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Pricing strategy for O2O delivery supply chain with anti-food waste regulation

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The rapid growth of Online-to-Offline (O2O) food delivery has exacerbated food waste, creating a challenge at the intersection of economic and environmental concerns. This paper examines how pricing strategies can balance merchant profit, consumer demand, and waste reduction under anti-food waste regulations. Using a game-theoretic model with a restaurant and a platform, we compare uniform and differentiated pricing under consumer appetite and value heterogeneity. Results show that regulations raise prices, especially online, and that their effect depends critically on regulatory stringency and consumer structure: a higher share of small appetite consumers lowers prices under lenient regulation but raises them under strict rules. Furthermore, while differentiated pricing often aligns supply chain interests under moderate regulation or high degree of differentiation in perceived value between the two types of consumers, platforms may prefer uniform pricing under high penalties. This paper provides a quantitative framework for O2O food waste analysis and suggests that effective mitigation requires context-aware regulation and adaptive pricing strategies.

KEYWORDS

food waste, O2O delivery, pricing strategy, regulation, supply chain

1 Introduction

The proliferation of internet technology and e-commerce has driven the widespread integration of Online-to-Offline (O2O) food delivery services into the culinary sector, profoundly reshaping daily life for consumers worldwide. The online food delivery market continues to gain traction globally, with a growing number of individuals choosing to order meals digitally. Market projections show that the global online food delivery sector, valued at USD 222 billion in 2025, is expected to reach USD 242.7 billion in 2026 and further expand to USD 540.6 billion by 2035, reflecting a compound annual growth rate (CAGR) of 9.3% from 2026 to 2035 (Online Food Delivery Market Report 2025). However, this rapid growth has introduced a significant challenge: the increase in food waste (Islam et al., 2023; Varese et al., 2024). A survey led by Tsinghua University's School of Environment, the China Chain-Store and Franchise Association, and the food delivery platform Meituan found that, on average, each takeaway user wastes about 57.5 grams of food per order. Given the massive scale of China's food delivery market, this represents a serious concern. Beyond economic losses for restaurants and platforms, this trend carries substantial environmental and social consequences, necessitating a deeper examination of the underlying drivers and effective mitigation strategies within the O2O ecosystem.

Food waste in the O2O food delivery sector is further intensified by prevalent marketing incentives—such as bulk discounts and oversized portions—that encourage consumers to order beyond their actual needs (Sharma et al., 2021). Although governmental and platform-led initiatives have sought to mitigate this issue by promoting small appetite and refining discount structures, food waste remains a persistent and pressing challenge (Cho et al., 2019; Trivedi et al., 2023; Manzoor et al., 2024). Policy intervention is widely regarded as a critical lever for scaling up effective food waste reduction solutions across the food system. In this regard, various policy measures have been proposed to systematically reduce food loss and waste at different stages of the supply chain (Shen et al., 2024).

In this context, a key research question arises: how can O2O food delivery platforms design pricing strategies that balance merchant profitability, consumer demand, and regulatory waste-reduction goals? Existing literature on food waste has focused mainly on qualitative analysis, examining factors such as consumer demographics, social norms, culture, habits, and values (O'Connor et al., 2021; Sarker et al., 2024). Broader supply-chain studies typically address food waste in traditional, non-O2O environments, identifying waste hotspots and proposing general mitigation measures (Aramyan et al., 2021; Bangar et al., 2024).

Meanwhile, pricing strategy research within O2O supply chains has addressed topics such as supplier participation thresholds, valaue-added services, matching mechanisms, and their implications for pricing (Huang and Yan, 2024). Other studies have analyzed the operational dynamics and challenges of parallel online-offline channels, as well as the role of supply chain power structures in shaping pricing and performance outcomes (Jin et al., 2021; Jiang and Wu, 2024). In the specific context of O2O food delivery, scholars have explored coordination contracts to safeguard restaurant profits and examined how self-service ordering technologies affect demand and profitability (Ma H. et al., 2024; Du and Fan, 2024).

Despite these advances, a notable research gap remains regarding food waste in the O2O food delivery supply chain—particularly from a quantitative and modeling-oriented perspective (Xu et al., 2024). Few studies have systematically examined how pricing mechanisms interact with consumer behavior, portion sizing, and regulatory frameworks to drive or deter waste in digital food delivery ecosystems.

Given these research gaps, this paper endeavors to bridge the divide by examining pricing strategies that cater to regulations against food waste, while considering the heterogeneity of consumers‘ appetites. Specifically, it explores how catering merchants and food delivery platforms can formulate pricing strategies that adapt to these regulations, based on consumers' varying appetites. Additionally, it analyzes the intricate interaction between anti-food waste regulations and different pricing strategies, offering actionable insights for policymakers and businesses. Specifically, this paper addresses the following core questions:

(1) How do different pricing strategies (uniform vs. differentiated) impact the profits of catering merchants and food delivery platforms with anti-food waste regulation?
(2) How does consumer appetite heterogeneity influence optimal pricing decisions and waste reduction outcomes in the O2O food delivery supply chain?
(3) How can the anti-food waste be designed to align the interests of supply chain members through differentiated pricing strategies, fostering sustainable collaboration?

The primary contribution of this paper is its examination of pricing strategies in the O2O food delivery supply chain that simultaneously align merchant profitability, consumer demand, and food waste reduction. By integrating government anti-food waste regulations and accounting for heterogeneity in consumer appetites, the study offers a quantitative framework to understand how restaurants and delivery platforms can adjust their pricing approaches in response to regulatory pressures and diverse consumer needs.

The remainder of this paper is structured as follows. Sec. 2 will review the relevant literature. Sec. 3 presents the problem description and model assumptions, laying the groundwork for the subsequent analysis. Sec. 4 constitutes the core of the research, focusing on model construction and analysis, which compares optimal decisions and profits across various scenarios. Sec. 5 employs numerical simulations to validate the model analysis and delve deeper into complex issues that cannot be directly compared through the model. Finally, Sec. 6 concludes the paper, summarizing the key findings and their implications. All the proofs can be found in the Appendix.

2 Literature review

With the rapid growth of Online-to-Offline (O2O) delivery services, the issue of food waste has emerged as a significant concern. This section reviews existing literature related to food waste and O2O supply chain pricing, with a focus on how these fields intersect and contribute to the current research gap.

2.1 Food waste

Food waste is a multifaceted challenge with profound environmental, economic, and social implications. A substantial body of research has been devoted to understanding the causes, consequences, and mitigation strategies of food waste (Magalhães et al., 2021; Kristia et al., 2023).

Early studies emphasized the role of consumer demographics, such as household size and composition, in influencing food waste generation (Edjabou et al., 2015, 2016; Li et al., 2021). Age has also been identified as a crucial factor, with younger individuals tending to waste more food compared to older individuals (Niaki et al., 2017). Furthermore, social norms, cultural background, shopping habits, and values have been shown to significantly impact food waste behavior (Aydin and Yildirim, 2021). Research has delved into the various stages of the food supply chain where waste occurs. In developing countries, food waste is predominantly generated in the upstream stages, whereas in developed countries, it is more prevalent in the downstream stages (Özbük and Coşkun, 2020). Corrado et al. (2019) argued that food waste is a result of inefficiencies within the food supply chain. Govindan (2018) suggested that effective food supply chain management practices can reduce food waste by up to 23%. Do et al. (2021) emphasized the importance of reducing food waste in food supply chain management, highlighting the potential benefits of recycling and reusing food waste, as well as improving operational strategies in the downstream stages.

