

Firstly, it is necessary to determine whether there is a maximum profit for the manufacturer. By taking the second-order partial derivatives of \( \pi'_m \) with respect to \( p'_e \) and \( \Delta'w \), the Hessian matrix is obtained:

\[ H = \begin{bmatrix} 
  \frac{\partial^2 \pi'_m}{\partial p'_e \partial p'_e} & \frac{\partial^2 \pi'_m}{\partial p'_e \partial \Delta'w} \\
  \frac{\partial^2 \pi'_m}{\partial \Delta'w \partial p'_e} & \frac{\partial^2 \pi'_m}{\partial \Delta'w \partial \Delta'w} 
\end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} \\
  f_{21} & f_{22} \end{bmatrix} \]  \hspace{1cm} (17)

where \( f_{11} = -\frac{2(1 - \lambda)}{t}, f_{12} = f_{21} = \frac{2 - \lambda}{2t}, f_{22} = -\frac{1}{t} \).

Therefore \( |H| = \frac{4 - 4\lambda - \lambda^2}{4t}, |H_1| = \frac{2(1 - \lambda)}{t} \).

When \( 0 < \lambda < 2(\sqrt{2} - 1) \), \( |H| > 0, |H_1| < 0 \). In the real cases, \( \lambda = \frac{1}{10} \) at most. So \( \pi'_m \) is strictly jointly concave in \( p'_e \) and \( \Delta'w \).

Then setting \( \frac{\partial \pi'_m}{\partial p'_e} = 0, \frac{\partial \pi'_m}{\partial \Delta'w} = 0 \), the optimal \( p'_e \) and \( \Delta'w \) are obtained as follows:

\[ p'_e = \frac{4t(1 - \lambda) - c'_e(2 - 3\lambda) + 2w(2 - \lambda)}{4 - 4\lambda - \lambda^2} \]  \hspace{1cm} (18)

\[ \Delta'w = \frac{2[t(2 - 3\lambda) + c'_e(1 - \lambda) + (w + t)\lambda^2]}{4 - 4\lambda - \lambda^2}. \]  \hspace{1cm} (19)

By substituting equations (18) and (19) into the aforementioned optimal value expressions for retail prices, profits, and market shares, respectively. Then other market parameters are obtained:

\[ p'_i = \frac{4t(1 - \lambda) - c'_e(2 - \lambda - \lambda^2) + w(8 - 6\lambda - \lambda^2)}{2(4 - 4\lambda - \lambda^2)} \]  \hspace{1cm} (20)

\[ p'_s = \frac{2t(1 - \lambda)(4 - \lambda) + c'_e(1 - \lambda)(2 + 3\lambda) + w(2 - \lambda)(4 - \lambda)}{2(4 - 4\lambda - \lambda^2)} \]  \hspace{1cm} (21)

\[ D'_s = \frac{2t\lambda(1 - \lambda) + c'_e(2 - 3\lambda + \lambda^2) + w\lambda(2 - \lambda)}{2t(4 - 4\lambda - \lambda^2)} \]  \hspace{1cm} (22)

\[ D'_i = \frac{4t(1 - \lambda) + c'_e(1 - \lambda)(2 + \lambda) + w\lambda(2 + \lambda)}{2t(4 - 4\lambda - \lambda^2)} \]  \hspace{1cm} (23)
\[ D'_c = \frac{t(2 - 3\lambda) - 2c'_e(1 - \lambda) - 2\lambda w}{t(4 - 4\lambda - \lambda^2)} \]  
(24)

\[ r'_c = \frac{\lambda[4t(1 - \lambda) + c'_e(3\lambda - 2) + 2w(2 - \lambda)] [t(2 - 3\lambda) + c'_e(2 - 2\lambda - \lambda^2) - 2\lambda w]}{t(4 - 4\lambda - \lambda^2)^2} \]  
(25)

\[ \pi'_l = \frac{[4t(1 - \lambda) + c'_e(2 + \lambda)(1 - \lambda) + w\lambda(2 + \lambda)]^2}{4t(4 - 4\lambda - \lambda^2)^2} \]  
(26)

\[ \pi'_s = \frac{[2t\lambda(1 - \lambda) + c'_e(2 - 3\lambda + \lambda^2) + w\lambda(2 - \lambda)]^2}{4t(4 - 4\lambda - \lambda^2)^2} \]  
(27)

\[ \pi'_m = \frac{2t^2(1 - \lambda)^2 + t(1 - \lambda)[c'_e(-2 + 3\lambda) + 2w(2 - \lambda)] - [c'_e(1 - \lambda) + w\lambda]^2}{t(4 - 4\lambda - \lambda^2)} \]  
(28)

