

Article

Parcel Lockers in Last-Mile Delivery: A Game-Theoretic Analysis for Urban Logistics from the Platform-Economy Perspective

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Abstract

With the promotion of public service infrastructure and the construction of intelligent communities, parcel lockers have become an effective alternative for last-mile delivery. But express companies still face strategic questions about whether to cooperate with third-party locker platforms, use advertising-supported platforms, or build their own platforms. This study examines how express companies and parcel locker operators should design pricing, advertising, and ownership strategies from a platform-economy perspective. Employing Stackelberg game models, four operational modes are analyzed: home delivery only, cooperation with a third-party platform, cooperation with an advertising-supported platform, and operating a self-built platform. We explore parcel locker strategies by considering customer-to-advertiser network externality and their impact on the pricing, advertising, and ownership decisions of parcel locker platforms. Comparative analyses show that introducing platform delivery increases express companies' profitability and expands total delivery demand, while advertising can further reduce platform delivery fees and increase the profits of both the express company and the parcel locker platform. However, the self-built decision depends mainly on self-building and operating cost, customers' perceived convenience, waiting cost, service substitutability, customer-to-advertiser network externality, service area, and locker capacity sufficiency. This study explains the economic and operational mechanisms through which parcel locker platforms may support more efficient and potentially more sustainable last-mile urban logistics.

Keywords: urban logistics; delivery service; pricing strategy; advertising; platform economy

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1. Introduction

The rapid development of digital technologies has created rich applications for e-commerce. These innovations have continuously increased customers' demands for logistics services. As an energy-intensive industry, logistics contributes about 9% to China's overall carbon emissions, with transportation and distribution accounting for approximately 85% of the sector's emissions [1,2]. Meanwhile, the German courier, express, and parcel (CEP) sector has increased its parcel volumes by 35% since 2016 while reducing

carbon emissions per shipment by 22%, representing an average annual carbon emission reduction of 3% [3]. This suggests that economic growth and carbon emission reduction may be jointly pursued in the logistics sector, highlighting the potential of alternative delivery modes such as parcel lockers to contribute to more efficient and potentially low-carbon last-mile urban logistics. According to the State Post Bureau of China, the business volume and business income of express delivery completed 145.08 billion and 1.1 trillion yuan, respectively, in the first three quarters of 2025, an increase of 17.2% and 8.9% year-on-year [4]. This rapid growth underscores the urgent need for more sustainable operational alternatives to last-mile delivery solutions. With the promotion of public service infrastructure and the construction of intelligent communities, parcel lockers have become an effective operational alternative with potential environmental benefits in the last-mile delivery market, as they may help reduce failed deliveries, repeated trips, and community-level congestion [5,6].

Currently, parcel lockers have been applied in more than 20 countries in Asia, North America, and Europe. As shown in Figure 1 and Table 1, some parcel lockers are operated by express companies or e-commerce companies, such as UPS and Amazon in the United States and DHL in Germany [7]. Some are operated by real estate companies or third-party enterprises, such as PUDO station in Japan, InPost in Poland, and Hive Box in China. Different parcel locker operators serve different types of customers and have different charging targets.

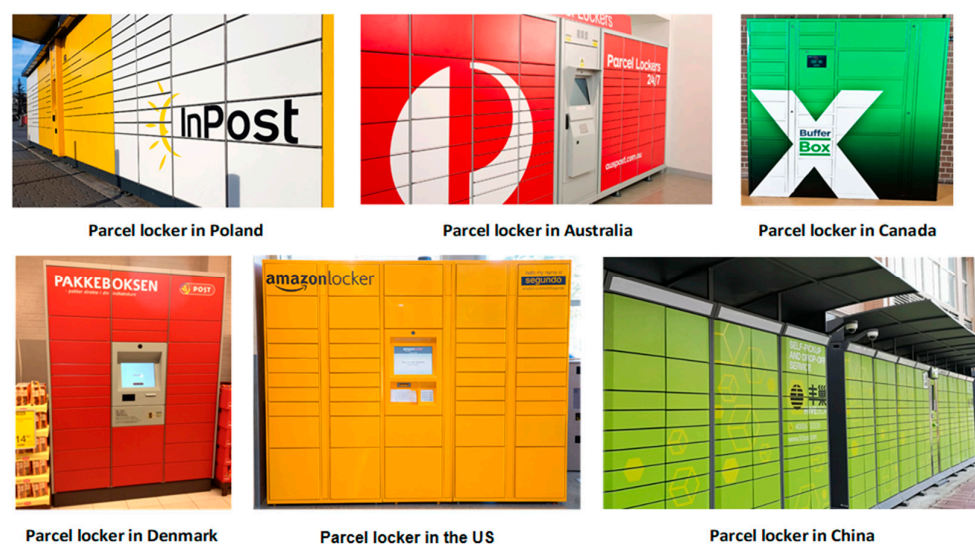


Figure 1. Parcel lockers in some countries.