More recent studies have focused on quantifying food waste and its environmental impact. Malefors et al. (2024) evaluated an automated tool for quantifying plate waste in primary school canteens and found that a minority of students contributed to the majority of the waste, emphasizing the importance of implementing targeted intervention measures for high wasters. Bogenreuther et al. (2024) calculated and analyzed the amount of food waste at five stages and seven sub-stages of the German food supply chain, traced the countries of origin of 204 food products, and quantified their potential impact on the loss of mammal, bird, amphibian, reptile, and plant species globally. Bechir et al. (2024) quantified the food loss in the Algerian food industry caused by the processing of various agricultural products and proposed practical solutions to minimize such losses, aiming to benefit the economy and food supply. Bahramian et al. (2024) conducted a critical assessment of the strengths, weaknesses, opportunities, and threats (SWOT) of Dynamic Life Cycle Assessment (DLCA) in the context of Household and Commercial Food Waste (HCFW) by reviewing 12 relevant studies from 1999 to 2022, highlighting the need for further research and standardization.

In addition to these qualitative and quantitative analyses, several studies have explored the use of technology and innovation to mitigate food waste. For instance, research on smart packaging and blockchain technology has demonstrated their potential in reducing food waste by improving traceability and shelf-life management (Trevisan and Formentini, 2023).

However, a notable gap remains in the literature concerning the specific issue of food waste in the O2O food delivery supply chain, particularly from a quantitative perspective.

2.2 O2O supply chain pricing

Pricing strategies in O2O supply chains have been extensively studied, with a focus on optimizing revenue, managing inventory, and enhancing customer satisfaction (Taleizadeh et al., 2023; Gu et al., 2023). Liu et al. (2019) established a profit-maximizing O2O platform model, considering the impact of supplier participation thresholds, value-added services, and matching capabilities on pricing decisions. Govindan and Malomfalean (2019) discussed the benefits and complexities of parallel operation in online and offline markets, emphasizing the need for effective coordination mechanisms. Chen et al. (2016) analyzed the influence of supply chain power structures on pricing decisions and overall performance.

Recent studies have delved deeper into specific pricing strategies within the O2O context. Cao and Wang (2024) investigated how price discrimination impacts consumer behavior in the O2O food delivery market, revealing that personalized pricing can significantly increase platform revenue. Zhou et al. (2024) studied the effect of dynamic pricing on consumer demand and platform profits in the O2O retail sector, demonstrating the potential benefits of real-time price adjustments. Li et al. (2020) explored the impact of platform commission on pricing and coordination in the O2O food delivery supply chain, highlighting the need for a balanced approach to commission structures. Dai et al. (2023) designed a two-layer supply chain model to investigate price and service strategies for restaurants and online platforms in the catering industry post-COVID-19, finding that optimal pricing strategies can maximize profits for both parties, influenced by customer sensitivity and service level cost coefficients. Unlike prior work that treats consumer demand mainly through sensitivity or service coefficients, we explicitly consider heterogeneity in consumer appetite (small vs. regular) and differentiated perceived value across channels. Furthermore, we analyze how regulatory stringency interacts with this heterogeneity to influence the choice between uniform and differentiated pricing. This allows us to derive context-dependent policy insights—for example, under what conditions differentiated pricing can align supply chain interests with waste-reduction goals.

Moreover, research has explored the role of technology and consumer preferences in shaping O2O pricing strategies. Feldman et al. (2023) proposed a coordination contract that protects restaurant profits by ensuring a minimum income for each food delivery order and flexibly allocating income between restaurants and platforms. Gao and Su (2018) investigated the impact of self-service ordering technology on customer demand and restaurant profits, finding that technology adoption can lead to increased efficiency and satisfaction. Chai et al. (2021) explored the impact of consumers‘ anticipated regret on retailers’ pricing, advertising decisions, and profits in the O2O supply chain under product value uncertainty. It was found that retailers should decide whether to introduce the BOPS channel based on the product matching rate, and that consumers‘ anticipated regret has different effects on retailers’ profits under different circumstances. Ma S. et al. (2024) investigated how catering businesses price and promote their products under two scenarios: with and without coupon stacking. It was found that reference price has a significant impact on business profits, and businesses that participate in coupon stacking tend to have higher profits. Additionally, when the commission rate rises, businesses should increase the prices of their meals.

Despite a well-established body of research on pricing strategies in O2O supply chains, a distinct gap persists regarding how pricing can be deliberately leveraged to mitigate food waste. Existing work has extensively explored channel-based pricing—comparing uniform vs. differentiated approaches across online and offline platforms—yet it has largely neglected the strategic role of pricing in addressing consumer appetite heterogeneity, a fundamental driver of waste. Prior studies have focused on coordination mechanisms, technology adoption, and general consumer preferences. However, the deliberate design of product portfolios—and the corresponding price differentiation needed to align portion sizes with actual consumption—remains underexplored. Existing models often assume homogeneous demand, neglecting the distinct behavior of small appetite consumers. These consumers produce disproportionately more waste when only standard-sized meals are offered. Shifting from a channel-centric to an appetite-centric pricing approach can address this gap. This can be done through structural menu changes, such as offering small appetite options alongside segmented pricing. Such an approach directly tackles the root cause of plate waste by matching supply to actual consumption capacity. This reorientation does more than extend O2O pricing theory into sustainable consumption. It also introduces a new analytical framework for studying how pricing design, consumer appetite segmentation, and waste reduction interact. In doing so, it fills an important research gap where operational pricing meets environmental sustainability in food delivery systems.

In summary, existing literature offers valuable insights into O2O supply chain management and delivery services. However, a significant research gap remains regarding food waste in O2O food delivery supply chains. This gap calls for more focused studies on how pricing strategies can reduce food waste in this context.

3 Model development

This paper considers an O2O food supply chain consisting of a restaurant and a food delivery platform. The restaurant offers both dine-in service and online meal delivery, while the platform specializes in providing online ordering and delivery services. Both parties are fully rational profit-maximizers and engage in a Stackelberg leader-follower game, with the platform acting as the leader and the restaurant as the follower. Specifically, the platform, as the leader, first determines the online selling price (including the delivery fee), while charging the restaurant a commission at a fixed rate on its online sales revenue. Subsequently, the restaurant, as the follower, decides its dine-in price.

The market consists of two types of consumers: regular appetites and small appetites. Referring to the processing methods in existing O2O supply chain operation management research such as Gao and Su (2018) and Feldman et al. (2023), for the convenience of analysis, this paper assumes that the proportions of the two types of consumers are known. To serve them, the restaurant may adopt one of two pricing strategies: (1) offering only regular appetite meals at a uniform price, or (2) offering differentiated pricing by providing both regular appetite and small appetite meals. Consistent with real-world behavior, we assume that regular appetites only choose regular appetite meals, while small appetites opt for regular appetite meals only if small appetite ones are unavailable. Regarding consumption value perception, for the same regular appetite meal: The perceived utilities of a regular appetite from dine-in and online delivery are denoted as v and θv, respectively; The perceived utilities of a small appetite, whether from a regular appetite or a small appetite meal, are denoted as λv, and $\theta\lambda v$, respectively. Here, $\lambda(0 < \lambda < 1)$ represents the degree of difference in perceived value between the two consumer types—a larger λ indicates a smaller difference. To capture consumer heterogeneity, following prior literatures (Gao and Su, 2018; Xu et al., 2024), we assume v is uniformly distributed over [0, V]. Considering that delivery time may reduce meal freshness and sensory quality, where $\theta < 1$ captures the value discount associated with online ordering.

