frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 29 April 2024
DOI 10.3389/fsufs.2024.1320242

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RECEIVED 12 October 2023
ACCEPTED 11 April 2024
PUBLISHED 29 April 2024

CITATION
Xu S, Du Y and Xu G (2024) Logistics strategies of food delivery O2O supply chain with anti-food waste regulation.
Front. Sustain. Food Syst. 8:1320242.
doi: 10.3389/fsufs.2024.1320242

Logistics strategies of food delivery O2O supply chain with anti-food waste regulation

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With the ever-growing popularity of food deliver, more and more consumers are embracing this convenience as part of their lifestyle. However, the issue of food waste created by the food deliver industry has become a pressing concern in society. This paper aims to examine the link between food waste and food delivery services, and investigate the effects of anti-food waste regulations on the generation of food waste and the choice of logistics strategies in an Online-to-Offline (O2O) supply chain. Using game-theoretical approach, we focus on two prominent logistics strategies—the restaurant-free self-logistics strategy (*RF* strategy) and the platform-charge logistics strategy (*PC* strategy). Our research results show that anti-food waste regulation can effectively reduce food waste in food delivery service under the *PC* logistics strategy. The choice of logistics strategy is constrained by the online market potential, the relative logistics costs of platform logistics, and anti-food waste regulations. If the anti-food waste regulation is strict, as long as the size of the food delivery market and the relative logistics costs of platform logistics are not simultaneously small, the *RF* strategy will be the equilibrium strategy, whereas the supply chain members should choose the *PC* strategy. The study thus offers useful inferences for theory and practice.

KEYWORDS

food waste, food delivery, food supply chain, O2O supply chain, logistics strategies

1 Introduction

In recent years, the online food delivery market has grown at an unprecedented pace globally (Habib et al., 2022; Traynor et al., 2022). The global online food delivery market size was valued at USD 221.65 billion in 2022 and is expected to expand at a compound annual growth rate (CAGR) of 10.3% from 2023 to 2030 (Grand View Research, 2023). The growth is mainly driven by the rising internet penetration coupled with the proliferation of smartphones, growing technology advancement, the and emergence of cloud kitchens. However, this growth has also spurred an unsettling surge in food waste (Trivedi et al., 2023). A survey conducted by the School of Environment at Tsinghua University, China Chain-Store and Franchise Association, and food delivery platform Meituan shows that each takeaway user squanders an average of 57.5 grams of food with each order (Wang, 2023). Considering China's huge food delivery market, that's a serious problem.

Food waste is a multifaceted issue with environmental, economic, and social ramifications (Dhir et al., 2020; Lins et al., 2021; Borghesi and Morone, 2023; Onyeaka Hemalatha et al., 2023). From an environmental perspective, food waste is a major contributor to greenhouse gas emissions. Economically, it implies the wasteful allocation of resources, estimated to cause a global financial loss of nearly $1 trillion annually. Socially, it raises ethical questions, with millions going hungry while edible food is discarded in large amounts. The United Nations Food and Agriculture Organization estimates that approximately one third of the food produced globally for human consumption every year — roughly 1.3 billion tons — is lost or wasted (Boliko, 2019;; Penalver and Aldaya, 2022). Hence, there has been an increased regulatory focus on reducing food waste, with numerous nations implementing anti-food waste regulations (Redlingshöfer et al., 2020; Szulecka and Strøm-Andersen, 2022).

Existing literature has explored the general impact of these anti-food waste regulations on restaurant industry (Feng et al., 2022; Filimonau et al., 2022). However, there's a conspicuous lack of research investigating their influence on the food waste followed in the booming online food delivery sector. Empirical studies in the area have completely ignored the possibility of linkage between online food delivery and food waste. This vacuum in the research is quite concerning since food waste issues are rising in this sector by the day. Recently, some scholars began to pay attention to the problem of food waste in food delivery service and mainly studied the causes of food waste. The study considered the influence of online consumers' overorder (Sharma et al., 2021; Trivedi et al., 2023), delivery time (Zhang et al., 2022), food quality (Talwar et al., 2023) and other factors (Kristia et al., 2023; Wei et al., 2023) on food waste in food delivery service. However, these studies did not consider anti-food waste regulatory scenarios. In addition, the research that only considers the single-channel environment of online food delivery is difficult to apply to today's mainstream Online-to-Offline (O2O) model. Therefore, this paper will consider the O2O dual-channel environment under the anti-food waste regulation, and aims to address the following key questions:

1. How does the anti-food waste regulation impact food waste in the food delivery O2O supply chain?
2. What is the impact of the introduction of the anti-food waste regulation on the decisions of food delivery O2O supply chain members?
3. How will the anti-food waste regulation change the choice of logistics strategies for the restaurant and the online food delivery platform?

In this paper, we develop two logistics strategies — the restaurant-free self-logistics strategy (*RF* strategy) and the platform-charge logistics strategy (*PC* strategy) and investigate how anti-food waste regulation affect logistics strategy and what strategies food delivery O2O supply chain members should use to cope with them. We provide new insights into the contextual factors such as online market potentials, relative logistics costs of platform logistics, and anti-food waste regulation, influencing the fitness and dynamics of the *RF* strategy and the *PC* strategy. We fill a critical research gap by providing insights into the interaction between anti-food waste regulation and logistics strategies in the food delivery O2O supply chain. In addition, our findings can guide businesses and regulators to collaboratively shape effective strategies, helping to balance the objectives of food waste reduction, economic sustainability, and operational effectiveness. Our research will set a stage for future investigations into creating resilient, sustainable supply chains within the online food delivery industry.

The rest of this paper is structured as follows. In Section 2, a literature review is conducted on O2O supply chain and food waste of supply chain. In Section 3, the materials and methods this paper are given. Section 4 uses numerical examples further investigates the relevant problems that cannot be analyzed comparatively due to the complexity of the model. Section 5 is the conclusions. All proofs of this paper are in the Appendix.