If \( \pi'_m \geq \pi^m \), the manufacturer will adopt the e-commerce mode, which implies:

\[ \frac{2t^2(1 - \lambda)^2 + t(1 - \lambda)[c'_e(-2 + 3\lambda) + 2w(2 - \lambda)] - [c'_e(1 - \lambda) + w\lambda]^2}{t(4 - 4\lambda - \lambda^2)} \geq \frac{3t}{8} + w. \]  
(29)

Combining equations (11), (15) and (29), the following inequalities is obtained:

\[
\begin{cases}
    t(2 - 3\lambda) - 2c'_e(1 - \lambda) + 2w\lambda > 0 \\
    2t\lambda(1 - \lambda) - c'_e(2 - \lambda - 2\lambda^2) + w\lambda(2 - \lambda) > 0 \\
    \frac{2t^2(1 - \lambda)^2 + t(1 - \lambda)[c'_e(-2 + 3\lambda) + 2w(2 - \lambda)] - [c'_e(1 - \lambda) + w\lambda]^2}{t(4 - 4\lambda - \lambda^2)} \geq \frac{3t}{8} + w.
\end{cases}
\]  
(30)

If the commission rate \( \lambda \) and express cost \( c'_e \) satisfy the inequalities (30), the manufacturer will be inclined to open an e-shop to increase their profits relative to the dual-channel scenario.

3.3. Coordination model

In this section, an O2O strategy is proposed: “Order Online, Self-Pickup at the Fringe Retailer”. This strategy offers notable advantages, including substantial reductions in logistics costs and waiting times.

As the cost of e-commerce is relatively low, under this O2O model, the fringe retailer gradually loses its retailing function and only exists as a self-pickup point. To ensure the success of the collaborative effort, the manufacturer must ensure that the fringe retailer maintains its original profit levels, at least when compared to the multi-channel model. This is achieved by the manufacturer providing compensation to the fringe retailer, with the compensation amount being equivalent to the profit earned under the multi-channel scenario. Additionally, customers who choose self-pickup also contribute to the sales of other products. Consequently, the fringe retailer demonstrates a willingness to cooperate. Thus, the coordination model structure transforms into a dual-channel setting comprising the dominant retailer and the e-manufacturer, denoted with a superscript "'.

The expression for customers decision-making under O2O scenario is as follows:

\[ \max[V - tx'' - p''_e, V - t(1 - x'') - p''_f]. \]  
(31)

Similar to Section 3.3, the boundary line of the market share is determined by:

\[ x'' = \frac{p''_e - p''_f}{2t} + \frac{1}{2}. \]  
(32)

And the profits and the revenue of the e-platform can be determined as follows:

\[ \pi''_l = (p''_e - w)x'' \]  
(33)

\[ \pi''_m = (1 - \lambda)p''_e x'' + w(1 - x'') \]  
(34)
\[ r''_e = \lambda p'' x''. \]  

(35)

The manufacturer acts as the leader and sets the e-price, while the dominant retailer acts as the follower and determines the retail price accordingly. By using Stackelberg game theory and solving for \( \frac{\partial \pi''_m}{\partial p''_i} = 0, \frac{\partial \pi''_{m+i}}{\partial p''_e} = 0 \), we obtain the following expressions for the optimal retail prices:

\[ p''_l = t + \frac{w(3 - 2\lambda)}{3(1 - \lambda)} \]  

(36)

\[ p''_e = t + \frac{w(3 - \lambda)}{3(1 - \lambda)}. \]  

(37)

Obviously, \( p''_l < p''_e \).