Furthermore, our model incorporates two core assumptions grounded in China's regulatory context: first, that the delivery platform bears primary responsibility for food waste generated in the online channel; second, that it faces a government penalty proportional to the waste amount. These assumptions are justified as follows: (1) Legally, the Anti-Food Waste Law (National People's Congress of China, 2021) mandates online platforms to remind consumers to order appropriately, establishing their formal accountability for waste on their services. This liability is reinforced by the 2024 "Guidelines for Preventing Food Waste in Online Catering", which detail platforms' obligations in monitoring and reducing waste. (2) Operationally, platforms—as the transaction orchestrators—possess the data and interface control to influence ordering behavior most directly, making them the natural focal point for regulation, unlike dine-in consumption where direct restaurant supervision is feasible. (3) Analytically, the penalty is modeled as a linear function of waste volume, a standard reduced-form approach in economic analysis to represent continuous regulatory pressure rather than a literal fee structure. It thus quantifies the real-world compliance risks associated with waste scale as an explicit cost factor within the decision-making framework.

To summarize the above, our model parameters are summarized in Table 1. The following assumptions are made to facilitate the analysis:

Assumption 1. The cost for the restaurant to prepare one regular appetite meal and one small appetite meal is c and σc $(0 < \sigma < 1)$, respectively.

Assumption 2. Consumers incur a hassle cost (e.g., travel time or expense) when dining in.

Assumption 3. The delivery platform bears primary responsibility for food waste in online orders and is subject to government penalties accordingly.

Assumption 4. In the short term, consumer behavior regarding food waste in online orders is difficult to change. Refer to the

TABLE 1 Summary of basic notations.

Parameters	
α	Proportion of consumers with small appetites
v	Perceived value of a regular appetite when dining offline
λ	Degree of difference in perceived value between the two consumer types
θ	Value discount associated with online ordering
t	Hassle cost for consumers when dining offline
c	Unit cost of a regular appetite meal
η	Commission rate charged by the food delivery platform
k	Government's penalty cost per unit of delivery food waste
ρ	Online unit waste ratio for regular appetites of both pricing strategies and for small appetites the differentiated pricing strategy
$\mu\rho$	Online unit waste ratio for small appetites of the uniform pricing strategy
Decision variables	
p_i^j	Meal price of channel i under pricing strategy j
Independent variables	
d_i^j	Demand quantity of channel i under pricing strategy j
π_i^j	Profit of supply chain members i under pricing strategy j
W^j	Waste quantity from online orders under pricing strategy j

existing literatures (Zhang et al., 2022; Trivedi et al., 2023), which indicates that higher delivery volumes lead to increased waste, we assume a linear relationship between the quantity of online orders and the amount of food waste. Specifically, the waste proportion for regular appetites of both pricing strategies and for small appetites the differentiated pricing strategy are ρ, whereas the waste proportion for small appetites of the uniform pricing strategy is $\mu\rho$ ($\mu > 1$).

Additionally, the subscripts $i \in \{r, o\}$ used in this paper represent the catering business and the food delivery platform, respectively; the superscripts $j \in \{S, D\}$ denote pricing strategies such as uniform pricing and differentiated pricing; and the superscript "$*$" represents the optimal solution or optimal profit. The specific model parameters and descriptions in this chapter are shown in Table 1.

4 Pricing strategy

While offering smaller portions to consumers with smaller appetites can reduce production costs for caterers, these meals are inevitably priced lower than regular appetite ones, which may correspondingly erode profit margins. Therefore, caterers face a critical pricing decision: whether to adopt a uniform strategy by providing only standard-sized meals at a single price, or to implement a differentiated strategy by tailoring portion sizes and prices to the heterogeneous appetites of consumers.

4.1 Uniform pricing

When a caterer adopts a uniform pricing strategy—offering the same portion size at the same price to all consumers, regardless of their appetite type—the utility functions for a small appetite consumer choosing between online ordering and offline dining are given as follows:

$$u_{o1}^S = \theta\lambda v - p_o^S \text{ and } u_{r1}^S = \lambda v - p_r^S - t \tag{1}$$

Correspondingly, the utility functions for regular appetite consumers choosing online ordering and offline dining can be respectively expressed as follows:

$$u_{o2}^S = \theta v - p_o^S \text{ and } u_{r2}^S = v - p_r^S - t \tag{2}$$

Based on Equation 1, when $\frac{p_o^S}{\theta\lambda} < \frac{p_r^S+t-p_o^S}{\lambda(1-\theta)} < V$, If $\frac{p_o^S}{\theta\lambda} < v < \frac{p_r^S+t-p_o^S}{\lambda(1-\theta)}$, then $u_{o1}^S > 0$ and $u_{o1}^S > u_{r1}^S$, i.e., $d_{o1}^S > 0$; If $v > \frac{p_{r1}^D+t-p_{o1}^D}{\lambda(1-\theta)}$, then $u_{r1}^S > 0$ and $u_{r1}^S > u_{o1}^S$, i.e., $d_{r1}^S > 0$. Therefore, under the uniform pricing strategy, the market demands for small appetite consumers in the online and offline channels can be respectively derived as:

$$\begin{aligned} d_{o1}^S &= \alpha\left(\frac{p_r^S+t-p_o^S}{\lambda(1-\theta)} - \frac{p_o^S}{\theta\lambda}\right) \text{ and} \\ d_{r1}^S &= \alpha\left(V - \frac{p_r^S+t-p_o^S}{\lambda(1-\theta)}\right) \end{aligned} \tag{3}$$

Based on Equation 2, when $\frac{p_o^S}{\theta} < \frac{p_r^S+t-p_o^S}{1-\theta} < V$, If $\frac{p_o^S}{\theta} < v < \frac{p_r^S+t-p_o^S}{1-\theta}$, then $u_{o2}^S > 0$ and $u_{o2}^S > u_{r2}^S$, i.e., $d_{o2}^S > 0$; If $v > \frac{p_r^S+t-p_o^S}{1-\theta}$, then $u_{r2}^S > 0$ and $u_{r2}^S > u_{o2}^S$, i.e., $d_{r2}^S > 0$. Therefore, under the uniform pricing strategy, the market demands for regular appetite consumers in the online and offline channels can be respectively derived as:

$$\begin{aligned} d_{o2}^S &= (1-\alpha)\left(\frac{p_r^S+t-p_o^S}{1-\theta} - \frac{p_o^S}{\theta}\right) \text{ and} \\ d_{r2}^S &= (1-\alpha)\left(V - \frac{p_r^S+t-p_o^S}{1-\theta}\right) \end{aligned} \tag{4}$$

When the uniform pricing strategy is adopted, no distinction is made between consumer appetite types. Consequently, the profit functions for the restaurant and the online delivery platform can be formulated as follows:

$$\begin{aligned} \pi_r^S &= (1-\eta)p_o^S(d_{o1}^S + d_{o2}^S) + p_r^S(d_{r1}^S + d_{r2}^S) \\ &\quad - c(d_{o1}^S + d_{o2}^S + d_{r1}^S + d_{r2}^S) \end{aligned} \tag{5}$$

$$\pi_o^S = \eta p_o^S(d_{o1}^S + d_{o2}^S) - k\mu\rho d_{o1}^S - k\rho d_{o2}^S. \tag{6}$$

In Equation 5, the first term is the online revenue after deducting the takeout commission, the second term is the revenue from offline dining, and the last term is the production cost of both online and offline meals. Simultaneously, in Equation 6, The first item is the commission income from takeout services provided by the restaurant, and the last two items are respectively the penalties imposed by the government for the waste of takeout services by consumers with small and regular appetites.