2 Literature review

This paper deals with two core research topics such as O2O supply chains management and anti-food waste regulation. This section will delve into the relevant research literature to better understand the interdependencies and differences between this paper and the existing literature.

2.1 O2O supply chain management

In the era of digital disruption, the O2O model is a combined online and offline business model. To address the definition problem of the O2O model, Lee et al. (2022) proposed a systematic definition method. They believe that the O2O model is a business model that guides consumers to purchase goods or services in offline physical stores through online channels.

The study also explores the application of the O2O model in the supply chain, including online-to-offline and offline-to-online models (Govindan and Malomfalean, 2019; Guo et al., 2022; Qiu et al., 2022; Gu et al., 2023; Tan et al., 2023). In examining the strategic value of O2O supply chains, Yang and Tang (2019) found businesses that integrate online and offline operations gain not only enhanced service quality but a competitive edge in the market. Similarly, Wang and He (2024) further confirm a mechanism for coordinated efforts between online and offline channels and their robustness against adverse market situations, leading to better profitability and efficiency.

Amidst the burgeoning prominence of e-commerce, the seamless merging of online-offline channels welcomes a new set of logistical challenges as studied by Liu et al. (2020), specifically in order delivery—unlike the traditional supply chain, where items travel from manufacturer to retailer and then to customers, the O2O model requires much more versatile logistics operations due to its unique delivery dynamic. Nonetheless, while aforementioned raise offers new challenges, it also births innovative solutions such as Buy Online Pickup in Store (BOPS) or Buy Online Deliver from Store (BODS) strategies, which help diffuse internal channel competition and augment retail performance (Hu et al., 2022; Yang et al., 2022; Sarkar and Dey, 2023).

In the context of food delivery, the O2O logistics model has become an increasingly prevalent application (Zou et al., 2022). Companies rely on technology to bridge the gap between consumers and food providers, using data-driven insights to streamline operations, improve efficiency, and increase profits (Rejeb et al., 2020). The recent two literatures published by Niu et al. (2021) and Du et al. (2023) are closely related to our research. They discussed the choices of pricing policy and logistics strategies mode for a restaurant that adopted O2O dual-channel sales. Their results showed that the restaurant should choose the self-logistics mode when the potential market size of the online channel and the consumers' sensitivity to the price difference between the two channels were small, otherwise, the restaurant chose the platform delivery mode. While Niu et al. (2021) and Du et al. (2023) provide vital insights for maximizing profit in O2O operations, our work pushes the boundaries by incorporating anti-food waste regulations, connecting practical strategies to achieve sustainability in a profitable and efficient manner in the food delivery O2O supply chain. This paper provides a unique insight into the complex workings of the food delivery O2O supply chain by considering different layers than the existing research.

2.2 Anti-food waste regulations

Food waste is a significant issue affecting global supply chains, impacting not only the economics of food production but also environmental sustainability and social equity (Raak et al., 2017; Ali et al., 2019; Dumitru et al., 2021; Krishnan et al., 2022). Literature provides a well-structured account of food waste prevention strategies and the regulatory mechanisms designed to cope with such wastage (Teng et al., 2021; Mesiranta et al., 2022; Szulecka and Strøm-Andersen, 2022; Steenmans and Malcolm, 2023).

Governmental regulations, as explored by Göbel et al. (2015), serve as one pivotal approach to mitigate food waste along the supply chain. They enforce waste management practices and foster waste reduction momentum, like the example set by the European Union's "Waste Framework Directive" (Grosso et al., 2010). The French government's "Gaspillage Alimentaire" law stands as another example, implementing penalties against supermarkets throwing away edible food, thus enhancing waste management effectiveness (Cane and Parra, 2020). Regulations inevitably create implications for firms along the supply chain. Parfitt et al. (2010) have critiqued such regulations suggesting that while they encourage compliance from firms, they can unintentionally create economic strain, particularly for small-scale businesses. Alternatively, the implementation of such policies may spur innovations in food logistics, encouraging businesses to optimize inventory management or implement technologies to extend product shelf life, as pointed out by Ali et al. (2019) and Diaz-Ruiz et al. (2019). Moreover, these regulatory policies often operate in conjunction with incentives to foster corporate investments in waste management initiatives (Thi et al., 2015; Chalak et al., 2016). Investments may include funding for research or incentives for implementing waste-reducing technologies or practices, such as tax breaks for companies that donate edible food that would otherwise be discarded (Walia and Sanders, 2019).

This paper aims to contribute to the existing body of research on anti-food waste by investigating the influence of regulatory policies on the logistics strategy of the online food delivery industry. While previous studies primarily concentrate on the effects of these policies on consumers and producers, this research focuses on the less-explored aspects of transportation and delivery within the intermediate links of the food supply chain. By examining how these regulations impact delivery patterns and the decision-making process of supply chain members, this study aims to uncover valuable insights into the optimization of the supply chain and the reduction of food waste. Furthermore, unlike broader research that examines anti-food waste regulations across various sectors, this study specifically targets the food delivery O2O supply chain, providing a more targeted and practical understanding of the food waste issue in this emerging industry.

3 Materials and methods

3.1 Problem description and assumptions

Consider a food delivery O2O supply chain system consisting of a food delivery platform providing online services and a restaurant providing online delivery and offline dining. In this food delivery O2O supply chain system, there will be two logistics strategies for online orders: restaurant-free self-logistics strategy (*RF* strategy) and platform-charge logistics strategy (*PC* strategy). Under *RF* strategy, the restaurant will decide food prices for online and offline 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 *PC* strategy, the platform first decides the delivery service fee for online orders, and then the restaurant decides the food price for online and offline channels.

