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Promotion strategies of food delivery O2O supply chain considering service congestion effect with anti-food waste regulation

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Amidst the rapid expansion of the online-to-offline (O2O) food delivery sector, this paper investigates the promotion strategies employed by restaurants and food delivery platforms within the supply chain, and explores how these entities select promotion strategies under different conditions, including the intensity of government anti-food waste regulations, service congestion effect, and commission ratio, with the aim of improving profits and reducing food waste. Utilizing a game-theoretical approach, we focus on three primary promotion strategies: a no-promotion strategy (*N* strategy), a price discount strategy (*D* strategy), or a volume-based price discount strategy (*S* strategy). Our results reveal that the restaurant's choice of promotion strategy is significantly correlated with the offline congestion effect, but not directly associated with anti-food waste regulations. Conversely, the platform's optimal strategy and the extent of food waste are more closely related to the stringency of anti-food waste penalties. Under specific conditions, a win-win scenario can be achieved where both restaurants and platforms benefit economically while reducing food waste.

KEYWORDS

food waste, food supply chain, online-to-offline, service congestion effect, promotion strategy

1 Introduction

The global online food delivery sector has witnessed remarkable expansion, altering dietary habits worldwide. Owing to the adoption of the online-to-offline (O2O) business model, conventional food delivery services have undergone a paradigm shift. In recent years, there has been an exponential increase in consumer demand for dining convenience, which online food delivery platforms satisfy by providing not only ease of ordering but also a broader selection of culinary choices (Das and Ramalingam, 2023). According to the Global Digital Report 2023 released by We Are Social USA, as of the beginning of 2023, there were 5.44 billion global mobile phone users and 5.16 billion internet users, with 94.8% using mobile phones to access the internet (Creativebrief, 2023). The ascendancy of food delivery platforms, exemplified by Meituan, Ele.me, and Didi, signifies the burgeoning popularity of the food delivery sector, particularly among urban dwellers. The fusion of internet technology with market activities, coupled with the ubiquity of smartphone applications and online payment systems, has facilitated the provision of diverse electronic menus by these platforms. This innovation enables consumers to not only order food online but also to evaluate their purchases, thereby enriching the consumer experience with added variety and convenience

(Niu et al., 2021). Nevertheless, the swift expansion of the food delivery industry has given rise to certain challenges, the two primary issues being service congestion and food waste.

One significant challenge inherent in the food delivery O2O supply chain is service congestion. With an increase in the volume of orders, there is competition between food delivery and dine-in orders for the restaurant's kitchen resources. This competition can result in service delays and a subsequent decline in customer satisfaction when the kitchen's effective processing capacity is exceeded (Du et al., 2023). This congestion not only erodes the efficiency of the supply chain but also contributes to higher operating costs and squandered resources. The repercussions of service congestion extend to increased fuel consumption, heightened traffic congestion, and detrimental environmental impacts. The ramifications of these issues extend beyond the financial and operational spheres of the supply chain, encompassing social implications such as elevated greenhouse gas emissions and the depletion of natural resources (El-Didy et al., 2024).

Another serious issue confronting the food distribution sector is food waste. Due to the nature of the industry, consumers can order an extensive array of dishes, resulting in a significant disparity between the quantity ordered and the amount consumed, with a degree of waste at home for food delivery users. This mismatch generates a substantial amount of food waste, exacerbating the global challenge of food waste (Khalil et al., 2021; Graham-Rowe et al., 2014). Food waste represents not only an environmental challenge but also a financial burden for delivery platforms and restaurants (Heidari et al., 2020). Furthermore, food waste undermines the objective of sustainable development, as these resources could otherwise be allocated to nourish the world's increasingly populous inhabitants. Presently, governmental anti-food waste regulations primarily target the restaurant industry as a whole, without singling out the swiftly expanding food distribution sector for special consideration (Aiden et al., 2024). Additionally, there is a paucity of academic research in this domain and a shortage of scientific theoretical frameworks for government regulation, resulting in persistent waste issues within the food distribution industry.

According to the latest statistics published by the China Internet Network Information Center (CNNIC) as of December 2023, the user base for online food delivery in China has expanded to 545 million, an increase of 23.38 million from December 2022. This growth underscores the continuous influx of new establishments onto platforms such as "Ele.me" and "Meituan" alongside the closure of some shops due to various circumstances. The food delivery platforms, exemplified by "Ele.me" and "Meituan" experience a daily influx of new stores while simultaneously witnessing the exit of some establishments, indicating robust competition within the restaurant (Han et al., 2019). The burgeoning food delivery sector has precipitated a greater demand for streamlined and sustainable supply chain processes. In response to these difficulties, there is an immediate necessity for the development of impactful marketing strategies and the enhancement of food delivery O2O supply chain operations. Such strategies must factor in the triggers of service congestion and integrate actions to mitigate food waste, thereby diminishing waste and augmenting customer satisfaction. Moreover, offering high-quality food delivery services is a critical aspect that can bolster the competitive edge of food service enterprises (Anbumathi et al., 2023).

The objective of this study is to furnish restaurants with viable strategic alternatives for addressing real-world challenges, comprehensively considering the intricacies of service congestion and the necessity for anti-food waste regulations. It is anticipated that the findings of this research will yield actionable insights for food delivery platforms, supply chain managers, and policymakers, thereby facilitating the optimization of operational procedures and the abatement of service congestion. These efforts aim to curtail food waste, lessen economic burdens, and contribute to global endeavors aimed at reducing food waste. This investigation is of profound significance and broad implications in tackling the worldwide issue of food waste and in fostering sustainable patterns of food consumption.

Furthermore, this research contributes to the enrichment of the current scholarly discourse on food delivery supply chains and sustainability. It offers a thorough examination of the obstacles faced by the online-to-offline (O2O) food delivery supply chain, with a particular focus on service congestion and food waste. The strategic outreach initiatives and recommendations put forth offer tangible and viable solutions to these issues, thereby making a significant contribution to the domain of supply chain management and sustainability.

In summary, the food delivery industry, enabled by the Online-to-Offline (O2O) business model, has significantly transformed how food is ordered and distributed. Nonetheless, the accompanying issues of service congestion and food waste necessitate resolution. Through the formulation of efficient promotion strategies (Somesh and Priyanka, 2020), the operation of the food delivery O2O supply chain can be enhanced to reduce food waste. By tackling these challenges, this study advocates for the adoption of sustainable food delivery practices and contributes to the development of a more efficient, sustainable, and responsible food delivery industry.