From the above analysis, we obtain the following theorem 1.

Theorem 1. When $f_1 > 0$ and $f_2 > 0$, the optimal prices for online ordering and offline dining under the uniform pricing strategy are derived as follows:

$$\begin{aligned} p_o^{S*} &= \frac{\theta\left((1-\theta)\lambda V + (1-\alpha)\lambda + \alpha)t\right)}{2(\eta\theta + 2(1-\theta))((1-\alpha)\lambda + \alpha)} \\ &\quad + \frac{k\rho\left((1-\alpha)\lambda + \mu\alpha\right)}{2\eta((1-\alpha)\lambda + \alpha)} \end{aligned} \tag{7}$$

$$\begin{aligned} p_r^{S*} &= \frac{(1-\theta)(\eta\theta + 2(2-\theta))\lambda V}{4(\eta\theta + 2(1-\theta))((1-\alpha)\lambda + \alpha)} - \frac{(4-(6-3\eta)\theta)t}{4(\eta\theta + 2(1-\theta))} \\ &\quad + \frac{k\rho(2-\eta)\left((1-\alpha)\lambda + \mu\alpha\right)}{4\eta((1-\alpha)\lambda + \alpha)} \end{aligned} \tag{8}$$

Where: $f_1 = (1-\theta)(2(\eta\theta + 2(1-\theta))(2(1-\alpha)\lambda - (1-2\alpha)) + \eta\theta)\lambda V + (\eta\theta + 4(1-\theta))t + k\rho(\eta\theta + 2(1-\theta))((1-\alpha)\lambda + \alpha\mu)$;

$$\begin{aligned} f_2 &= \eta\theta((1-\theta)\lambda V + ((1-\alpha)\lambda + \alpha)t) - k\rho(\eta\theta \\ &\quad + 2(1-\theta))((1-\alpha)\lambda + \alpha\mu). \end{aligned}$$

Using Theorem 1 and substituting Equations 7 and 8 into 3 and 4, respectively, we obtain the optimal demands for the online and offline channels as follows:

$$
\begin{aligned}
d_{o1}^{S*} &= \frac{\alpha f_2}{4\eta\theta\lambda(1-\theta)(\alpha+(1-\alpha)\lambda)} \text{ and} \\
d_{r1}^{S*} &= \frac{\alpha f_1}{4(1-\theta)(\alpha+(1-\alpha)\lambda)(\eta\theta+2(1-\theta))} \qquad (9) \\
d_{o2}^{S*} &= \frac{(1-\alpha)f_2}{4\eta\theta(1-\theta)(\alpha+(1-\alpha)\lambda)} \text{ and } d_{r2}^{S*} = (1-\alpha)(1-\lambda)V \\
&+ \frac{(1-\alpha)f_1}{4(1-\theta)(\alpha+(1-\alpha)\lambda)(\eta\theta+2(1-\theta))} \qquad (10)
\end{aligned}
$$

Accordingly, we can derive the amount of online food waste as:

$$
W^S = \mu\rho d_{o1}^{S*} + \rho d_{o2}^{S*} = \frac{(\mu\alpha+(1-\alpha)\lambda)\rho f_2}{4\eta\theta\lambda(1-\theta)(\alpha+(1-\alpha)\lambda)} \qquad (11)
$$

4.2 Differentiated pricing

Under a differentiated pricing strategy, the restaurant offers varying portion sizes at different prices for online and offline channels, according to consumer appetite. The utility functions for small appetite consumers are thus defined as follows:

$$
u_{o1}^D = \theta\lambda v - p_{o1}^D \text{ and } u_{r1}^D = \lambda v - p_{r1}^D - t \qquad (12)
$$

Correspondingly, under the differentiated pricing strategy, under the differentiated pricing strategy, the utility functions for regular appetite consumers are given by:

$$
u_{o2}^D = \theta v - p_{o2}^D \text{ and } u_{r2}^D = v - p_{r2}^D - t \qquad (13)
$$

Based on Equation 12, when $\frac{p_{o1}^D}{\theta\lambda} < \frac{p_{r1}^D+t-p_{o1}^D}{\lambda(1-\theta)} < V$, If $\frac{p_{o1}^D}{\theta\lambda} < v < \frac{p_{r1}^D+t-p_{o1}^D}{\lambda(1-\theta)}$, then $u_{o1}^D > 0$ and $u_{o1}^D > u_{r1}^D$, i.e., $d_{o1}^D > 0$; If $v > \frac{p_{r1}^D+t-p_{o1}^D}{\lambda(1-\theta)}$, then $u_{r1}^D > 0$ and $u_{r1}^D > u_{o1}^D$, i.e., $d_{r1}^D > 0$. Therefore, under the differentiated pricing strategy, the market demands for small appetite consumers in the online and offline channels can be respectively derived as:

$$
\begin{aligned}
d_{o1}^D &= \alpha(\frac{p_{r1}^D+t-p_{o1}^D}{\lambda(1-\theta)} - \frac{p_{o1}^D}{\theta\lambda}) \text{ and} \\
d_{r1}^S &= \alpha(V - \frac{p_{r1}^D+t-p_{o1}^D}{\lambda(1-\theta)}) \qquad (14)
\end{aligned}
$$

Based on Equation 13, when $\frac{p_{o2}^D}{\theta} < \frac{p_{r2}^D+t-p_{o2}^D}{1-\theta} < V$, If $\frac{p_{o2}^D}{\theta} < v < \frac{p_{r2}^D+t-p_{o2}^D}{1-\theta}$, then $u_{o2}^D > 0$ and $u_{o2}^D > u_{r2}^D$, i.e., $d_{o2}^D > 0$; If $v > \frac{p_{r2}^D+t-p_{o2}^D}{1-\theta}$, then $u_{r2}^D > 0$ and $u_{r2}^D > u_{o2}^D$, i.e., $d_{r2}^D > 0$. Therefore, under the differentiated pricing strategy, the market demands for regular appetite consumers in the online and offline channels can be respectively derived as:

$$
\begin{aligned}
d_{o2}^D &= (1-\alpha)(\frac{p_{r2}^D+t-p_{o2}^D}{1-\theta} - \frac{p_{o2}^D}{\theta}) \text{ and} \\
d_{r2}^D &= (1-\alpha)(V - \frac{p_{r2}^D+t-p_{o2}^D}{1-\theta}) \qquad (15)
\end{aligned}
$$

Consequently, When the differentiated pricing strategy is adopted, the profit functions for the restaurant and the online delivery platform can be formulated as follows:

$$
\begin{aligned}
\pi_r^D &= (1-\eta)(p_{o1}^D d_{o1}^D + p_{o2}^D d_{o2}^D) + p_{r1}^D d_{r1}^D + p_{r2}^D d_{r2}^D \\
&- c(\sigma(d_{o1}^D + d_{r1}^D) + d_{o2}^D + d_{r2}^D) \qquad (16) \\
\pi_o^D &= \eta(p_{o1}^D d_{o1}^D + p_{o2}^D d_{o2}^D) - k\rho(d_{o1}^D + d_{o2}^D) \qquad (17)
\end{aligned}
$$

In Equation 16, the first term is the online revenue after deducting the takeout commission, the second and the third terms correspond to the revenue from dine-in services for the two consumer segments, and the last term is the production cost of both online and offline meals. Simultaneously, in Equation 17, The first item is the commission income from takeout services provided by the restaurant, and the last item are the penalties imposed by the government for the waste of takeout services by consumers with small and regular appetites.