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 Table 1.

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

> Assumption 1: The food delivery platform takes the lead in formulating strategies, including pricing, service quality, and collaboration terms. As a follower, the restaurant responds to these strategies by deciding whether to partner with the platform and adjusting menu prices accordingly. Subsequently, the platform observes the restaurant's decisions and adjusts its own strategies to maximize its interests. This iterative interaction continues until both parties reach a stable state known as the Nash equilibrium. Through the modeling of the Stackelberg game, we can deeply analyze the decision-making processes between the two parties, providing crucial insights for understanding economic relationships, predicting market trends, and developing effective strategies.
>
> Assumption 2: Since it is easy to dispose of excess food offline, we only consider that food waste occurs in online ordering, and consider that the delivery platform should bear the responsibility of anti-food waste.
>
> Assumption 3: The service cost of the delivery platform and the unit production cost of the restaurant are assumed to be 0, and the service crowding effect is not considered, that is, the waiting cost of customers for online and offline is 0.

TABLE 1 Summary of notations.

Parameters	
λ	Substitutability of the online and the physical store
θ	Online market potential
η	Platform's commission rate
k	Unit penalty cost of food waste by government
$\propto$	Unit waste ratio of online food
c_r	Unit logistics cost under the *RF* strategy
c_o	Unit logistics cost under the *PC* strategy
ρ	Relative cost of platform logistics, $\rho = c_o / c_r$
Decision variables	
p_r	Food price of offline channel
p_o	Food price of online channel
s	Unit logistics service fee under the *PS* strategy
Dependent variables	
q_r	Food sales quantity of offline channel
q_o	Food sales quantity of online channel
W^j	Amount of food waste under the *j* strategy, $j \in \{RF,PC\}$
$\neq_R^j$	Profit of the restaurant under the *j* strategy, $j \in \{RF,PC\}$
$\neq_P^j$	Profit of the platform under the *j* strategy, $j \in \{RF,PC\}$

Assumption 4: In order to ensure that the restaurant is willing to accept online orders, the platform's commission rate η is assumed that $\eta < \eta_0 = \frac{2(1-\lambda)}{2-\lambda}$.

Assumption 5: The average proportion of food wasted by online consumers is affected by many factors such as menu size, consumer food intake, delivery efficiency and timeliness of meals. In different development processes or technical backgrounds, its value may be different. Therefore, this paper assumes that unit waste ratio of online food $\propto$ is an exogenous variable.

Assumption 6: In order to ensure that the number of online channel sales under each strategy is positive, the online market potential θ is assumed that $\theta_0 < \theta < 1$ and $\theta_0 = \max\left\{k\mu + c_o, \frac{2\left(1-\lambda^2\right)(1-\eta)\Delta_r + \eta\lambda}{\eta\lambda^2 - 2\lambda^2 - 2\eta + 2}\right\}$.

According to the above, following the references Niu et al. (2021) and Du et al. (2023), the sales sales quantity function of offline and online channels under the *RF* strategy and *PC* strategy can be assumed as:

$$q_r^{RF} = 1 - p_r^{RF} + \lambda p_o^{RF}, q_o^{RF} = \theta - p_o^{RF} + \lambda p_r^{RF} \quad (1)$$

$$q_r^{PC} = 1 - p_r^{PC} + \lambda\left(p_o^{PC} + s\right), q_o^{PC} = \theta - \left(p_o^{PC} + s\right) + \lambda p_r^{PC} \quad (2)$$

Thus, by Equations (1) and (2), the amount of food waste in the downstream channels of the two strategies can be obtained as follows:

$$W^{RF} = \mu\left(\theta - p_o^{RF} + \lambda p_r^{RF}\right) \quad (3)$$

$$W^{PC} = \mu\left(\theta - \left(p_o^{PC} + s\right) + \lambda p_r^{PC}\right) \quad (4)$$

Further, by Equations (3) and (4), the profit function of restaurant and platform under the two strategies can be obtained as follows:

$$\pi_R^{RF} = p_r^{RF}\left(1 - p_r^{RF} + \lambda p_o^{RF}\right) + \left((1-\eta)p_o^{RF} - c_r\right)\left(\theta - p_o^{RF} + \lambda p_r^{RF}\right) \quad (5)$$

$$\pi_P^{RF} = \eta p_o^{RF}\left(\theta - p_o^{RF} + \lambda p_r^{RF}\right) - k\mu\left(\theta - p_o^{RF} + \lambda p_r^{RF}\right) \quad (6)$$

$$\pi_R^{PC} = p_r^{PC}\left(1 - p_r^{PC} + \lambda\left(p_o^{PC} + s\right)\right) + (1-\eta) p_o^{PC}\left(\theta - \left(p_o^{PC} + s\right) + \lambda p_r^{PC}\right) \quad (7)$$

$$\pi_P^{PC} = \left(\eta p_o^{PC} - c_o\right)\left(\theta - \left(p_o^{PC} + s\right) + \lambda p_r^{PC}\right) - k\mu\left(\theta - \left(p_o^{PC} + s\right) + \lambda p_r^{PC}\right) \quad (8)$$

In Equations (5), (7), the first item is the profit of offline channels and the second item is the profit of online channels. In Equations (6), (8), the first item is the profit of the online channel and the second item is the penalty cost of food waste in the online channel. In the second item although the waste ratio is assumed to be an exogenous variable, since the amount of waste contains decision variables, in the Stackelberg game, the decision-making of supply chain members will be affected by anti-food waste regulation and food waste ratio, which is obviously different from the work of Niu et al. (2021).

Using backward induction, we summarize the optimal decision results under the two strategies in Table 2.

3.2 Model analysis

In this section, we first analyze the effects of anti-food waste regulation and online market potential on optimization decisions under the two strategies. Then we compare and analyze the optimal decision results of the *RF* strategy and *PC* strategy.