This study aims to investigate the promotion strategies employed within the restaurant and food delivery O2O supply chain within the context of government anti-food waste legislation, specifically within the scenario where users have the option to choose between dual channels for food ordering. The research concentrates on examining the effects of anti-food waste regulations and offline service congestion on food waste within the supply chain, as well as how these factors shape the decision-making process and the selection of promotion strategies among supply chain participants.

Specifically, this paper addresses the following core questions:

(1) How do anti-food waste regulations and offline service congestion effect influence food waste within the O2O food delivery supply chain?
(2) How do these factors impact the decision-making processes of O2O food delivery supply chain participants?
(3) How do these factors alter the selection of promotion strategies by restaurants and online delivery platforms?

To address these issues, this paper examines three promotion strategies: no promotion strategy, price discount promotion strategy, and volume-based price discount strategy and analyzes the influence of key factors, including anti-food waste regulations, offline service congestion effect, and commission percentages, on the selection of these promotion strategies. The paper explores how the two primary stakeholders, restaurant and online platform, in the O2O food delivery supply chain, are affected by these factors in their promotion decision-making processes, and offers recommendations for appropriate strategy choices. The key contributions of our study can

be summarized: (1) The impact of promotion strategies on profitability varies depending on market conditions, highlighting the need for flexibility in strategy selection. (2) Consumer sensitivity to price changes is a pivotal consideration in strategy selection, as it directly influences the effectiveness of price-based promotions. (3) Restaurants must be accommodating in modifying their promotion strategies to optimize profitability and bolster market position, taking into account the dynamic nature of the market and consumer preferences. Drawing on the findings and conclusions of the study, government regulators can fashion more potent regulatory approaches and collaborate with industry players to lessen food waste, promote economic sustainability, and enhance operational efficiency.

The paper is structured as follows: Section 2 offers a literature review on the subjects of food waste, service congestion effect, and promotion strategies within the O2O food delivery supply chain. Section 3 outlines the problem statement and the assumptions made, and calculates the optimal solution under different promotion strategies. Section 4 delves into the analysis of the impact of key parameters on the decision variables. Section 5 explores issues that cannot be comparatively analyzed due to the complexity of the model through numerical examples, and synthesizes the study's findings. The proofs are provided in the Supplementary material.

2 Literature review

This section presents a comprehensive literature review focusing on three central themes: anti-food waste regulations, offline service congestion effect, and promotion strategies. Through an in-depth analysis of the current research on these topics, this section aims to identify the connections and distinctions between the existing body of knowledge and the present study. This aim is to more accurately situate the current study within the academic discourse and highlight its unique research contributions.

2.1 Anti-food waste regulation

Our study is situated within the context of governmental anti-food waste regulation, which is inherently linked to anti-food waste management. Food waste is an intricate and widespread issue, yet with the escalating concerns surrounding sustainability, including environmental degradation, economic burdens, and food crises, both governments and societies are reassessing their approaches to food waste regulation. Scholars have similarly investigated this matter, and the extant literature systematically outlines strategies to prevent food waste and the prudent application of regulatory mechanisms by oversight agencies.

Food waste poses a significant and far-reaching global problem, impacting the economy, society, environment, and ethics (Dumitru et al., 2021). As discussed by Göbel et al. (2015), government regulations play a crucial role in reducing food waste within the supply chain. The imposition of penalties for food waste, through the enforcement of regulations, can serve as a deterrent and help decrease the amount of food wasted. Corrado and Sala (2018) suggest that food waste is often a manifestation of inefficiencies within the food supply chain. Govindan (2018) suggests that more effective management of the food supply chain can lead to a 23% reduction in food waste. Kourmentza et al. (2018) note that the mitigation of food waste is increasingly being recognized as a fundamental aspect of food supply chain management. Additionally, the French government has taken steps to enhance waste control by implementing penalties for supermarkets that discard edible food, which has proven to be an effective measure in reducing waste (Cane and Parra, 2020). The existing literature provides a coherent account of strategies to prevent food waste and the regulatory mechanisms designed to cope with it (Szulecka and Strøm-Andersen, 2022; Steenmans and Malcolm, 2023).

Government regulations have a significant impact on companies in the supply chain, promotion would tend to disturb consumers' efforts tempting to plan and manage their food purchases in relation to their needs and stocks (Farr-Wharton et al., 2014). However, different forms of promotions may alter in different ways consumers' attitudes towards promotions and choice. Indeed, consumers have become increasingly concerned about food waste (Evans, 2011) and may take into account the perceived probability of waste when they buy perishable products with different forms of promotion. Given that food waste is a consequence of consumption patterns, it is essential for consumers to reassess their consumption habits and minimize or repurpose food that would otherwise be wasted (Ferrara and Missios, 2016). Consumers can diminish the quantity of food waste (FW) within their households by consuming less, avoiding overbuying, and encouraging their friends, family, and acquaintances to adopt similar practices (Foon et al., 2020). Furthermore, anti-food waste regulations are effective in curbing food waste in food delivery services (Xu et al., 2024). Consumers' efforts to reduce their food intake can significantly contribute to the overall decrease in food waste (Kim et al., 2019).

Much of the existing research on anti-food waste regulations concentrates on the inhibitory impact of these regulations on food waste practices, alterations in consumer behavior, the determinants of these changes, and the assessment of the effectiveness of policy implementation. In contrast, this paper examines how restaurants and food delivery platforms respond to varying levels of penalties to protect their interests, using anti-food waste legislation as the research context. It focuses on how these entities can maintain or enhance their economic efficiency while reducing food waste by analyzing the government's different penalty mechanisms and the corresponding promotion strategies chosen by restaurants and platforms. While existing studies primarily consider the perspectives of policymakers and consumers, this paper addresses a research gap by exploring the impact of regulations on corporate behavior from the corporate perspective. Based on the findings, specific policy recommendations are provided to assist policymakers in optimizing regulations and improving their implementation. Additionally, the paper offers concrete suggestions for firms to comply with regulations, helping them achieve both economic and environmental goals.

2.2 Service congestion effect

Perceived human congestion refers to the current environment in which people are in close proximity, and there is a feeling of physical congestion. A higher perceived human congestion directly and negatively impacts consumers' shopping satisfaction (Eroglu et al., 2004). The occupancy level of a store determines its population density, which, in turn, influences the customers' experience of congestion. The presence of a substantial number of people in a retail setting has been shown to have a pronounced effect on consumer perceptions, emotional responses, and behavioral patterns (Mehta,

2013). Besides, some studies have proved that tourists found some amount of congestion during festivals or sightseeing activities acceptable (Zehrer and Raich, 2016).