From the above analysis, we obtain the following theorem 2.

Theorem 2. When $f_3 > 0$ and $f_4 > 0$, the optimal prices for online ordering and offline dining under the differentiated pricing strategy are derived as follows:

$$
\begin{aligned}
p_{o1}^{D*} &= \frac{\eta\theta((1-\theta)\lambda V + t) + k\rho(\eta\theta+2(1-\theta))}{2\eta(\eta\theta+2(1-\theta))} \qquad (18) \\
p_{o2}^{D*} &= \frac{\eta\theta((1-\theta)V + t) + k\rho(\eta\theta+2(1-\theta))}{2\eta(\eta\theta+2(1-\theta))} \qquad (19) \\
p_{r1}^{D*} &= \frac{\eta((1-\theta)(\eta\theta+2(2-\theta))\lambda V - (3\eta\theta+2(2-3\theta))t) + k\rho(2-\eta)(\eta\theta+2(1-\theta))}{4\eta(\eta\theta+2(1-\theta))} \qquad (20) \\
p_{r2}^{D*} &= \frac{\eta((1-\theta)(\eta\theta+2(2-\theta))V - (3\eta\theta+2(2-3\theta))t) + k\rho(2-\eta)(\eta\theta+2(1-\theta))}{4\eta(\eta\theta+2(1-\theta))} \qquad (21)
\end{aligned}
$$

Where: $f_3 = (1-\theta)(3\eta\theta+4(1-\theta))\lambda V - (\eta\theta+4(1-\theta))t + k\rho(\eta\theta+2(1-\theta))$ and $f_4 = \eta\theta((1-\theta)\lambda V+t) - k\rho(\eta\theta+2(1-\theta))$.

Using Theorem 2 and substituting Equations 18, 19, 20 and 21 into 14 and 15, respectively, we obtain the optimal demands for the online and offline channels as follows:

$$
\begin{aligned}
d_{o1}^{D*} &= \frac{\alpha f_4}{4\eta\theta\lambda(1-\theta)} \text{ and } d_{r1}^{D*} = \frac{\alpha f_3}{4\lambda(1-\theta)(\eta\theta+2(1-\theta))} \qquad (22) \\
d_{o2}^{D*} &= \frac{(1-\alpha)f_6}{4\eta\theta(1-\theta)} \text{ and } d_{r2}^{D*} = \frac{(1-\alpha)f_5}{4(1-\theta)(\eta\theta+2(1-\theta))} \qquad (23)
\end{aligned}
$$

Where: $f_5 = (1-\theta)(3\eta\theta+4(1-\theta))V - (\eta\theta+4(1-\theta))t + k\rho(\eta\theta+2(1-\theta))$ and $f_6 = \eta\theta((1-\theta)V+t) - k\rho(\eta\theta+2(1-\theta))$.

Accordingly, we can derive the amount of online food waste as:

$$
W^D = \rho(d_{o1}^{D*} + d_{o2}^{D*}) = \frac{\rho(\alpha f_4 + \lambda(1-\alpha)f_6)}{4\lambda(1-\theta)(\eta\theta+2(1-\theta))} \qquad (24)
$$

4.3 Model analysis

Drawing on the equilibrium results from the optimization model, this section examines the sensitivity of the relevant optimal decisions with respect to critical parameters, thereby establishing the propositions below.

Proposition 1. *(1)* $\frac{dp_o^{S*}}{dk} > \frac{dp_r^{S*}}{dk} > 0$ *and* $\frac{dp_{o1}^{D*}}{dk} = \frac{dp_{o2}^{D*}}{dk} > \frac{dp_{r1}^{D*}}{dk} = \frac{dp_{r2}^{D*}}{dk} > 0$; *(2)* $\frac{dW^S}{dk} < 0$, $\frac{dW^D}{dk} < 0$ *and* $\left|\frac{dW^S}{dk}\right| > \left|\frac{dW^D}{dk}\right|$.

Proposition 1 indicates that the introduction of anti-food-waste regulations leads to higher meal prices in both online and offline channels, regardless of whether a uniform or differentiated pricing strategy is employed. This price increase is economically driven by the regulatory cost pass-through mechanism: platforms, as the primary entities penalized for waste, transfer a portion of the expected penalty costs to consumers through higher online prices. Restaurants subsequently adjust dine-in prices upward to maintain cross-channel price consistency and protect profit margins. The effect is more pronounced in the online channel because the penalty is directly tied to delivery volume, creating a stronger incentive to curb consumption through price elevation.

Furthermore, the proposition indicates that such regulations effectively reduce food waste, with a more substantial reduction observed under a uniform pricing strategy compared to a differentiated one. This differential impact stems from the inherent inflexibility of uniform pricing: with only one portion size offered, price increases suppress demand across all consumer types, including small appetite consumers who generate disproportionately high waste per order. Under differentiated pricing, the availability of smaller appetites partially offsets the demand-reducing effect of higher prices, thereby moderating the overall waste reduction.

These findings suggest that regulatory efficacy is not uniform across pricing structures. Stricter regulations are particularly effective when applied to businesses using a uniform pricing strategy, as the absence of portion-size options forces consumption cuts primarily through price signals. In contrast, under differentiated pricing, lenient regulations may still permit waste levels to persist, since smaller appetite alternatives can sustain order volume even as prices rise. Consequently, policymakers should consider tailoring regulatory stringency based on the prevailing pricing model to optimize waste-reduction outcomes while minimizing market distortion.

Proposition 2. *(1)* ① *If* $k \le k_1$, *then* $\frac{dp_r^{S*}}{d\alpha} < \frac{dp_o^{S*}}{d\alpha} \le 0$; ② *If* $k_1 < k \le k_2$, *then* $\frac{dp_r^{S*}}{d\alpha} \le 0 < \frac{dp_o^{S*}}{d\alpha}$; ③ *If* $k > k_2$, *then* $\frac{dp_o^{S*}}{d\alpha} > \frac{dp_r^{S*}}{d\alpha} > 0$; *(2)* $\frac{dp_{o1}^{D*}}{d\alpha} = \frac{dp_{o2}^{D*}}{d\alpha} = \frac{dp_{r1}^{D*}}{d\alpha} = \frac{dp_{r2}^{D*}}{d\alpha} = 0$; *(3)* ① *If* $k \le k_3$, *then* $\frac{dW^S}{d\alpha} \ge 0$, *otherwise* $\frac{dW^S}{d\alpha} < 0$. ② *If* $k \le k_4$, *then* $\frac{dW^D}{d\alpha} \ge 0$, *otherwise* $\frac{dW^D}{d\alpha} < 0$.

Where: $k_1 = \frac{(1-\lambda)(1-\theta)\eta\theta V}{(\mu-1)(\eta\theta+2(1-\theta))\rho}$; $k_2 = \frac{(1-\lambda)(1-\theta)(\eta\theta+2(2-\theta))\eta V}{(\mu-1)(2-\eta)(\eta\theta+2(1-\theta))\rho}$; $k_3 = \frac{(1-\lambda)(1-\theta)\eta\theta\lambda^2 V+(\mu-\lambda)((1-\alpha)\lambda+\alpha)^2\theta t}{\rho f_7}$; $k_4 = \frac{\eta\theta t}{\rho(\eta\theta+2(1-\theta))}$; and $f_7 = (\mu(\alpha(1-\lambda)+2\lambda)-\lambda((1+\lambda)+(1-\lambda)\alpha))((1-\alpha)\lambda+\mu\alpha)(\eta\theta+2(1-\theta))$.