3.2.1 The impact of anti-food waste regulation

Proposition 1: Under the RF 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 with the increase of anti-food waste punishment, the platform's profits will decrease.

TABLE 2 Optimal decision results under the *RF* strategy and *PC* strategy.

Variables	*RF strategy*	*PC strategy*
p_r^{j*}	$\frac{(1-\eta)((2-\eta)\lambda\theta+\eta\lambda\Delta_r+2)}{A_1}$	$\frac{4(1-\eta)\lambda\theta+2(2-\eta)+(\theta+c_o+k\mu)\eta\lambda}{4(2-\eta)\left(1-\lambda^2\right)}$
p_o^{j*}	$\frac{(1-\eta)(2\theta+A_2)+\lambda}{A_1}$	$\frac{4(1-\eta)\theta+2(2-\eta)\lambda-(\theta+c_o+k\mu)A_3}{4(1-\eta)(2-\eta)\left(1-\lambda^2\right)}$
s^{j*}	N/A	$\frac{(\theta+c_o+k\mu)A_1-2\eta(2(1-\eta)\theta+(2-\eta)\lambda)}{4(1-\eta)(2-\eta)\left(1-\lambda^2\right)}$
q_r^{j*}	$\frac{(1-\eta)\left(2+\left(\eta\theta-(2-\eta)\left(\lambda-\Delta_r+\lambda^2\Delta_r\right)\right)\lambda\right)}{A_1}$	$\frac{(\theta+c_o+k\mu)\lambda+2}{4}$
q_o^{j*}	$\frac{(\theta-\text{”}_r)A_3-(1+\lambda\text{”}_r)\eta\lambda}{A_1}$	$\frac{\theta-c_o-k\mu}{2(2-\eta)}$
W^{j*}	$\frac{\mu((\theta-\Delta_r)A_3-(1+\lambda\Delta_r)\eta\lambda)}{A_1}$	$\frac{\mu(\theta-c_o-k\mu)}{2(2-\eta)}$
π_r^{j*}	$\frac{(1-\eta)\left((1-\eta)\theta^2+((2-\eta)\lambda-A_2)\theta+A_4\right)}{A_1}$	$\frac{(\theta-c_o-k\mu)A_1+4(1+\lambda\theta)+(2-\eta)^2}{16(2-\eta)^2\left(1-\lambda^2\right)}$
π_o^{j*}	$\left(\frac{\eta((1-\eta)(2\theta+A_2)+\lambda)}{A_1}-k\mu\right)\left(\frac{(\theta-\Delta_r)A_3-(1+\lambda\Delta_r)\eta\lambda}{A_1}\right)$	$\frac{(\theta-c_o-k\mu)^2}{4(2-\eta)}$

Where $A_1=4(1-\eta)\left(1-\lambda^2\right)-\eta\lambda^2$, $A_2=\lambda+\left(2-2\lambda^2+\eta\lambda^2\right)\Delta_r$, $A_3=2(1-\eta)\left(1-\lambda^2\right)-\eta\lambda^2$, $A_4=1+\eta\lambda\Delta_r+(1-\eta)\left(1-\lambda^2\right)\Delta_r^2$.

Proposition 1 demonstrates that the restaurant has the autonomy to determine food prices for both online and offline channels based on the *RF* strategy, irrespective of the regulatory responsibility of the platform in combating food waste. The optimization decisions made by the restaurant are independent of the platform's anti-food waste regulations. By adopting the *RF* strategy, the restaurant is not subjected to penalties for food waste, allowing it to flexibly adjust its business strategy to maximize profits based on operational conditions and environmental changes. However, the platform, under the *RF* strategy, becomes liable for fines associated with food waste, directly impacting its profitability. With the government's anti-food waste policy being further implemented, the pressure of such fines is expected to increase. In response, the platform may increase the service commissions for online channels to offset the costs of anti-food waste measures. Nevertheless, regardless of these adjustments, the *RF* strategy does not effectively reduce food waste from online channels, rendering the platform's regulatory responsibility for anti-food waste ineffective. Consequently, in terms of the delivery strategy for online channel orders from restaurants, the government should not solely hold platforms accountable for anti-food waste but should also include restaurants within the regulatory framework.

Proposition 2: *(i)* $\frac{dp_r^{PC*}}{dk}>0, \frac{dp_o^{PC*}}{dk}<0, \frac{d\left(p_o^{PC*}+s^{PC*}\right)}{dk}>0$ *and* $\frac{dp_r^{PC*}}{dk}<\left|\frac{dp_o^{PC*}}{dk}\right|<\frac{d\left(p_o^{PC*}+s^{PC*}\right)}{dk}$. *(ii)* $\frac{dq_r^{PC*}}{dk}>0, \frac{dq_o^{PC*}}{dk}<0, \frac{dW^{PC*}}{dk}<0$ *and* $\frac{dq_r^{PC*}}{dk}<\left|\frac{dq_o^{PC*}}{dk}\right|$. *(iii)* $\frac{d\pi_r^{PC*}}{dk}<0, \frac{d\pi_o^{PC*}}{dk}<0$ and $\left|\frac{d\pi_r^{PC*}}{dk}\right|<\left|\frac{d\pi_o^{PC*}}{dk}\right|$.