Regarding retail store congestion, Esmark and Noble (2018) and Palcu et al. (2015) highlighted the importance of the relationship between employees and management. Employees can better maintain retail store cleanliness with reduced congestion. A smooth working environment improves employees' handling and adaptability, which indirectly improved sales performance. Changes in demand for limited recreational resources can swiftly result in overcrowding, which brings about unwelcome experiences for visitors and poses substantial difficulties for managers of these resources. Studies indicate that people strategically predict the scheduling decisions of other patrons, yet they often only take into account their congestion expectations to a certain degree when deciding when to visit (Han et al., 2010).

Soobeen's research revealed that the radial layout tended to result in the most intense congestion scenarios. This finding emerged from simulations of shopping behaviors within virtual shopping centers that employed three distinct configurations: radial, linear, and circular. The study identified three key retail congestion effects: socialization, spatial size, and constraints related to shopping convenience. This work offers a novel empirical perspective that enriches our understanding of congestion dynamics in retail settings (Soobeen and Zhang, 2019). From the viewpoint of a retail store, environments that are crowded and cluttered can convey an impression of contamination, which in turn diminishes the likelihood of customers making a purchase. However, for non-ingestible items, such as detergent, it is the clutter associated with storage rather than the presence of people that may be perceived as an indication of contamination. Furthermore, research has investigated the impact of perceived scarcity, finding that in the context of edible products, the perception of scarcity can counteract the negative influence of pollution-related concerns on customers' intentions to buy (Gupta and Coskun, 2021).

The service congestion effect is a significant aspect within the O2O food delivery supply chain, where the impact of service congestion on customer satisfaction, service quality, and operational efficiency has been the focus of prior research. However, this paper argues that service congestion in restaurants is a significant variable that profoundly influences consumer decision-making. It explores the impact of service congestion on consumer behavior from the perspective of consumer decision-making. The paper not only analyzes the effects of service congestion but also proposes specific strategic adjustments that serve as practical guidelines for restaurants and online food delivery platforms. By examining the impact of service congestion on specific variables of consumer decision-making, such as waiting time, perceived service quality, and price sensitivity, the paper provides a more detailed and nuanced research perspective.

2.3 Food delivery O2O supply chain

In recent years, the development of internet technology has garnered significant attention from scholars both domestically and internationally, leading to a growing body of research on online-to-offline (O2O) supply chains. Gu et al. (2023) aimed to develop a theoretical model to investigate how anticipated regret influences retailers' pricing and advertising decisions, as well as their profits, within online-to-offline (O2O) supply chains. Guo et al. (2022) examine the impacts of online and offline channel integration, derive the optimal decisions of retailing price and ordering quantity. The study shows that the impacts of O2O modes on retailer's profit depends on the delivery cost in online channel and service cost in offline channel. Narang and Shankar (2019) primarily concentrate on the parallels and distinctions among retailers utilizing mobile app platforms for both online and offline sales and returns. He et al. (2019) addressed the issue concerning the sale of fresh agricultural products in both online and offline markets while examining the optimal decisions made by agricultural supply chain members. Qiu et al. (2022) studies the coordination problem of a two-layer decentralized supply chain consisting of suppliers and retailers. Suppliers can control and adjust product quality, and retailers can sell products to consumers through offline and online (O2O) by reference quality effect. Research shows that the decision-making of supply chain members is dynamic and depends on the initial reference quality of consumers, the strength of reference quality effect and memory parameters. In the context of the epidemic, Tan et al. (2023) took the fresh agricultural products supply chain composed of B2C (Business-to-Consumer) or O2O (Online-to-Offline) e-commerce platforms and offline retailers as the research object. The Stackelberg game model is used to study the conditions for the implementation of blockchain technology in the B2C (O2O) supply chain, the best business model of e-commerce platform, and the conditions for offline retailers to cooperate with O2O e-commerce platform. In contrast to these investigations, primarily centered around e-commerce platforms, this paper specifically concentrates on food delivery platforms and restaurants, but the above research on the process of dual-channel coordination is worthy of reference.

Regarding the O2O food delivery service supply chain, Lin et al. (2022) focused on the importance of establishing distribution centers as the basis for food delivery and attempted to explore the factors affecting consumers' perception and acceptance of retail food delivery systems in urban China. Gharehgozli et al. (2017) identified the key characteristics of the food supply chain, and discussed some of the trends that will lead the future of food transportation. Wang et al. (2022) constructed two competitive models of food delivery service supply chains, analyzed the impact of consumers' reference-dependent characteristics on the pricing decisions of O2O food delivery platforms and caterers, and discussed the selection of optimal operation modes for food delivery service supply chains.

Through a comprehensive review of existing scholarly works, this portion of the text pinpoints gaps in the research conducted on the identified subject matters. It then proceeds to develop specific research questions and hypotheses to address these gaps. This process establishes the groundwork for the theoretical modeling and empirical examination that will be presented in the subsequent sections of the study. Problem description and hypotheses.

3 Materials and methods

3.1 Problem description and hypotheses

Consider an O2O food delivery supply chain system consisting of a food delivery platform providing online delivery services and a

restaurant providing online orders and offline dining. In this O2O food delivery supply chain system, to further enhance the profits of both parties, restaurants have the option to choose three promotion strategies for online orders: no-promotion strategy (*N* strategy), a price discount strategy (*D* strategy), or a volume-based price discount strategy (*S* strategy). Under the *D* strategy, the restaurant will decide food prices for offline channels and ratio of price discounts for online channels, and the platform does not make decisions and only charges a certain percentage of the service fee for the use of online channel by the restaurant. Under S strategy, the platform first decides the food price for online orders, and then the restaurant decides the food price for offline channels. The utility function varies under different strategies, and the demand function changes accordingly.

The food delivery platform extracts a certain proportion η of commission from online orders, while restaurants can earn profits from both offline dine-in and online orders. As all orders share the offline kitchen, dine-in customers will be exposed to some congestion (customers require more waiting time). In addition, to reduce food waste, the government will implement anti-food waste regulations. The penalty fee for anti-food waste units is k, and the higher the value, the greater the penalty. The notations are summarized in Supplementary Table 1.