Proposition 2 indicates a non-monotonic relationship between the share of small appetite consumers and equilibrium prices under a uniform pricing strategy—a pattern that reverses direction as regulatory stringency increases. The economic intuition stems from a shift in firms' primary incentive: under lenient regulation, competition for the growing small appetite segment drives prices down to stimulate demand; under strict regulation, penalty-avoidance dominates, leading firms to raise prices to curb the high-waste risk associated with small appetite consumers. In moderate regulatory regimes, asymmetric channel pressures emerge: online prices rise to mitigate delivery-focused penalties, while offline prices may fall to retain dine-in customers. This reversal highlights how policy intensity reshapes the fundamental trade-off between market share and compliance cost.

Under a differentiated pricing strategy, the proportion α does not directly influence optimal decisions, because menu differentiation already aligns portion sizes with consumer appetites, thereby decoupling consumer composition from waste-related pricing adjustments. Waste levels, however, remain sensitive to α, but again in a regulation-dependent manner: with lenient rules, more small appetite consumers increase waste through higher order volume; under stringent rules, the accompanying price increases can suppress overall consumption enough to reduce waste. Thus, the impact of α on waste is not inherent but mediated through the price channel that regulation activates.

These results show that effective food-waste policy cannot treat consumer composition as a fixed determinant of waste. Instead, regulators must recognize that the same market structure (high α) can lead to opposite outcomes depending on whether the policy environment encourages competitive pricing or penalty-driven price hikes. Consequently, dynamically calibrated regulations—tightening when α rises under uniform pricing, or allowing more flexibility under differentiation—are essential to align incentives across the supply chain and achieve sustained waste reduction without stifling market efficiency.

Proposition 3. *(1)* ① *If* $k \le k_5$, *then* $\frac{dp_r^{S*}}{d\lambda} > \frac{dp_o^{S*}}{d\lambda} \ge 0$; ② *If* $k_5 < k < k_6$, *then* $\frac{dp_o^{S*}}{d\lambda} < 0 \le \frac{dp_r^{S*}}{d\lambda}$; ③ *If* $k \ge k_6$, *then* $0 \ge \frac{dp_o^{S*}}{d\lambda} > \frac{dp_r^{S*}}{d\lambda}$; *(2)* $\frac{dp_{r1}^{D*}}{d\lambda} > \frac{dp_{o1}^{D*}}{d\lambda} > 0$ *and* $\frac{dp_{o2}^{D*}}{d\lambda} = \frac{dp_{r2}^{D*}}{d\lambda} = 0$; *(3)* ① *If* $k \le k_7$, *then* $\frac{dW^S}{d\lambda} \le 0$, *otherwise* $\frac{dW^S}{d\lambda} > 0$. ② *If* $k \le k_4$, *then* $\frac{dW^D}{d\lambda} \le 0$, *otherwise* $\frac{dW^D}{d\lambda} > 0$.

Where: $k_5 = \frac{(1-\theta)\eta\theta V}{(\mu-1)(1-\alpha)(\eta\theta+2(1-\theta))\rho}$; $k_6 = \frac{(1-\theta)(\eta\theta+2(2-\theta))\eta V}{(\mu-1)(1-\alpha)(2-\eta)(\eta\theta+2(1-\theta))\rho}$; $k_7 = \frac{(\mu-1)(1-\alpha)(1-\theta)\eta\theta\lambda^2 V+((1-\alpha)\lambda+\alpha)^2\mu\eta\theta t}{\rho f_8}$; and $f_8 = (\lambda(\alpha(2\mu-1)(1-\alpha)+\mu\alpha)((1-\alpha)\lambda+\mu\alpha)(\eta\theta+2(1-\theta))$.

Proposition 3 indicates how the convergence of perceived value between consumer types interacts with pricing strategy and regulation to determine prices and waste. The economic mechanism centers on the firm's ability to segment the market: under differentiated pricing, convergence allows the restaurant to raise prices for small appetite consumers without losing them to regular appetites, as their willingness-to-pay becomes more aligned. Regular appetite prices remain stable because that segment is already distinct. Under uniform pricing, however, the firm cannot separate consumers, so price adjustments must respond to the entire market's average valuation while also accounting for regulatory penalties.

This interaction explains the reversal of price effects under uniform pricing as regulation tightens. When regulation is lenient, convergence raises prices because the firm can extract more value from a less heterogeneous market without triggering a strong demand drop. When regulation is stringent, convergence instead lowers prices: with penalties tied to waste volume, the firm's priority shifts from value extraction to consumption control.

Reducing prices helps limit overall orders and thus penalties, even if it sacrifices some margin. This pivot illustrates how regulatory pressure can overwhelm ordinary demand-based pricing logic.

Consequently, waste outcomes also reverse with regulatory stringency. Under lenient rules, convergence reduces waste through higher prices; under strict rules, it increases waste by stimulating consumption via lower prices. This counterintuitive result shows that consumer cognitive structure and regulatory intensity jointly shape firms' strategic trade-off between profit maximization and compliance. Policies that ignore this joint influence may inadvertently increase waste—for example, strict penalties in a market with converging consumer values could backfire by encouraging firms to cut prices and boost volume. Therefore, effective regulation may be calibrated to the prevailing consumer-perception landscape and the pricing strategies firms employ.

5 Numerical simulation

Given the complexity of the analytical model, explicit closed-form expressions for the optimal profits of the restaurant and the platform under both pricing strategies are not provided in the model construction section. Furthermore, the preceding analytical discussion does not fully capture the impact of anti-food waste regulations and consumer appetite heterogeneity on the profitability of supply chain members. To address this gap, this section employs numerical simulation to analyze how key factors influence the optimal decisions and strategic choices of the supply chain. The parameters selected for this analysis include the government's penalty intensity for food waste, the proportion of small appetite consumers, and the service commission rate of the food delivery platform.

Based on the existing literature and the practical operation of enterprises, we assumed: $\theta = 0.7$, $\eta = 0.2$, $\sigma = 0.9$, $\theta = 0.7$, $\rho = 0.2$. Accordingly, we set the following parameter values: the commission rate for the food delivery platform at 20%; the production cost of small appetite meals at 90% of regular appetite meals; the food waste rate for online orders at 20%; and the value discount for online delivery relative to dine-in (reflecting quality degradation) at 70%. To ensure the validity of $\min\left\{f_1, f_2, f_3, f_4\right\} > 0$, further assumptions are made: $V = 100$, $\mu = 1.5$, $c = 5$, $t = 12$, $\alpha = \{0.2, 0.5, 0.8\}$, $k \in (0, 25)$ and $\lambda \in (0.7, 1)$.

5.1 Impact on the profits of supply chain members

This subsection examines how variations in key parameters influence the profits of supply chain members under different pricing strategies. Specifically, we analyze the effects of the government's penalty cost per unit of waste and consumers' perceived meal value, considering different proportions of small appetite consumers and levels of hassle cost. The corresponding results are presented in Figures 1, 2.

Figure 1 shows that restaurants should adopt a differentiated pricing strategy in two main cases: first, when perceived-value heterogeneity is high, regardless of regulatory stringency; and second, when regulations are either very lenient or very strict, regardless of heterogeneity. By contrast, a uniform pricing strategy is preferred only under a narrower set of conditions—specifically, when heterogeneity is high and regulation is moderate. Furthermore, as the share of small appetite consumers rises, anti-food-waste regulations further reduce the scenarios in which uniform pricing is optimal. Conversely, greater perceived-value heterogeneity slightly widens the range of situations where uniform pricing can be applied.