By simultaneously substituting equations (36) and (37) into equations (32)–(35). Other optimal market parameters are obtained as follows:

\[ x'' = \frac{1}{2} \left( \frac{\lambda w}{6t(1 - \lambda)} \right) \]  

(38)

\[ r'' = \frac{\lambda [3t(1 - \lambda) + w(3 - \lambda)][3t(1 - \lambda) - w\lambda]}{18t(1 - \lambda)^2} \]  

(39)

\[ \pi''_l = \frac{[3t(1 - \lambda) + \lambda w]^2}{18t(1 - \lambda)^2} \]  

(40)

\[ \pi''_{m+i} = \frac{9t^2(1 - \lambda)^2 + 6tw(1 - \lambda)(3 - \lambda) + w^2\lambda^2}{18(1 - \lambda)} \]  

(41)

As the manufacturer remains the same fringe’s profit, his profit is determined by:

\[ \pi''_m = \pi''_{m+i} - \pi''_s. \]  

(42)

So the preconditions for implementing the “order online, pickup offline” strategy are followed:

\[ \begin{cases} 
\pi''_m \geq \pi''_s \\
x'' > 0. 
\end{cases} \]  

(43)

Thus, we have completed the analysis of the preconditions for implementing strategies and the changes in the supply chain under different strategies. Figure 4 clearly shows the manufacturer’s decision-making process. Based on the actual market competition, the manufacturer decides whether to open an e-shop by satisfying the inequalities in equation (30). If the e-commerce strategy is adopted by the manufacturer, they will face the second multiple-choice question: whether to unite with the fringe retailer to solve the last mile problem. If the inequalities in equation (43) are satisfied, the coordination strategy can be implemented. Otherwise, the manufacturer will abandon the coordination program, the online orders will be delivered by third-party express companies.

In the next section, we conduct numerical experiments to examine the decision tree and study the characteristics of the coordination strategy.

4. Numerical studies

The numerical experiments section is divided into two parts: the first part uses the example of mobile phone to compare the profits and decision variables of the supply chain members under the three models. The second part examines the impact of setting the commission rate for the e-platform on its own revenue and the manufacturer’s profit.
First of all, to study the decision-making process of manufacturers, retail prices of channels and revenue of e-platform, we use the example of purchasing a phone with a wholesale price of $w = 2000$ CNY. This price range is widely representative of mobile phones in the Chinese market. Suppose a consumer located at the left end of a city $x = 0$ wants to buy a phone from a shopping mall located at the right end $x = 1$, which takes half a day to complete. We assume a distance coefficient of $t = 300$, taking into account daily income levels, transportation costs, and fatigue. Using data from the Tmall platform, we set the commission rate $\lambda = 0.02$ (or 2%), and based on the information provided in Sections 3.2 and 3.3, the express cost $c'_e$ is set as 15 CNY. Using these parameters, we obtain the following changes in the market parameters.

From the profits module in Table 4, we observe that the dominant retailer prefers a dual-channel environment for maximum profit $\pi_l$. However, as the leader of the supply chain, if the manufacturer chooses e-shop strategy, the profit of the dominant retailer $\pi_l$ will sharply decrease by 72%. If the manufacturer continues to adopt “order online, pickup offline” coordination strategy, the profit of the dominant retailer $\pi_l$ will rapidly increase by 74%, but it will still only be half of the profit in the dual-channel scenario. Thus, it is evident that the dominant retailer’s profit $\pi_l$ is heavily influenced by the manufacturer’s strategy. The impact of e-commerce on the profit of the fringe retailer $\pi_s$ is also significant, with a decrease of 96.8%. It is difficult for small retailers in certain commodity markets (e.g., phones, clothes) to survive under the e-commerce environment.

But from the manufacturer’s perspective, e-commerce and self-pickup can bring in more profits. Assuming a wholesale net profit margin of 5% for the mobile phone manufacturer [34], the cost for the manufacturer is 1904. In three different scenarios, the net profits for the manufacturer are 209, 218, and 229, respectively.
The net profit growth of 4.3% and 5% respectively is a substantial increase. Clearly, as the decision-maker, the manufacturer will open an e-shop and coordinate with the fringe retailer to provide self-pickup services. Simultaneously, the revenue module shows the e-platform also hopes to implement this coordination model for maximum revenue.

In summary, compared to the dual-channel model, the multi-channel model results in an increase in manufacturer’s profit, but a significant decrease in profit for both dominant and fringe retailers. In contrast, the coordination strategy model, when compared to the multi-channel model, leads to an increase in manufacturer’s profit and an increase in profit for dominant retailers. Therefore, the establishment of an e-commerce channel by the manufacturer is advantageous for their own interests, but it severely harms the interests of retailers. The coordination strategy, while increasing the manufacturer’s profit, further impairs the interests of large retailers. Next, we will analyze the impact of the e-commerce channel on the supply chain from the perspective of retail prices.