For the sake of analysis and without loss of generality, the following hypotheses are further stated:

Hypothesis 1: Since it is easy to dispose of excess food offline and the "clean plate campaign" has a significant impact on consumers' waste behavior, we only consider that food waste occurs in online ordering, and consider that the delivery platform should bear the responsibility of anti-food waste (Zheng et al., 2023).

Hypothesis 2: Assuming that the service cost of the delivery platform and the unit production cost of the restaurant are 0. Based on the fact that delivery orders can be booked in advance, the crowding effect is only for dine-in, which is jointly affected by the incremental increase in online and offline orders (Luan and Corman, 2022).

Hypothesis 3: In order to ensure that the number of online and offline channel sales under the no promotion strategy is positive, $\rho < \rho_1$ and $\eta_1 < \eta < 1$, where $\rho_1 = \frac{(1+\tau_r-\theta)V}{k}$, $\eta_1 = \frac{k\rho(2+\tau_r-2\theta)}{\theta(V(1+\tau_r-\theta)+k\rho)}$.

Hypothesis 4: In order to ensure that the number of online and offline channel sales under the price discount strategy is positive, $\delta < \theta$ and $\eta_2 < \eta < 1$, where $\eta_2 = \frac{(\tau_r{}^2+\tau_r)\delta^2+(-2\theta\tau_r-\tau_r{}^2+\theta-1)\delta-\theta^2+\theta\tau_r+\theta}{\delta\tau_r(\delta\tau_r+\delta-\theta)}$.

Hypothesis 5: In order to ensure that the number of online and offline channel sales under the volume-based discount strategy is positive, $\tau_r > \max\left\{\frac{k\rho}{V}+\beta\theta-1, \frac{\theta}{\mu}+\beta\theta-2\right\}$, $\eta_3 < \eta < 1$, where $\eta_3 = \frac{k\rho(\beta\mu\theta-\mu\tau_r-2\mu+\theta)}{\theta(V\beta\theta-V\tau_r+k\rho-V)}$

Hypothesis 6: In order to ensure that the parameter settings under the volume-based price discount strategy are realistic, $1 < \beta < \frac{1}{\theta}$, $\mu < 1$, and $\beta\mu < 1$.

Hypothesis 7: Both restaurateurs and delivery platforms are rational in their decision-making, both have their own profit maximization as their decision-making goal, and the choice of promotion strategies is decided by the restaurants.

According to the above, the sales quantity function of offline and online channels under the *N* strategy, *D* strategy and *S* strategy can be obtained as follows by Equations 1–4:

$$\begin{aligned} d_o^N &= \frac{V\theta\tau_r+\theta p_r-p_o\tau_r-p_o}{(1-\theta)\theta}, \\ d_r^N &= \frac{(1-\theta-\tau_r)V+(p_o-p_r)}{(1-\theta)}+\frac{p_o\tau_r}{(1-\theta)\theta} \end{aligned} \tag{1}$$

$$\begin{aligned} d_o^D &= \frac{(V\tau_r+p_r)}{(1-\theta)}-\frac{\delta p_r(1+\tau_r)}{(1-\theta)\theta}, \\ d_r^D &= \frac{V\theta^2+V\theta\tau_r-\delta\theta p_r-\delta p_r\tau_r-V\theta+\theta p_r}{(-1+\theta)\theta} \end{aligned} \tag{2}$$

$$\begin{aligned} d_o^S &= \frac{V\theta\tau_r-(1+\tau_r)\mu p_o+\theta p_r}{(1-\beta\theta)\theta}, \\ d_r^S &= \frac{(1-\tau_r-\beta\theta)\theta V+(\beta\theta+\tau_r)\mu p_o-\theta p_r}{(1-\beta\theta)\theta} \end{aligned} \tag{3}$$

Thus, the amount of food waste in the online channels of the three strategies $j \in (N, D, S)$ can be obtained as follows:

$$W^j = \rho d_o^j \tag{4}$$

Further, the profit function of restaurant and platform under the three strategies can be obtained as follows:

$$\pi_r^N = (1-\eta)p_o d_o^N + p_r d_r^N \tag{5}$$

$$\pi_o^N = \eta p_o d_o^N - k\rho d_o^N \tag{6}$$

$$\pi_r^D = (1-\eta)\delta p_r d_o^D + p_r d_r^D \tag{7}$$

$$\pi_o^D = \eta\delta p_r d_o^D - k\rho d_o^D \tag{8}$$

$$\pi_r^S = (1-\eta)\beta\mu p_o d_o^S + p_r d_r - (\beta-1)\Delta d_r^S \tag{9}$$

$$\pi_o^S = \beta\eta\mu d_o^S p_o - k\rho d_o^S \quad (10)$$

In Equations 5, 7, 9, the item is the profit of offline dining under the three strategies. In Equations 6, 8, 10, the item is the profit of the online delivery services under the three strategies. Using backward induction, we summarize the optimal decision results under the three strategies in Supplementary Table 2.

3.2 Model analysis

In this section, we first analyze the effects of anti-food waste regulation, offline congestion effect on optimization decisions under the three strategies. Then we compare and analyze the optimal decision results of the *N* strategy, *D* strategy and *S* strategy.

3.2.1 The impact of anti-food waste regulation

Proposition 1. (i) $\frac{dp_r^{N*}}{dk} > 0$, $\frac{dp_o^{N*}}{dk} > 0$, and if $\eta\theta \geq \tau_r$, $\frac{dp_r^{N*}}{dk} \leq \frac{dp_o^{N*}}{dk}$; if $\eta\theta < \tau_r$, $\frac{dp_r^{N*}}{dk} > \frac{dp_o^{N*}}{dk}$. (ii) $\frac{\partial d_r^{N*}}{\partial k} > 0$, $\frac{\partial d_o^{N*}}{\partial k} < 0$, and $\frac{\partial d_r^{N*}}{\partial k} < \left|\frac{\partial d_o^{N*}}{\partial k}\right|$. (iii) $\frac{dW^{N*}}{dk} < 0$.

Proposition 1 shows that when restaurants adopt the *N* strategy, increased government waste penalties result in higher food prices and increased dine-in demand across both offline and online channels. Concurrently, there is a reduction in sales and food waste within the online channel. In addition, the impact of anti-food waste regulations is more significantly felt on platform sales compared to the offline channel. When the offline congestion effect is low, higher penalty levels have a more pronounced impact on platform pricing, and conversely for dine-in pricing.