Proposition 2 demonstrates that the implementation of the *PC* strategy has significant effects on various aspects of the food industry. Firstly, it leads to an increase in food prices and sales quantity in offline channels, as well as an increase in the price consumers pay for online orders. Conversely, it results in a decrease in food prices and sales quantity in online channels, along with a reduction in food waste and profits for both the restaurant and platform. Furthermore, the impact of anti-food waste regulation on online channels is more pronounced compared to offline channels. Similarly, the regulation has a greater effect on the profits of the platform compared to those of the restaurant. Under the *PC* strategy, there are two main factors at play. Firstly, the increase in delivery costs raises the price of online meal purchases, potentially dampening consumers' willingness to make such purchases. Secondly, the regulation requires the platform to effectively manage and control the amount of food ordered, leading to a decrease in sales quantity and subsequently reducing food waste in online channels. Consequently, the purchase cost for online consumers increases due to strict anti-food waste regulation. During this period, offline channels may gain a price advantage as some consumers may opt for offline purchases, resulting in increased food prices and sales quantity in offline channels. Additionally, the *PC* strategy necessitates increased delivery costs and exposes the platform to fines for food waste. This places significant pressure on the online channel of the restaurant to reduce food waste and attract more consumers. However, the decline in online sales cannot be compensated by the growth of offline business, ultimately impacting the overall profitability of the restaurant.

In summary, the implementation of the *PC* strategy and anti-food waste regulation have complex effects on food prices, sales quantity, food waste, and profits in both online and offline channels. These dynamics highlight the challenges and considerations faced by the industry in managing food waste and optimizing profitability under regulatory constraints.

3.2.2 The impact of online market potential

Proposition 3: Regardless of RF strategy or PC strategy, with the online market potential increases, the food prices and sales quantity of online and offline channels, the amount of food wasted for online channel, and the profits of the restaurant and platform will increase accordingly.

Proposition 3 implies that when market demand increases, purchasing power also increases. In this case, both the restaurant and the platform are likely to raise prices to achieve higher revenue. At the same time, due to the growth in the number of consumers, sales quantity will also increase. Regardless of *RF* strategy or *PC* strategy, there is a need to meet this increased demand, and this increased demand can also lead to higher prices. Due to the increase in the number of online orders, food waste from online channels has increased. In addition, the profits for both restaurants and platforms will improve due to increased sales and higher prices.

3.3 Comparative analysis

Proposition 4: If $\eta \geq \eta_1$ or $\eta < \eta_1$ and $\theta < \theta_1$, then $p_r^{RF*} > p_r^{PC*}$, $p_o^{RF*} > p_o^{PC*} + s^{PC*}, q_r^{RF*} > q_r^{PC*}, q_o^{RF*} < q_o^{PC*}$ and $W^{RF*} < W^{PC*}$. If $\eta < \eta_1$ and $\theta > \theta_1$, then $p_r^{RF*} < p_r^{PC*}$, $p_o^{RF*} < p_o^{PC*} + s^{PC*}$, $q_r^{RF*} < q_r^{PC*}, q_o^{RF*} > q_o^{PC*}$ and $W^{RF*} > W^{PC*}$.

Where $\eta_1 = \dfrac{2(1-\Delta_r)(1-\lambda)}{2(1-\Delta_r)(1-\lambda)+\lambda}$, $\theta_1 = \dfrac{B_2 - (k\mu + \Delta_o)A_1}{B_1}$,

$$B_1 = (2-2\eta+2\lambda-\eta\lambda)(2-2\eta-2\lambda+\eta\lambda),$$

$$B_2 = 2(2-\eta)\Big(2\big(1-\lambda^2\big)(1-\eta)\Delta_r + \eta\lambda\Big).$$

Proposition 4 shows that if the online service commission ratio obtained by the platform is large or small and the online market potential is small (or the government's punishment against food waste is small), compared with the *PC* strategy, the *RF* strategy will increase the food price and sales quantity of offline channels. However, it will reduce the sales volume of online channels and the amount of food waste in online channels. Otherwise, if the online service commission ratio obtained by the platform is small and the online market potential is large (or the government's anti-food waste punishment is relatively large), compared with the *RF* strategy, the *PC* strategy will increase the food price and the sales quantity of offline channels, but the *PC* strategy will reduce the sales quantity of online channels and the amount of food waste in online channels. When the service commission ratio of the platform is large, the restaurant-led delivery strategy is likely to increase the price of food in the online and offline channels. That's because restaurants are required to pay higher commissions, and that cost is likely to be passed on to consumers. Restaurants may also increase their offline sales to entice customers to eat directly in their stores and avoid paying hefty commissions, but online sales may fall, leading to less food waste. Further, when the commission ratio of online services is small and the online market potential is small (or the government's anti-food waste punishment is small), the restaurant's responsible delivery may still lead to higher food prices, because the delivery cost will increase; Offline sales may increase because consumers may consider buying directly in stores rather than ordering online. From the perspective of food waste, the platform may have less incentive to reduce food waste because the punishment from the government is not strong. On the other hand, since the online market potential is smaller, the sales volume of online channels may decline, which in turn will reduce the amount of food waste. However, when the online service commission is small and the online market potential is large (or the government anti-food waste penalties are large), if the platform is responsible for the delivery of food orders, we may have a different impact. At this point, due to the high potential of the online market, offline channel sales may increase, but online sales may barely increase because consumers may be deterred by higher online channel prices. In addition, strict anti-food waste regulations may force platforms to raise the cost of online purchases for consumers and reduce purchases to reduce food waste.

4 Results

Considering the complexity of the model, the previous section did not compare and analyze the profits of the restaurant and the platform under the *RF* strategy and the *PC* strategy. In view of this, this section will conduct numerical simulation analysis on the logistics strategies selection of the restaurant and the platform. Key parameters selected in this section include the unit penalty cost of food waste by government k, the online markets potential θ and the relative logistics cost of the platform ρ. Other parameters are assigned as: $\eta = 0.1$, $\lambda = 0.7$, $c_r = 0.2$, $c_o = 0.7\rho$ and $\mu = 0.1$. The specific results are shown in Figures 1–3.