From the retail prices module in Table 5, we can infer the following: (1) The introduction of e-commerce channels leads to a significant decrease in retail prices for both the dominant retailer and the fringe retailer, which benefits consumers. (2) In the multi-channel scenario, the dominant retailer offers the cheapest mobile phone prices due to its advantage in wholesale pricing. However, distant consumers who purchase from this retailer incur additional time and travel costs. (3) In the multi-channel scenario, consumers’ payment costs amount to 2328 (retail price plus express fee), which is similar to the payment cost of 2327 in the coordinated scenario. Hence, consumers do not benefit from channel coordination. In summary, from the perspective of retail prices, the introduction of e-commerce channels benefits both consumers and manufacturer, while the dominant retailer incurs the greatest loss. The above analysis focused on the decision-making entities within the supply chain. The following discussion will examine these scenarios from the perspective of the e-platform.

Here, we select two distinct products with different wholesale prices to examine the variations in manufacturer’s profit and the revenue of e-platform by manipulating the commission rate $\lambda$.

Figure 5a illustrates the following observations: (1) As the commission rate $\lambda$ of the e-platform increases, the manufacturer’s profit decreases. (2) The commission rate $\lambda$ exhibits a maximum value. In the multi-channel scenario, the commission rate $\lambda$ cannot exceed 3%; otherwise, the manufacturer will not establish an e-commerce channel. However, under the coordination scenario, the maximum value of the commission rate $\lambda$ can be extended to 4.8%. If the commission rate $\lambda$ exceeds this threshold, the manufacturer will abandon the coordination strategy.

### Table 5. Changes of market parameters under different scenarios (Prices).

<table>
<thead>
<tr>
<th></th>
<th>$\Delta w$</th>
<th>$p_s$</th>
<th>$p_e$</th>
<th>$p_l$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual-channel</td>
<td>450</td>
<td>2600</td>
<td>–</td>
<td>2480</td>
</tr>
<tr>
<td>Multi-channel</td>
<td>298</td>
<td>2312</td>
<td>2313</td>
<td>2164</td>
</tr>
<tr>
<td>Coordination</td>
<td>–</td>
<td>–</td>
<td>2327</td>
<td>2314</td>
</tr>
</tbody>
</table>

### Table 6. Changes of market parameters under different scenarios (Revenue).

<table>
<thead>
<tr>
<th></th>
<th>E-commerce platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual-channel</td>
<td>–</td>
</tr>
<tr>
<td>Multi-channel</td>
<td>19.7</td>
</tr>
<tr>
<td>Coordination</td>
<td>22.2</td>
</tr>
</tbody>
</table>
Figure 5. Results with $w = 2000$. (a) Manufacturer’s profit with $w = 2000$. (b) Revenue of e-platform with $w = 2000$.

Figure 6. Results with $w = 500$. (a) Manufacturer’s profit with $w = 500$. (b) Revenue of e-platform with $w = 500$.

From Figure 5b, it can be observed that if the manufacturer adopts the coordination strategy, the e-platform can generate more revenue. Therefore, combining the findings from the two figures, the e-platform should encourage O2O coordination between manufacturers and offline retailers.

To compare the characteristics of different commodities, we set the total price to be 500. As shown in Figures 6a and 6b, the feasible range of the commission rate $\lambda$ is wider, up to 9%. Therefore, the e-platform sets the commission rate $\lambda$ for cheaper products at 9%, which is justifiable. The comparison indicates that the lower the price of the goods, the higher the commission rate $\lambda$ will be.

5. Sensitivity analysis

In this section, we analyze the impacts of variations in parameter values (% change) on profits. To conduct the sensitivity analysis, we systematically increase the value of each parameter by 20%, individually, while keeping the remaining parameters unchanged. Assuming the wholesale price $w = 2000$ CNY, the distance coefficient $t = 300$, the commission rate of e-platform $\lambda = 0.02$, the express cost under multi-channel scenario $c_e = 15$ CNY. the corresponding results are given in Table 7.