Under the *N* strategy, these regulations establish a correlation between waste levels and platform demand, compelling platforms to actively manage and regulate ordering volumes. Consequently, this leads to a decrease in platform sales and, to some extent, food waste within the online channel. As platforms curtail sales volumes by elevating prices, dine-in options become more appealing. With stringent enforcement of anti-food waste regulations, both restaurants and platforms increase prices. Platforms employ these higher prices to safeguard their profits, while restaurants may experience greater increases in profitability. However, in doing so, the government effectively exercises control over the amount of waste generated from the online channel.

Proposition 2. Under the *D* strategy, food prices and sales quantity of online and offline channels, online food waste and the restaurant's profits are not affected by the anti-food waste regulation, but the platform's profits will change with the strength of the anti-food waste regulation.

Proposition 2 indicates that under the *D* strategy, restaurants maintain autonomy over pricing in the offline channel, while the platform applies discounted pricing on top of the offline prices, in accordance with this strategy. The restaurant's optimization decisions are independent of the platform's obligations to enforce food waste regulations. With the *D* strategy, the restaurant is exempt from government waste penalties and has the freedom to adapt its strategy to optimize profits based on its own operational conditions and evolving circumstances. However, under the *D* strategy, the platform assumes the responsibility for food waste penalties, which directly impacts the platform's profitability. In light of the government's focus on anti-food waste, delivery platforms may encounter a substantial increase in waste fines. In response to the elevated costs arising from anti-food waste measures, platforms may opt to raise their commission rates for online services. Yet, under the *D* strategy, the government's aim to reduce waste through the adjustment of penalty levels may not be achieved. Instead, the government should intervene in the strategy development for restaurants to effectively manage discount rates, thereby controlling waste.

Proposition 3. (i) $\frac{dp_r^{S*}}{dk} > 0$, $\frac{dp_o^{S*}}{dk} > 0$, and $\frac{dp_r^{S*}}{dk} > \frac{dp_o^{S*}}{dk}$ (ii) $\frac{\partial d_r^{S*}}{\partial k} > 0$, $\frac{\partial d_o^{S*}}{\partial k} < 0$, and $\frac{\partial d_r^{S*}}{\partial k} < \left|\frac{\partial d_o^{S*}}{\partial k}\right|$. (iii) $\frac{dW^{S*}}{dk} < 0$.

Proposition 3 indicates that when restaurants adopt the *S* strategy, it results in an increase in food prices in both the offline and online channels, as well as an increase in dine-in demand. Concurrently, sales and food waste in the online channel decrease. Under the *S* strategy, penalty levels have a more significant impact on dine-in pricing than on platform pricing, whereas the reverse is true for demand. Since platforms offer discounts for ordering a specified amount of food under the *S* strategy, an increase in waste is expected. In response, the government has intensified regulations to curtail online sales and, consequently, food waste in the online channel. With rigorous implementation of anti-food waste regulations, platforms raise their prices to offset the costs associated with anti-food waste penalties, and restaurants adjust their pricing to enhance profitability.

3.2.2 The impact of cost of offline dinning

Proposition 4. (i) $\frac{dp_r^{N*}}{d\tau_r} < 0$, $\frac{dp_o^{N*}}{d\tau_r} > 0$, $\left|\frac{dp_r^{N*}}{d\tau_r}\right| < \frac{dp_o^{N*}}{d\tau_r}$.(ii) $\frac{\partial d_r^{N*}}{\partial \tau_r} < 0$, $\frac{\partial d_o^{N*}}{\partial \tau_r} > 0$, and $\left|\frac{\partial d_r^{N*}}{\partial \tau_r}\right| > \frac{\partial d_o^{N*}}{\partial \tau_r}$. (iii) $\frac{dW^{N*}}{d\tau_r} > 0$.

Proposition 5. (i) $\frac{dp_r^{D*}}{d\tau_r} < 0$.(ii) $\frac{\partial d_r^{D*}}{\partial \tau_r} > 0$, $\frac{\partial d_o^{D*}}{\partial \tau_r} > 0$, and $\frac{\partial d_r^{D*}}{\partial \tau_r} < \frac{\partial d_o^{D*}}{\partial \tau_r}$. (iii) $\frac{dW^{D*}}{d\tau_r} > 0$.

Proposition 6. (i) $\frac{dp_r^{S*}}{d\tau_r} < 0$, $\frac{dp_o^{S*}}{d\tau_r} > 0$, $\left|\frac{dp_r^{S*}}{d\tau_r}\right| < \frac{dp_o^{S*}}{d\tau_r}$.(ii) $\frac{\partial d_r^{S*}}{\partial \tau_r} < 0$, $\frac{\partial d_o^{S*}}{\partial \tau_r} > 0$, and $\left|\frac{\partial d_r^{S*}}{\partial \tau_r}\right| > \frac{\partial d_o^{S*}}{\partial \tau_r}$. (iii) $\frac{dW^{S*}}{d\tau_r} > 0$.

Propositions 4, 5, and 6 demonstrate that the offline congestion effect is inversely related to offline dine-in pricing and positively related to online prices across all three strategies. *D* Strategy, in particular, has no impact on online prices. The congestion effect exerts a more significant influence on platform pricing than on the offline channel. Under both the *N* and *S* strategies, an increase in the offline congestion effect reduces dine-in demand, while platform demand increases and significantly impacts dine-in demand. This is because

an increase in platform demand is often a customer response to the inconvenience of dine-in congestion. Under *D* strategy, the offline congestion effect affects both demands, with a greater impact on platform demand. The rise in platform demand under all three strategies leads to an increase in food waste.

These findings suggest that as the offline congestion effect changes, platform prices are more responsive to these changes, while the demand for dine-in services experiences a more pronounced impact. Restaurants may enhance their profitability by reducing prices to attract a greater variety of consumer choices, while platforms may elevate their online prices. Restaurants, functioning as shared kitchens in both offline and online channels, introduce congestion that could deter customers from choosing dine-in services. This congestion prompts some customers to opt for the online channel, thereby decreasing demand for the offline channel. In response, restaurants may lower their offline prices to retain customers, albeit at the cost of some profit margin. However, the increase in platform demand can lead to an escalation in food waste. To address this issue, the government should enforce anti-food waste regulatory measures to control the volume of orders on the platform. Coordinated efforts can then be made to tackle the challenges associated with kitchen capacity and waste management.