The market for the parcel locker industry is expanding year by year. For example, by the end of 2025, Amazon had installed over 10,000 locker locations across the United States, and over 95% of the US population lives within 10 miles of an Amazon hub locker [8]. In 2023, 44% of European e-shoppers selected out-of-home delivery options, including lockers. Denmark's SWIPBOX had installed 40,000 lockers by September 2023. By the end of 2024, around 1000 solar lockers had been installed in France [9]. According to its annual report, the InPost group delivered over one billion parcels and operated 46,977 parcel lockers by the end of 2024, of which more than 25,000 were located in Poland, and the coverage of parcel lockers in Poland was reported to have reached 78% by the end of 2025 [10].

Parcel lockers are usually installed in densely populated areas such as convenience stores, pharmacies, railway stations, office buildings, and residential areas. In the past few years, the Chinese government has put forward a number of proposals on building low-

carbon, smart and sustainable communities; hence, parcel lockers are becoming one of the most important infrastructures for sustainable operational last-mile delivery development. Using parcel lockers can reduce the number of failed deliveries and the congestion of delivery vehicles in communities; hence, the carbon emissions associated with repeated vehicle trips and individual deliveries may be reduced, contributing to more potential sustainable last-mile logistics [11–13]. Moreover, compared with other delivery methods such as drones and autonomous electric vehicles [14,15], parcel lockers have low installation cost, low uncertainty, and low technical requirements, while also offering potential carbon-saving opportunities through consolidated deliveries and reduced failed trips. They can provide 24/7 flexible services to end customers [16,17]. As observed in reality, parcel lockers can be integrated with retail businesses around communities. Through screens of parcel locker cabinets or online apps, precision marketing strategies can be implemented for residents, and the accumulated traffic of customers using parcel lockers can be converted into commercial value.

Table 1. The development of the parcel locker industry in some countries [18].

Country	Representative Enterprise	Operating Enterprise	Service Target	Charging Target
United States	UPS	Express company (UPS), e-commerce companies (Amazon), real estate agents, and property companies	Proprietary users	Users
United States	Amazon		Proprietary users and users from contracted express companies	Real estate agents and property companies
Germany	Packstation	Express company (DHL)	Users from contracted express companies	E-commerce and express companies, and some users
Japan	PUDO station	Government and property companies	Proprietary users	Charging users in the form of property fee
Denmark	SWIPBOX	Independent parcel locker operator (SWIPBOX)	Users from contracted express companies	Express companies and some users
Poland	InPost	Independent parcel locker operator (InPost)	Users from contracted express companies	Some users are free, some are charged
Netherlands	Post Netherlands	Express company (Post Netherlands)	Proprietary users and users from contracted express companies	Express companies and some users
China	Hive box (Fengchao)	Independent parcel locker operator (Hive box)	Users from contracted express companies	Users, express companies, and advertisers

Although the parcel locker industry is developing at a high speed and demonstrating significant value in the last-mile delivery market, there are still practical problems to be resolved. According to existing parcel locker business models, the main revenue in this industry comes from charging customers and express companies, advertising, and other value-added services; however, most parcel locker operators have been struggling to make a profit, which hinders the long-term financially sustainable operation of the industry and limits the realization of its potential benefits [19]. Even some companies whose business models are not yet clear began to install a large number of parcel lockers. Take China's Hive Box as an example: after a rapid expansion in the parcel locker market, the company suffered a serious loss of 2.511 billion RMB in the first three quarters in 2020. Especially when the company started charging customers for overtime and membership fees, its market share dropped from 69% to 16%. The gross profit margin of Hive Box remained low for years, standing at about 10.6% in 2023 (recovering from a negative gross margin in 2021), after paying for the operation costs such as venue rental, depreciation,

maintenance, electricity, and networking [20]. This situation highlights the critical role of platform governance and platform-based revenue design [21]. In addition, large regional differences exist in the promotion and popularity of parcel lockers. For example, in Poland and Estonia, there are nearly nine sets of parcel lockers per 10,000 people, whereas in the UK there are only 0.6 sets of parcel lockers per 10,000 people [22]. To sum up, there is an increasing need for mature and systematic pricing and operational strategies for parcel locker operators in practice.