It can be seen from Figure 1 that regardless of anti-food waste regulation, when the online market potential is high or the relative cost of platform logistics is high enough, the restaurant prefers the *RF* strategy to the *PC* strategy. However, only when the online market potential and the relative cost of platform logistics are sufficiently low, the restaurant may adopt the *PC* strategy over the *RF* strategy. In the absence of anti-food waste regulations or excessive anti-food waste penalties, if the online market potential is low enough, the restaurant may not provide the *RF* strategy regardless of the relative cost of platform logistics. In addition, if the online market potential and the relative cost of platform logistics remain unchanged, the restaurant will be more likely to prefer the *RF* strategy as the anti-food waste regulation become stricter.

Figure 1 suggests that when the online market potential is high, higher demand can result in a substantial return on a restaurant's investment in self-delivery. At the same time, the lack of cost-effectiveness of platform logistics gives self-distribution an advantage in the cost–benefit ratio, which in turn reduces overhead and improves profit margins. Conversely, when both the online market potential and

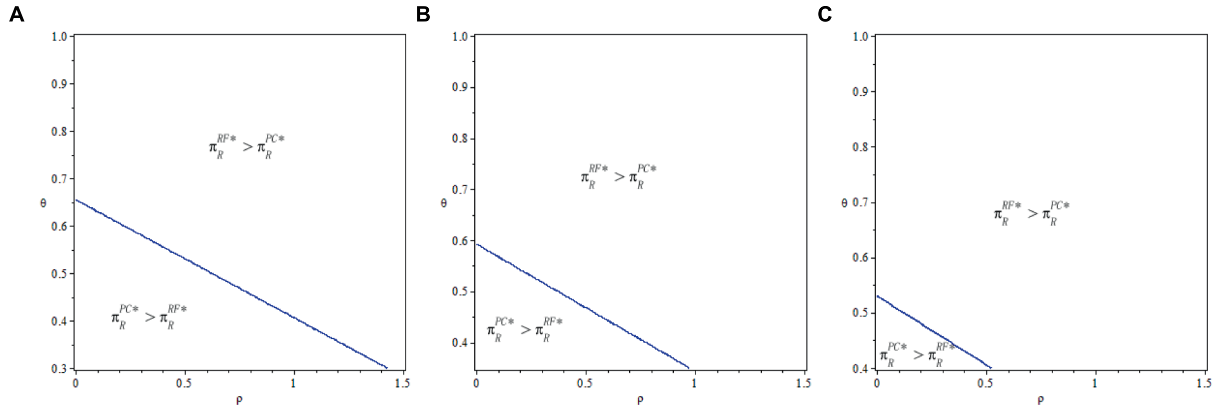

FIGURE 1
The impact of θ and ρ on the choice of logistics strategies for the restaurant.

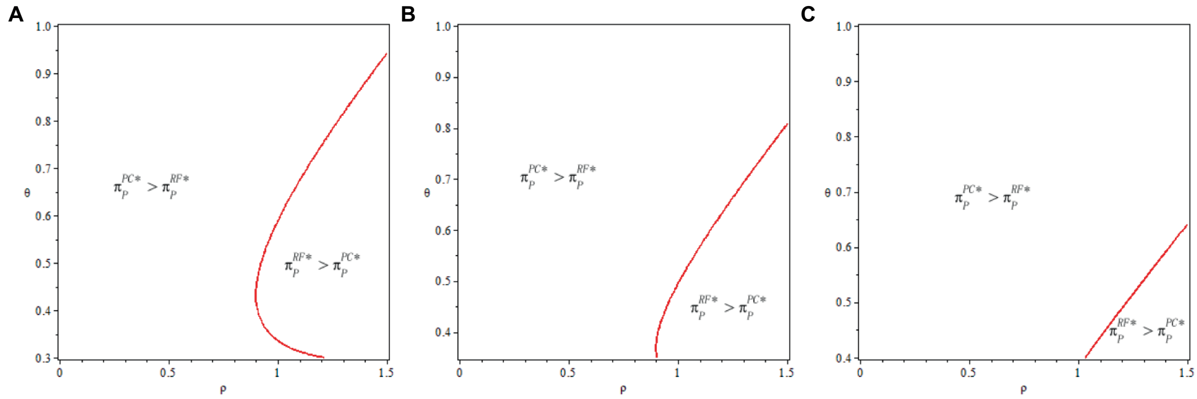

FIGURE 2
The impact of θ and ρ on the choice of logistics strategies for the platform.

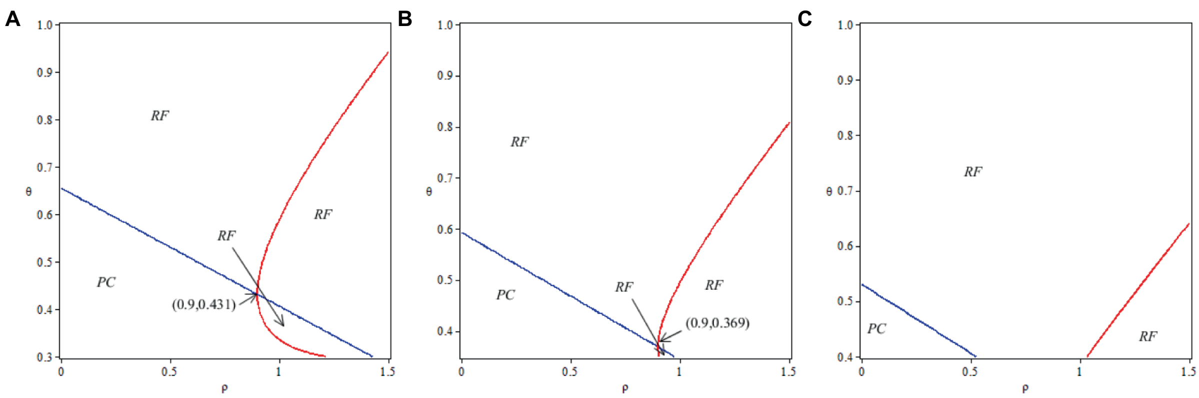

FIGURE 3
The impact of θ and ρ on the equilibrium strategies.

the cost-effectiveness of platform logistics are low, restaurants are likely to implement platform-led logistics strategies. The reason behind this decision lies in its operational and financial implications. Due to the low potential of the online market, investing in self-delivery may not yield much return. In addition, the low cost of platform logistics makes it a more economical option to devote resources to improving the core business units - food preparation and service quality.