4 Numerical analysis and results

Considering the complexity of the model, the previous section did not examine the effect of the unit penalty cost of food waste by government k and the cost of offline dining T on the online and offline profits, the specific results are shown in Supplementary Figures 1, 2. In view of this, in this section, the choice of promotion strategies for restaurants and platforms will be analyzed by numerical simulation. Key parameters selected in this section include the unit penalty cost of food waste by government k, the commission percentage η and the cost of offline dining T. The specific results are shown in Supplementary Figures 3, 4. Other parameters are assigned as: $V = 100$, $\eta = 0.1, \delta = 0.8, \theta = 0.82, \mu = 0.8, \beta = 1.1, \rho = 0.1, \mathrm{T} = 8, k = 0.8$ and $\Delta = 4$.

As depicted in Supplementary Figure 1, the impact of increasing anti-food waste penalties is notable across all three strategies. With stricter penalties, the platform's profit margins decline, while the restaurant's profits rise. Under the *D* strategy, the restaurant's profits remain unaffected by the strength of the anti-food waste penalty. However, when restaurants opt for the *S* strategy, the magnitude of price adjustments in both the online and offline channels in response to penalty changes is most pronounced.

Both the restaurant and the platform experience increased profits when the *S* strategy is chosen. For the platform, the adoption of the *S* strategy guarantees a significant boost in profits, irrespective of the promotional strategy employed. Conversely, from the restaurant's perspective, choosing the *D* strategy would be detrimental, as it would result in reduced profits compared to adopting no promotional strategy at all.

Supplementary Figure 1 indicates that heightened government regulation aimed at reducing food waste can enhance the profitability of restaurants. This is particularly true as consumers increasingly prefer offline dining experiences, granting restaurants greater leverage to increase their prices. Delivery platforms, in response, will also elevate prices to safeguard their revenue streams, yet this is counteracted by a reduction in sales volume, which overall leads to lower profitability. When restaurants adopt promotion strategies, there is a notable enhancement in profit margins, with the *D* Strategy showcasing a more pronounced effect. This strategy can provide restaurants with objective profit gains, while strategy offers incremental profit increases over the status quo. For delivery platforms, the implementation of promotion strategies can effectively elevate their profits, with the *D* strategy being particularly promising as it has the potential to drive exponential profit growth. Considering the strength of the anti-food waste penalty alone, the *D* strategy emerges as the preferred option, given its direct impact on profit margins.

Supplementary Figure 1 illustrates that as the intensity of anti-food waste penalties increases, the profitability of restaurants may decline, particularly in the offline channel, while platform profits can be more resilient. This is due to the direct cost implications of waste management and the potential for increased pricing to offset these costs. However, the adoption of the *S* strategy can lead to a significant increase in profits for restaurants, especially when coupled with effective waste reduction measures. In contrast, the *D* strategy, which may involve more lenient penalties or different forms of regulation, does not appear to offer the same level of profitability enhancement. This could be because the *D* strategy does not incentivize restaurants to actively manage food waste or because the absence of stringent penalties leads to less behavioral change among consumers, thereby limiting the effectiveness of waste reduction efforts. It's important to note that while Supplementary Figure 1 provides a general trend, specific outcomes may vary based on a multitude of factors, including the nature of the restaurant, the effectiveness of waste management systems, and the regulatory environment. Additionally, the impact of different strategies on profitability should be considered in the context of their broader implications for sustainability and social responsibility.

Supplementary Figure 2 illustrates the impact of offline congestion effect on platform and restaurant profits across three distinct strategies—*N*, *D*, and *S*. As the offline congestion effect intensifies, platforms observe an increase in profits across all strategies, with the *S* strategy leading to the most significant profit augmentation. Concurrently, the profit gap between the *S* strategy and the other two strategies (*D* and *N*) expands, positioning the *D* strategy in the middle with a consistent positive profit differential. For restaurants, the relationship is more complex. Under the *N* strategy, profits initially decrease with the growth of the offline congestion effect but subsequently increase. Conversely, the *D* strategy results in a substantial decline in profits, while the *S* strategy exhibits an increasingly pronounced profit growth. At low levels of offline congestion effect, restaurants adopting the *D* strategy achieve the highest profits. However, as the congestion effect escalates, profits under the *D* strategy plummet to the lowest, reflecting the most dramatic change. In contrast, profits for restaurants under the *S* strategy escalate with the offline congestion effect, peaking when the congestion effect is most pronounced.

Specifically speaking, Supplementary Figure 2 suggests that restaurants should align their strategies with the level of offline congestion effect to maximize profits. The *S* strategy is particularly advantageous in high-congestion scenarios, while the *D* strategy may be more appropriate when congestion is minimal. The *N* strategy occupies an intermediate position, with profits oscillating in response to the intensity of the congestion effect. Therefore, when formulating strategic decisions, restaurants must consider these dynamics to

optimize their financial performance amidst evolving consumer behaviors and market conditions.

Supplementary Figure 2 delineates the promotion strategies employed by restaurants and platforms in response to the offline congestion effect, quantifying their impact on profitability as dining-in costs vary. The analysis reveals that delivery platforms garner consistent benefits as the cost of in-store dining increases, with consumers gravitating towards delivery services due to utility-driven motivations. Among the three strategies—*N*, *D*, and *S*, the *S* strategy is associated with the most substantial increase in platform revenues, while the *D* strategy yields moderate profits. For restaurants, the *N* strategy results in a slight decline followed by a modest increase in profits, which is overshadowed by the more dynamic responses of the *S* and *D* strategies. Initially, the *D* strategy leads to a stable profit level, but as the offline congestion effect intensifies, profits plummet, indicating that price discounts are particularly attractive when consumers face high in-store dining costs, thereby making platform ordering a more appealing option. Conversely, under the *S* strategy, restaurants witness a significant surge in profits, creating a win-win situation for both the restaurant and the platform. This strategy enables consumers to mitigate the negative impacts of rising offline dining costs through increased sales and enhanced pricing, thereby benefiting both parties.

Supplementary Figure 2 underscores the importance of tailoring promotion tactics to the utility consumers seek from different dining options and adjusting these strategies in response to fluctuating costs and preferences. By aligning promotion strategies with consumer utility and financial objectives, restaurants can enhance the dining experience, attract and retain customers, and fulfill their ethical responsibilities while optimizing profitability.