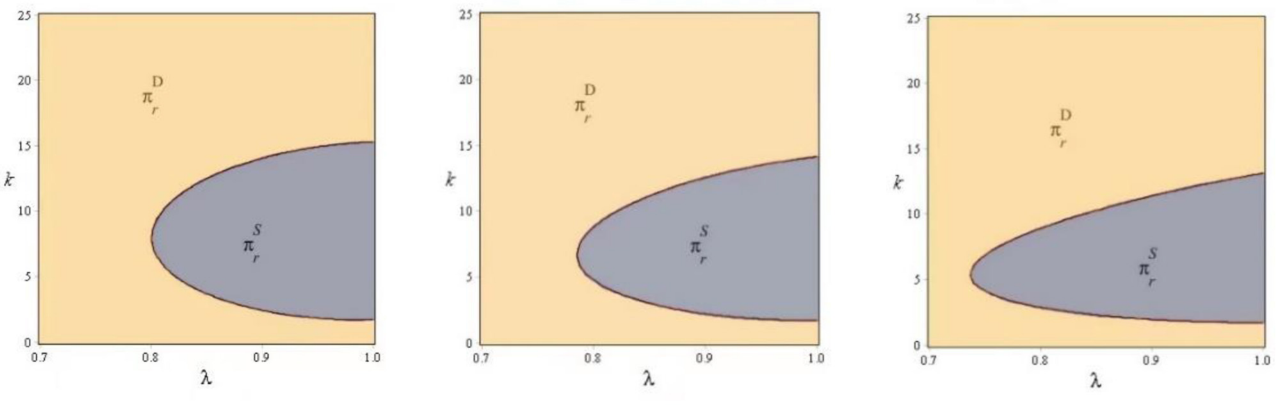
Figure 2 indicates that platform profits are driven mainly by regulatory stringency, with perceived-value heterogeneity playing a minor role. When regulations are not too strict, a differentiated pricing strategy is generally more profitable for the platform. Under stringent regulations, however, a uniform pricing strategy becomes advantageous because it allows for higher prices that reduce order volume—and thus penalty costs. Moreover, as the share of small appetite consumers rises, uniform pricing is increasingly favorable to the platform under relatively strict regulatory conditions. Figure 2 also reveals that regulatory stringency, not perceived-value heterogeneity, is the primary driver of platform profits. A differentiated pricing strategy yields higher profits when regulations are relatively lenient. Conversely, under stringent regulations, uniform pricing becomes more advantageous: by enabling higher prices, it suppresses order volume and reduces associated penalty costs. This preference for uniform pricing is further strengthened as the proportion of small appetite consumers increases.

The analysis of Figures 1, 2 indicates that differentiated pricing can align the interests of the restaurant and the platform, whereas uniform pricing tends to create divergent incentives. This alignment occurs primarily under two conditions: when regulations are moderately stringent, or when consumers exhibit high heterogeneity in perceived value. Figures 1, 2 underscore the context-dependence of optimal pricing: firms must dynamically select strategies based on regulatory and market conditions. They also reveal that regulatory impact is non-linear—moderate stringency creates nuanced trade-offs, whereas extreme regulations push strategies toward differentiation. Importantly, the common divergence in restaurant and platform preferences highlights a systemic channel conflict. Policies that disregard this tension risk worsening coordination failures. Therefore, effective governance should promote incentive alignment across the supply chain, not merely constrain individual behavior.

5.2 Impact on the food waste

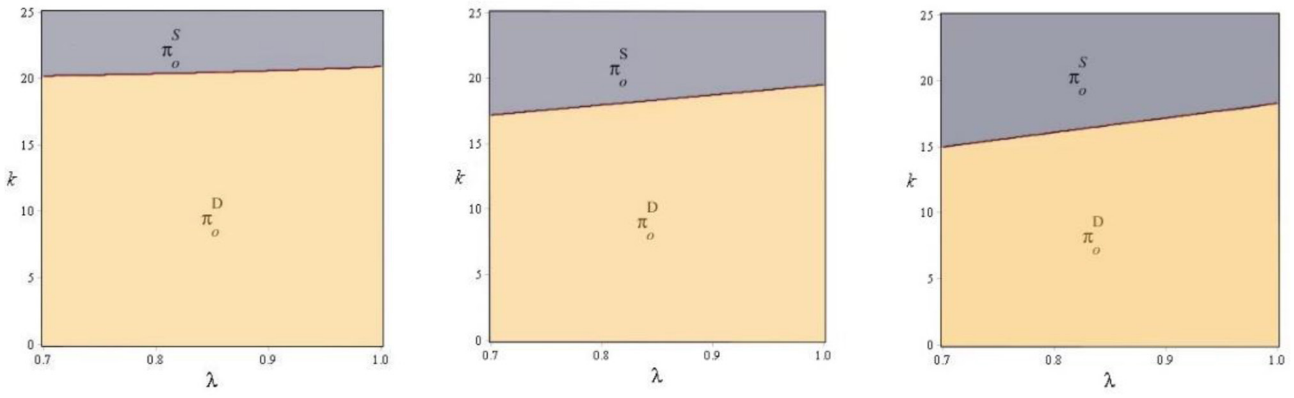
This subsection analyzes the impact of key parameters on food waste under different pricing strategies. We examine how the government's penalty cost per unit of waste and consumers' perceived meal value affect waste levels, considering variations in the proportion of small appetite consumers and the hassle cost of dining in. The results are summarized in Figure 3.

Figure 3 shows that, in the context of reducing food waste, the degree of perceived-value differentiation between consumer types has a limited direct influence on the choice of pricing strategy. A decrease in this differentiation slightly increases waste under uniform pricing, while slightly decreasing it under differentiated pricing. However, regulatory stringency exerts a strong moderating effect: under lenient regulations, uniform



(*a*) (*b*) (*c*)

FIGURE 1
The impact of k and λ on the profits of restaurant with different α. **(a)** $\alpha = 0.2$, **(b)** $\alpha = 0.5$, **(c)** $\alpha = 0.8$.



(*a*) (*b*) (*c*)

FIGURE 2
The impact of k and λ on the profits of delivery platform with different α. **(a)** $\alpha = 0.2$, **(b)** $\alpha = 0.5$, **(c)** $\alpha = 0.8$.

pricing generates higher waste; under stringent regulations, differentiated pricing tends to produce more waste than uniform pricing.

A cross-plot analysis incorporating the share of small appetite consumers further shows that, under stricter regulations, a larger proportion of such consumers can lead to higher waste when firms use differentiated pricing. This occurs because differentiation stimulates additional orders from small appetite consumers, raising total delivery volume—and consequently waste. Therefore, Figure 3 suggests an important alignment between policy and pricing strategy: stringent regulation is more effective for firms employing uniform pricing, as it directly restrains over-ordering. In contrast, a relatively lenient approach is better suited to firms using differentiated pricing, as it lowers penalty costs and supports supply-chain coordination toward the "small appetite" model. These observations also clarify why, under sufficiently strict regulation, a uniform pricing strategy becomes more favorable for the platform.

Figure 3 further indicates that regulatory effectiveness depends critically on the pricing structure firms employ. A uniform, "one-size-fits-all" approach is therefore unlikely to yield optimal outcomes. Instead, pairing stringent regulation with uniform pricing can help curb over-ordering in standardized meal services, while combining lenient regulation with differentiated pricing can harness market mechanisms—such as small appetite options and price signals—to steer consumers toward more rational ordering. These results point to the need for more refined, context-sensitive regulatory designs that provide differentiated guidance aligned with distinct business models.