In addition, in a situation where the anti-food waste regulation is lax or non-existent and online market potential is low, the restaurant may choose not to engage in the *RF* strategy regardless of the cost-effectiveness of platform logistics. Non-strict regulations provide restaurants with little incentive to manage food waste, while self-delivery has the advantage of allowing tighter control over production and inventory. However, as anti-food waste regulation becomes more stringent, the restaurant is increasingly favoring the *RF* strategy as long as other factors are equal. Penalties from tough the anti-food waste regulation serves as economic counter-incentives, and the restaurant may mitigate the inevitable fines by adjusting production to real-time demand created by self-delivery. Still, if the efficiency of using platform logistics is significantly better than the cost of self-delivery, the restaurant may return to a platform-led strategy. The operational efficiencies that a platform can provide may provide an optimal return on investment, negating the advantages of self-control and driving the decision matrix toward platform dependence.

Overall, Figure 1 shows how strict anti-food waste regulation is driving the restaurant to shift to a self-delivery strategy. When this is combined with the market potential on the high line, this will become increasingly attractive. However, it also highlights the advantages of platform-led logistics, when their efficiency is superior to the cost of self-delivery, showing how strategy choices can vary based on a number of factors. This analysis provides an in-depth and comprehensive understanding of the dynamic decision-making process for optimal logistics strategies for the restaurant in an O2O environment.

According to Figure 2, regardless of anti-food waste regulation and online market potential, as long as the relative cost of platform logistics is not high, the platform is more willing to choose the *PC* strategy than the *RF* strategy. However, in the case that anti-food waste regulation and online market potential are not large enough, when the relative cost of platform logistics is large, the platform prefers the *RF* strategy rather than the *PC* strategy. In addition, the online market potential and the relative cost of platform logistics remain unchanged, and as anti-food waste regulation becomes stricter, the platform will be more willing to provide logistics services for online orders.

Figure 2 provides salient insights into logistical decision-making by the platform in response to online orders and reveals that the choice between the *RF* strategy and the *PC* strategy varies depending on these factors. We first observe that regardless of the stringency of anti-food waste regulation and the potential of the online market, the platform is predisposed towards managing logistics themselves (*PC* strategy), as long as the relative cost of doing so is not high. This observation is deeply rooted in cost–benefit analyses. With a lower relative cost, the platform can effectively control the logistic process, potentially enhancing service speed, customer experience, and the cohesive alignment of the business ecosystem. This level of control could also potentially decrease error rates and lead to increased overall efficiency. However, a significant caveat arises when the cost efficiency of platform logistics is high, but the potential of the online market and the severity of anti-food waste regulations are meager. In such a scenario, the platform tends more toward the *RF* strategy, opting not to manage self-logistics. The justification for this strategy rests on financial and operational grounds. The high cost of platform logistics coupled with a lower online market potential minimizes the likelihood of receiving substantial returns on platform's investment. Furthermore, a lenient anti-food waste regulation does not incentivize the platform to exert enhanced control over logistics, a move he may otherwise have considered to mitigate waste-related penalties.

Another intriguing observation that Figure 2 highlights is that with the increasing stringency of anti-food waste regulation and a constant potential of the online market and the relative cost of platform logistics, the platform exhibits an increased willingness to undertake logistics for online orders himself. Strict regulation compels the platform to leverage his control over logistics to mitigate the risk of penalties. Even at lower cost efficiencies, there is an inclination for the platform to undertake the logistics for online orders; the decision-making power the platform gains seem to compensate for the diminished cost efficiency.

In summary, Figure 2 raises the notion that within the spectrum of decision-making for logistics services for online orders, the stringency of anti-food waste regulation potentially holds more weight than the relative cost efficiency of platform logistics. Even when the cost efficiency is lower, the platform is willing to bear the extra cost for the sake of command over the logistics process as he navigate stringent regulations. Interestingly, the potential of the online market seems to have the least impact on platform's decision regarding logistics strategy among the three key influencing factors.

By conducting an analysis of Figures 1, 2, this study identifies the specific conditions that both restaurants and platforms must consider when selecting a logistics strategy within the food delivery O2O supply chain system. However, it is important to note that the game equilibrium between the restaurant and the platform also comes into play when considering non-dominant strategies. In this context, the restaurant, acting as the food provider, has the agency to prioritize whether to adopt the *RF* strategy. Conversely, the platform, serving as the service provider, can influence the restaurant's decision by withholding the *PC* strategy. Consequently, apart from the dominant strategies, the *RF* strategy becomes an equilibrium strategy if it proves advantageous for the restaurant or if the *PC* strategy proves disadvantageous for the platform. By integrating the insights from Figures 1, 2, the study derives the game equilibrium strategies of the supply chain members, as depicted in Figure 3.