Supplementary Figure 3 examines the interplay between the commission percentage, the offline congestion effect, and food waste penalties on platform profits across different penalty levels. The analysis indicates that the distribution interval of platform profits remains relatively stable despite varying food waste penalty levels. The *S* strategy is more beneficial to platforms when the commission ratio is low; however, as the commission ratio increases, the *S* strategy is only favored under conditions of very low or very high offline congestion effects. In all other scenarios, the *D* strategy is identified as the most optimal. This observation suggests that the government's food waste penalty magnitude does not significantly influence the platform's strategic decision-making. Instead, the platform's strategy selection is predominantly guided by the interplay between the commission ratio and the offline congestion effect. When the commission ratio is low, platforms experience higher revenues, and the utility derived by consumers from the *S* strategy is markedly enhanced, leading to increased consumer contributions to platform revenues. In contrast, under conditions of high commission rates and pronounced offline congestion effects, the *D* strategy becomes the platform's profit-maximizing approach.

In the context of stricter government regulations on food waste, platforms are likely to continue employing promotion strategies to stimulate sales, albeit potentially incurring higher penalty costs. The complex dynamics between regulatory constraints, platform commissions, and the offline congestion effect require a sophisticated approach to promotion strategy. This approach must balance profitability with social responsibility, ensuring that platforms can navigate the competing demands of economic gain and environmental sustainability.

Supplementary Figure 3 elucidates the influence of commission rates on platforms' promotion strategies in response to fluctuations in the offline congestion effect. The study reveals that at lower commission rates, platforms do not require strategic adjustments, with the *S* strategy proving effective in revenue generation. Additionally, an intensified offline congestion effect motivates consumers to prefer online ordering, thereby benefiting platforms that adopt the *S* strategy, especially when both commission rates and in-store dining costs are low, as it offers greater utility to consumers and consequently drives higher platform revenues. Conversely, when restaurants impose higher commissions on platforms amidst a moderate offline congestion effect, the *D* strategy becomes optimal for platform profit maximization. In the context of stringent government regulations on food waste, platforms may experience increased sales due to promotion strategies, yet this could also result in higher penalty costs, thus affecting overall profitability. The analysis underscores the criticality of considering the interplay between commission rates, offline congestion effects, and regulatory environments when devising promotion strategies. Platforms and restaurants must strike a balance between attracting customers and managing the financial implications of such strategies, including their impact on profitability and adherence to governmental policies.

In conclusion, Supplementary Figure 3 highlights the complex relationship between anti-food waste regulations, promotion strategies, and platform profits. The severity of penalties does not inherently induce platforms to reevaluate their promotion tactics. This analysis provides valuable insights into the development of promotion strategies by platforms in offline-to-online (O2O) marketplaces, emphasizing the necessity of considering regulatory constraints, market dynamics, and contractual agreements when formulating strategic decisions in this sector.

Supplementary Figure 4 illustrates the impact of commission rates and offline congestion on restaurant profits in the context of different anti-food waste penalties. The findings reveal that the choice of promotion strategy is influenced by a combination of these factors, with varying degrees of sensitivity to the level of penalties. When penalties are low, restaurants tend to opt for the *D* strategy when the commission rate is either high or very low, especially if the offline congestion effect is minimal. This strategy enhances profits by attracting more customers through price discounts. Conversely, when the offline congestion effect is high, the *S* strategy consistently yields higher profits. This is because the *S* strategy effectively manages the increased demand and reduces the negative impact of congestion. As the level of waste penalties fluctuates, discernible differences in promotion strategy selection emerge primarily when both commission rates and offline congestion are low. In these conditions, the *D* strategy has a broader choice interval, making it a more flexible option for restaurants. Overall, the level of penalties does not solely dictate the choice of a restaurant's promotion strategy. Instead, the interplay between commission rates and offline congestion plays a more significant role. When the offline congestion effect is low, restaurants prefer the *D* strategy when the commission rate is very low or high. This is because the *D* strategy maximizes profits by leveraging the platform's pricing structure and the restaurant's decision-making authority.

From Supplementary Figure 4, it can also be noticed that more consumers are drawn to delivery platforms as the offline congestion effect increases. In this context, the *S* strategy becomes the preferred choice for restaurants, especially in the presence of government regulation. The *S* strategy not only attracts consumers by offering enhanced utility but also aligns with the regulatory objectives of reducing food waste. The impact of the *D* strategy is more pronounced when both commission rates and offline congestion are minimal. However, the *S* strategy proves more beneficial in a wider range of scenarios, requiring strategy adjustments only in specific cases. This suggests that increased government regulation aimed at reducing food waste will have a limited impact on restaurants' overall profit strategies, although it may influence their choice of promotion strategies to some degree. From a restaurant perspective, the government can exercise significant control over the promotion strategies adopted by restaurants, thereby regulating the overall promotion landscape. This approach aims to minimize waste while ensuring the protection of profits, creating a balanced environment where both regulatory objectives and business interests are aligned.

In summary, Supplementary Figures 3, 4 provide a comprehensive demonstration of the strategic decisions made by restaurants and delivery platforms in response to varying levels of regulation, commission rates, and offline congestion effects. When selecting promotion strategies, restaurants must consider their interests, the platform's profitability, and waste management. The level of government penalties does not significantly influence the choice of promotion strategy. Instead, the adoption of the *D* strategy by restaurants is primarily driven by commission rates, while the *S* strategy tends to result in a win-win outcome for both restaurants and platforms.

Generally, when the commission percentage is low, *S* strategies are implemented to enhance consumer utility and safeguard revenue. In contrast, when the commission percentage is high, both restaurants and platforms may opt for *D* strategies to maximize profits. The selection of promotion strategies is beneficial for the mutual prosperity of restaurants and platforms, irrespective of the level of punishment. This comprehensive analysis offers valuable insights into the complex dynamics of promotion strategy decisions under government regulation within O2O food delivery systems.

Platforms achieve the highest profits by employing different strategies in various scenarios, necessitating that restaurants select their promotion strategies based on their specific circumstances. Although the choice of promotion strategy does not vary significantly under different penalty levels, the platform remains an important consideration in this decision-making process. Therefore, platforms must effectively manage the penalties associated with wasteful promotion activities. Interestingly, the profits of restaurants under high penalty levels are not substantially different from those under low penalty levels, indicating that restaurants are not significantly impacted by anti-food waste regulatory policies. This finding underscores the importance of striking a balance between regulatory compliance and strategic business decisions to maximize profits in the restaurant delivery O2O environment.