In above table, ↑, ↓ and – represent increase, decrease and irrelevant respectively. Based on the findings presented in Table 7, several observations can be made. (1) the wholesale price $w$ demonstrates the greatest impact on the profits of manufacturers and retailers, primarily due to its larger absolute value. However, in the context of coordination, the profit of the dominant retailer is significantly affected by an increase in the wholesale price. This effect can be attributed to the O2O coordination strategy, which attracts a considerable number of customers to choose online transactions. (2) The distance coefficient $t$ emerges as the next significant factor. As
the distance coefficient $t$ increases, the profits of all supply chain parties also increase. This relationship can be attributed to the rise in consumer income associated with greater distances. (3) the effects of express costs $c'_e$ and commission rate $\lambda$ on manufacturers and the dominant retailer are relatively small. However, they have a significant impact on the profit of the fringe retailer. The increase in express cost and commission rate benefits the fringe retailer by promoting its offline sales. Therefore, in the decision-making context, special attention should be given to the values of the wholesale price for the successful implementation of the coordination strategy.

### 6. Managerial Implications

This study provides useful insights for companies facing competition across multiple sales channels in today’s growing e-commerce landscape. Several key implications for managers are summarized below.

- Account for the impact of asymmetric retailers: manufacturers must recognize the varying impacts of e-commerce channel on retailers with different market positions before developing a long-term supply chain strategy. It is anticipated that offline retailers will expand their online presence in the future.
- Develop a coordination strategy: developing an effective coordination strategy can unify different retailer channels and facilitate the implementation of a multi-channel approach. The “Order Online, Pickup Offline” approach can be particularly effective in coordinating the supply chain, enabling manufacturers to enhance efficiency and reduce delivery costs.
- Commission rates setting: e-platforms can incentivize manufacturers to adopt O2O strategy by reducing commission rates, thereby increasing their own revenue. The commission rates vary by product prices, with cheaper goods permitting higher rates. Therefore, e-platforms should optimize commission rates according to product value to maximize profits across their diverse product portfolios.

In complex multi-channel environments, consideration of these implications can guide manufacturers, retailers and e-platforms towards cooperation, pricing optimization, and profitable long-term strategies aligned with changing retail dynamics. Coordinated approaches balancing stakeholder interests may prove most sustainable.

### 7. Conclusions

To examine the manufacturer’s decision-making and coordination strategy in an asymmetric multi-channel environment (e.g., should an e-shop be established? If so, should it be coordinated with offline retailers?), we utilize a customer utility function and create a three-channel model that includes a dominant retailer channel, fringe retailer channel, and e-channel via an e-platform. There are three scenarios: the traditional dual-channel scenario, the multi-channel scenario, and the multi-channel scenario with an “order online, pickup offline” coordination strategy. By utilizing a two-stage optimization technique and a Stackelberg game framework, we derive the inequalities (30) and (43) that aid manufacturers in making decisions. Thus, we theoretically solve the manufacturer’s decision-making problem, which constitutes the primary contribution of this article.

To illustrate the impact of e-commerce on stakeholders, we examine the case of phone sales on the Tmall platform. Our results show that (1) profits of retailers drop sharply, especially for the fringe retailer whose profit
decreases by 97%; similarly, the market share falls by 80%, indicating that e-commerce significantly increases competition among channels and enhances the manufacturer’s market power. (2) The coordination strategy is good for the manufacturer, with profits increasing by 17% compared to the traditional dual-channel scenario. (3) E-commerce leads to a decline in consumer spending. (4) Furthermore, we compare commission rates for different whole prices, revealing that higher-priced products have lower commission rates, which is useful for e-platforms in setting charge standards.

In conclusion, this study highlights the importance of proactive decision-making and strategic coordination for manufacturers in the face of evolving market conditions. The introduction of manufacturer-led e-commerce as a new sales channel reduces customers’ expenditures, ultimately leading to a significant decline in customer numbers and profits for offline retailers. A reshuffle of the retail industry is inevitable. This research explored new supply chain decision issues under e-commerce background through a novel coordination pattern, validated through quantitative methodology. The findings contribute to both theoretical research and practical applications.

Several topics warrant further investigation. As mentioned earlier, we highlight the cross-selling effect of the coordination strategy, which increases the customer arrival rate for the fringe retailer and drives sales of other products. Does this cross-selling effect influence the decision-making of the fringe retailer regarding coordination? Additionally, if consumers prefer “order online, home-delivery offline” instead, how should the designed coordination strategy be improved? These questions are intriguing and hold research value.

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