Figure 3 provides an illustrative visualization of the strategic interplay between the restaurant and the platform under different regulatory, economic, and operational conditions. The intersections of the blue and red lines in Figures 3A,B, alongside the solitary blue line in Figure 3C, denote win-win areas for both the restaurant and the platform. These are the regions succinctly characterized by a lower propensity of online market potential and a lower relative cost of platform logistics. In these identified areas, the *PC* strategy emerges as the dominant strategy. Interestingly, such predominance of the *PC* strategy remains consistent even when regulation against food waste is relatively relaxed and the online market potential diminishes. This observation implies that resorting to the *PC* strategy could be mutually beneficial for both parties in the supply chain, despite considerable relative costs of platform logistics. Outside of these identified regions, all other areas in the decision matrix advocate for the *RF* strategy as the equilibrium approach suggesting that under specific conditions, the restaurant might assume more logistics responsibilities. In the upper-right regions above the blue line, characterized by a larger online market potential, the restaurant uniformly opt for a the *RF* strategy. This strategic choice occurs despite a small relative cost for the platform to provide the *PC* strategy, further emphasizing the complex dynamics between market potential and the relative cost of logistics in decision-making. Moreover, in the middle region trapped by the blue and red lines in Figures 3A,B, characterized by a smaller online market potential and a larger cost of platform logistics, the *PC* strategy is disadvantageous for the platform. Under such circumstances, the platform tends to abstain from action, compelling the restaurant to assume logistics responsibilities. It happens even if the restaurant's preference leans towards the platform providing logistics services, suggesting that preferences alone cannot determine actual strategy and that practical considerations like cost play a huge role. Furthermore, as the force of anti-food waste regulation intensifies, both restaurant and platform seem to gravitate more towards the *RF* strategy. Primarily, to reduce the negative implications of strict regulation, the restaurant adopts a more proactive approach by managing logistics herself. However, even though the platform may also be willing to provide the *PC* strategy, he is forced to acquiesce to the *RF* strategy due to restaurant holding the initiative.

Figure 3 plays a crucial role in illustrating the impact of stringent anti-food waste regulations on the equilibrium strategy within the supply chain. Particularly when these regulations are enforced with significant intensity, the equilibrium strategy tends to favor non-dominance. This shift occurs even when other relevant parameters remain constant and can result in decreased efficiency in supply chain operations. From an academic standpoint, this implies that both restaurants and platforms must strengthen their collaborative dynamics to effectively address this challenge in the face of strict regulations and evolving market conditions. These findings emphasize the changing dynamics between dominant and dominated stakeholders in business environments governed by stringent regulations and emphasize the importance of strategic alliances, cost management, and operational harmony.

5 Discussion and conclusion

In this paper, we have explored and analyzed the complex dynamics between the food delivery platform and the restaurant under various regulatory, economic, and operational conditions. More specifically, we have delved into two distinct logistics strategies that shape the interactions between the platform and the restaurant: the restaurant-free self-logistics strategy (*RF* strategy) and the platform-charge logistics strategy (*PC* strategy).

Our findings first reveal that anti-food waste regulation will be ineffective in the face of the *RF* strategy, and only under the *PC* strategy can anti-food waste regulation effectively reduce food waste. To this end, for the *RF* strategy, the government needs to consider making restaurants bear some responsibility for anti-food waste.

Then we found that under certain conditions, the platform naturally emerge as the dominant provider of logistics for online orders. This occurs particularly when the potential of the online market is small, and the relative cost of platform logistics is low. In contrast, in scenarios where the potential of the online market is high, even when the relative cost of platform logistics is low, the restaurant may adopt the *RF* strategy. However, different from previous studies, anti-food waste regulation will change the choice of logistics strategy of supply chain members. Under anti-food waste regulation, retailers tend to choose *RF* strategy, while delivery platforms prefer *PC* strategy, resulting in increased supply chain conflict effect.

Finally, we found that as the force of anti-food waste regulation increases, both the restaurant and the platform seemingly lean towards the *RF* strategy. Specifically, with the increase of anti-food waste regulation, supply chain balance strategy will gradually shift from PC strategy to RF strategy. In other words, different from previous studies, supply chain equilibrium results have changed under anti-food waste regulation. The primary reason for this shift is that to mitigate the adverse effects of stringent mandates, the restaurant actively manages logistics. Consequently, even if the platform is willing to perform the *PC* strategy, he might be coerced into accepting the *RF* strategy due to action initiation by the restaurant.

This paper highlights the significant role of research in guiding restaurants and platforms in the face of strict regulations and changing market conditions. It emphasizes the importance of strengthening strategic alliances and aligning cost-management and operational strategies in highly regulated business environments. Furthermore, the logistics strategies proposed in this research should encourage critical thinking among stakeholders in online food delivery ecosystems, particularly platforms and restaurants. Adapting strategies continuously to maintain supply chain efficiency and competitive advantage is vital, with an emphasis on data-driven insights, cost–benefit assessments, operational risk management, and flexible responses to regulatory changes.

The academic and practical implications of this research can prove invaluable to policymakers and stakeholders in the food delivery industry. It offers insights that can facilitate the development of harmonized policies and strategies, ensuring economic sustainability and environmental responsibility while meeting the growing global demands for online food delivery. Ultimately, this paper underscores the importance of aligning logistics strategies to comply with anti-food waste regulations. These conclusions provide a crucial foundation for future research in framing effective supply chain strategies in the food delivery industry, and also highlight the profound influence of government regulations on operational decision-making.

Nevertheless, various limitations of the study need to be considered when interpreting the results. In this study, the linear function of price demand is used for modeling analysis, and the influence of consumer behavior on channel selection is ignored. In fact, different consumers have heterogeneity in different channels and food intake, so the correlation analysis of demand model based on consumer behavior will have more extensive research value. Furthermore, the problem of food waste requires the cooperation of the members of the supply chain, and we have only considered the different logistics strategies adopted by both sides. Future research can consider the impact of the pricing strategy and promotion strategy between the restaurant and the platform on food waste. Finally, food quality has a significant impact on food waste. Based on the research in this paper, it is necessary to introduce food quality as a key factor in future research.

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/s.

Author contributions

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

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This work was supported by Project of Scientific Research Preparation Plan for colleges and universities in Anhui Province (2022AH050640).

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.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1320242/full#supplementary-material

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