Promotion strategies may be only slightly influenced by stringent food waste policies, particularly when regulations are rigorously enforced. Restaurants, which are not directly governed by waste regulations and are the primary entities making promotional strategy decisions, typically base their choices on their profit margins. The offline congestion effect is more pronounced for restaurants, and platforms can enhance their demand and pricing power within this context. From the perspective of the entire supply chain, restaurants and platforms should collaborate to devise promotion strategies that mitigate external constraints and governmental regulations, achieving mutually beneficial profits while managing waste. The factor of the offline congestion effect becomes a significant consideration in the O2O food delivery supply chain, distinct from the influence of offline dining costs examined in previous studies. This is because the offline congestion effect is intricately linked to both offline and online demand, thereby having a profound impact on waste levels and the profitability of both parties.

5 Conclusion

In this paper, we investigate the intricate dynamics of the relationship between food delivery platforms and restaurants under a spectrum of regulatory, economic, and operational conditions. Our analysis focuses on three distinct promotion strategies that shape the interaction between these entities: the no-promotion strategy (*N* strategy), the price discount promotion strategy (*D* strategy), and the volume-based price discount promotion strategy (*S* strategy). Our research findings indicate that anti-food waste regulations targeting food delivery platforms alone do not significantly influence the choice of promotion strategies, as restaurants, as decision-making agents, remain largely unaffected. However, these regulations play a role in reducing wastefulness, suggesting that the government should consider assigning some responsibility for anti-food waste to restaurants. We further observe that the level of penalty—whether high or low—does not substantially alter the promotion strategies chosen by restaurants across different scenarios, exerting only a marginal influence. In contrast, platforms exhibit a reluctance to employ promotion strategies under high penalty conditions, which may limit the effectiveness of anti-food waste penalties for platforms. Nonetheless, under certain conditions, both restaurants and platforms can achieve win-win outcomes through the use of promotion strategies.

This win-win situation, however, is contingent upon specific conditions, particularly when faced with stringent anti-food waste penalties, as platforms tend to avoid adopting promotional strategies. When the cost of offline dining is moderate, both restaurants and platforms are inclined to adopt the price discount strategy. Moreover, stricter anti-food waste regulations intensify the tendency to forgo promotional strategies. This trend suggests that as regulatory penalties escalate, platforms may incur higher penalties, and restaurants may suffer losses as a consequence. Lastly, we find that both restaurants and platforms gravitate towards the *D* strategy when the government reduces penalties, primarily because restaurants can more effectively control prices, and platforms are less concerned about incurring excessive penalty costs. Conversely, under strong penalties, platforms may be compelled to adopt either the *D* strategy or the *S* strategy due to the proactive actions of restaurants, even if they prefer not to implement a promotion strategy.

The complex interplay between government regulation, market conditions, and the strategic collaboration between restaurants and platforms within the O2O food delivery supply

chain have been explored in the paper. From an economic and managerial perspective, the increasing regulatory landscape and evolving market dynamics necessitate closer cooperation between these entities. This collaboration is crucial for fostering strategic alliances, coordinating cost management, and aligning operational strategies in a highly regulated environment. In a broader societal sense, the promotion strategies discussed in this paper should encourage rational thinking among stakeholders, particularly restaurants and platforms. The critical importance of strategic choices in maintaining competitive advantage, increasing revenue, and driving sustainability cannot be overstated. This underscores the need for a holistic cost–benefit assessment of the supply chain, flexibility in responding to regulatory changes, and responsiveness to green policies. Collaboration between restaurants and platforms can lead to strategies that not only comply with regulatory requirements but also enhance market positions. Such collaboration can result in more efficient operations, reduced waste, and improved customer satisfaction, which are essential for long-term success in the O2O food delivery services.

The academic and practical implications of this study serve as a valuable resource for policymakers and stakeholders in the restaurant industry involved in dual-channel operations. The insights provided may inform the development of more rational policies and strategies aimed at ensuring economic sustainability and environmental responsibility. In conclusion, this paper highlights the adaptability of promotion strategies within the context of anti-food waste regulations, laying a crucial foundation for future research into the development of promotion strategies tailored for dual-channel operations in the restaurant industry. The study also emphasizes the profound impact of government regulations on the operational decisions of both restaurants and platforms, necessitating ongoing research and adaptation in response to changing regulatory landscapes. In the context of promotion strategy selection for restaurants, our study offers a nuanced framework that incorporates market dynamics and consumer behavior trends. Through numerical simulations, we provide clear insights to assist regulators and managers in making informed decisions regarding promotion strategies. Our research underscores the critical role of understanding consumer price sensitivity in crafting effective promotions and the necessity for restaurants to maintain flexibility and adaptability in their management approaches. In a market that is constantly evolving, the ability to swiftly adjust promotion strategies in response to shifts in competition and demand is essential for maximizing profits and enhancing competitiveness.

For restaurants and platforms, understanding the real-world performance of various marketing strategies is essential for crafting effective promotion programs and boosting profitability. The insights provided by our research are valuable for public policymakers, who can use our findings to gain a deeper understanding of market dynamics, enabling them to design more targeted policies that foster industry growth. For instance, policymakers might explore offering incentives to food and beverage companies that adopt promotion strategies shown to enhance efficiency and profitability.

While the modeling work in this paper effectively captures the core elements of promotion strategies within the O2O supply chain of the restaurant at an abstract level, it acknowledges that there may be additional factors influencing the choice of promotion strategies. These factors could include online and offline congestion effects, as well as the regulatory environment specific to restaurants. Future research could build upon the findings of this study by investigating the impact of these additional factors on promotion strategy decisions. Understanding the interplay between these factors and promotion strategies could provide a more comprehensive framework for policymakers and stakeholders to develop and implement effective strategies that balance economic sustainability with environmental responsibility. This could involve exploring the dynamics of crowding effects on consumer behavior, the implications of different regulatory frameworks, and the potential for strategic partnerships between restaurants and platforms to mitigate the negative impacts of waste.

While this study successfully identifies key factors influencing promotion strategies within the restaurant O2O supply chain through modeling at an abstract level, we acknowledge that there may exist other variables that impact the selection of promotion tactics. Such factors could encompass rider delivery challenges and governmental initiatives to control restaurant waste, among others. Future research might extend the findings of this manuscript by investigating these additional variables that could influence promotion strategy choices. A deeper understanding of the interplay between these variables and promotion strategies will equip policymakers and industry stakeholders with a more robust framework for designing and executing strategies that balance environmental stewardship with sustainable economic growth.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

GX: Conceptualization, Supervision, Writing – review & editing. YT: Writing – original draft, Formal analysis, Methodology. SX: Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1512675/full#supplementary-material

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