Drawing together the findings from Figures 1–3, we observe a complex interdependence among pricing strategies, consumer perceived-value heterogeneity, regulatory stringency, and consumer-segment composition. A differentiated pricing strategy proves most beneficial when both regulatory penalties and perceived-value differentiation are low; under these conditions, it aligns offerings with varied demand, improving outcomes for both

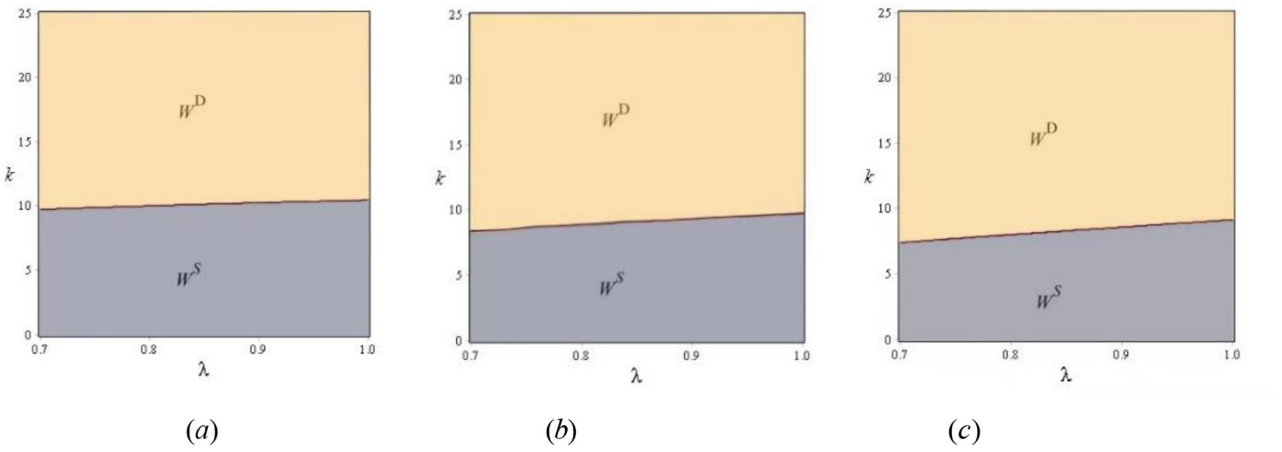


FIGURE 3
The impact of k and λ on the food waste with different α. **(a)** $\alpha = 0.2$, **(b)** $\alpha = 0.5$, **(c)** $\alpha = 0.8$.

restaurants and platforms. As regulatory penalties rise, however, a strategic misalignment emerges: while restaurants still gain from differentiation, platforms often find uniform pricing more profitable because it reduces order volume and penalty exposure. The influence of perceived-value heterogeneity grows with the share of small appetite consumers, leading restaurants to weigh it more heavily in their strategy. Notably, under moderately stringent regulation, a differentiated strategy can align the interests of both parties, yielding mutual gains. These insights underscore the need for a calibrated policy-business framework that simultaneously considers regulatory intensity, consumer-segment structure, and perceptual heterogeneity. Such an integrated approach is essential for promoting economically viable and waste reducing practices in O2O food delivery.

6 Conclusion

This paper focuses on the critical research question of how pricing strategies in O2O food delivery supply chains can be formulated to balance merchant profits, consumer demand, and food waste reduction under anti-food waste regulations. The core purpose of this study is to provide actionable insights for policymakers and businesses to harmonize regulatory compliance with economic viability in the context of the rapidly growing O2O food delivery industry.

Our research reveals several key findings. First, when penalty costs for food waste are low and consumer perception gaps are wide, differentiated pricing maximizes profits for both caterers and platforms. This demonstrates that market-driven pricing can encourage more sustainable consumer behavior and reduce waste. Second, as regulatory penalties rise, platforms often adopt uniform pricing to limit compliance risks. In contrast, caterers may continue using differentiated pricing to help offset these costs. This tension shows how regulatory pressure interacts with market incentives. Policymakers must therefore balance enforcement with market freedom. Finally, our results highlight the importance of two factors in pricing decisions: the proportion of small appetite consumers and their perception coefficients. This insight helps businesses tailor offerings to different consumer segments, which can reduce waste while meeting diverse needs.

The key contribution of this paper is its quantitative analysis of food waste in O2O food delivery. This addresses a gap in existing research. By modeling consumer appetite diversity and regulatory penalties, we offer new insights into how pricing strategies can be aligned with waste reduction goals. Our findings give policymakers actionable guidance for designing regulations. These regulations should encourage responsible consumption while protecting business interests. For businesses, this research highlights the potential benefits of differentiated pricing. Such strategies can enhance profits and reduce waste, particularly under moderate regulatory penalties. Additionally, our analysis stresses the importance of consumer diversity in shaping effective anti-waste policies. It emphasizes the need for targeted interventions that consider differences in consumer appetites and perceptions.

Beyond these theoretical contributions, our findings offer concrete, evidence-based guidance for regulators seeking to design effective and context-sensitive anti-waste policies. Rather than applying a one-size-fits-all penalty, regulators should tailor interventions based on the prevailing pricing strategy adopted by businesses:

(1) For businesses using uniform pricing, we recommend stricter penalty rates or progressive penalties tied to waste intensity. Our results show that uniform pricing, in the absence of portion differentiation, relies heavily on price increases to suppress demand and reduce waste. A stronger penalty signal is therefore necessary to compel meaningful waste reduction and encourage a shift toward more structurally efficient portion-size offerings.
(2) For businesses adopting differentiated pricing, we advise moderate or incentive-based regulation. Since differentiated pricing inherently reduces waste by aligning portions with appetites, overly stringent penalties may inadvertently push platforms toward uniform pricing—which, under lenient regulation, can increase waste. Instead, regulators should consider subsidies, or tax incentives for promoting small appetite options, or set compliance benchmarks based on

the proportion of small appetite sales. Such measures would reinforce the waste-reducing potential of differentiation without distorting strategic incentives.

While this study contributes to the field, it also has several limitations. First, the model assumes that consumers have full information about meal prices and portion sizes—an assumption that may not always hold in reality. Future research could explore how information asymmetry affects consumer choices and pricing strategies. Second, our analysis focuses on a simplified supply chain with one restaurant and one delivery platform. Future work could extend the model to multiple players and more complex interactions, offering deeper insights into food waste reduction dynamics in O2O delivery. Third, the numerical simulations rely on specific parameter assumptions, so findings may be context-dependent. Further empirical research is needed to validate the model and identify context-specific drivers of pricing and waste reduction. Finally, this study examines only the case where the platform faces the penalty. In practice, regulations may involve shared or shifted accountability (e.g., platform and caterer jointly liable, or only the caterer penalized). How different penalty structures affect supply chain decisions, pricing, and waste outcomes remains an important area for future research. Systematic comparison of equilibrium outcomes under alternative accountability mechanisms would help build a more robust theoretical foundation for designing effective, coordinated anti-waste regulations. Finally, this study assumes that consumer appetite types (small vs. regular) are fully observable to the restaurant and platform when implementing differentiated pricing. In practice, appetite is often private information, leading to information asymmetry. Future research could examine a setting where firms only know the distribution of consumer types but cannot identify individual appetites.

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

QW: Funding acquisition, Writing – original draft. XW: Conceptualization, Formal analysis, Methodology, Writing – review & editing. GX: Supervision, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work 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 author(s) declared that generative AI was not used in the creation of this manuscript.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2026.1726916/full#supplementary-material

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