The widespread use of parcel lockers in reality has attracted academic attention, such as studies on customers' intention to use parcel lockers [23–25], the design of locker banks [26], site selection [27,28], and mode selection in the last-mile delivery [29]. Nonetheless, several issues still remain to be explored theoretically. Firstly, parcel locker operators are inherently incapable of executing delivery services independently. Serving as a crucial component of the last-mile logistics infrastructure, their efficacy is contingent upon collaboration with express companies that possess extensive transportation networks and direct delivery capabilities. Given the pivotal role of express companies within the express industry, they have the dominant status to decide whether and how to utilize parcel lockers. However, existing studies seldom delve into the problem of how express companies develop operationally sustainable delivery strategies in the face of parcel-locker-based last-mile delivery. Secondly, parcel lockers not only serve as a medium platform connecting express companies and customers for delivery services but also function as a novel advertising platform within the last-mile delivery market. Considering the traffic value of customers through the lens of platform economics [30], there exists a notable research gap regarding how express companies and parcel locker operators devise service pricing strategies that capitalize on the distinctive attributes of this emerging ecosystem. Unlike a standard pricing model that simply adds advertising revenue, the platform-economy perspective in this study emphasizes the customer-to-advertiser network externality generated by parcel locker users and examines how this traffic value affects pricing, advertising, and ownership decisions.

In this study, two commonly used delivery services are considered, i.e., home delivery and parcel-locker-platform-based delivery (hereafter “platform delivery”). Accordingly, four delivery service modes are proposed as in Table 2.

Table 2. Delivery service modes in the last-mile delivery market.

	First- And Last-Mile Logistics	Ownership of Parcel Lockers	Advertising Strategy of the Platform
Mode a	Home delivery service	-	-
Mode b	Home and platform delivery services	Third-party parcel locker platform	Not operating
Mode c	Home and platform delivery services	Third-party parcel locker platform	Operating
Mode d	Home and platform delivery services	Express company	Operating

To fill the research gaps and resolve the practical issues summarized above, three research questions are proposed: First, with the existence of platform delivery, what is the optimal delivery service mode for the express company? Second, what are the optimal service pricing strategies for the parcel locker operator and the express company in different delivery service modes? Third, how do some important factors affect the above decisions of the stakeholders? The factors include customers' perceived convenience of using parcel lockers, express companies' service area, and customer-to-advertiser network externality.

To answer these questions, Stackelberg game models are built and solved to maximize the profit (or utility) of stakeholders. The following comparative analyses are conducted. Comparing Modes a and b is to examine how the emerging platform delivery service affects the operation strategies of the express company. Comparing Modes b and c is to examine the benefits of introducing advertisers into the parcel locker platform. Comparing Modes c and d is to provide the conditions for the express company to build its own parcel locker platforms. These comparisons also distinguish between market expansion caused by the introduction of platform delivery, customer substitution between home and platform delivery, and ownership choices between cooperation and self-building.

This paper contributes to the literature in three aspects. First, this paper investigates the pricing and operation strategies of parcel locker platforms from the perspective of the platform economy by incorporating customer-to-advertiser network externality into a game-theoretic analysis of parcel-locker-based last-mile delivery modes. The impact of this network externality on stakeholders' optimal decisions is investigated in the last-mile delivery market. Second, by theoretical analyses, it is found that the emerging platform delivery can increase the express company's total profit. But whether the express company should build and operate the parcel locker platform itself is up to the customers' perceived convenience of using parcel lockers and the construction and operation costs of the platform. Third, managerial implications are given to stakeholders in the last-mile delivery market. For example, if home and platform delivery co-exist, express companies can raise the home delivery fees and provide value-added home delivery services. Moreover, it is profitable for parcel locker operators to improve customers' perceived convenience of using parcel lockers and customer-to-advertiser network externality. Therefore, the contribution of this study mainly lies in explaining the economic and operational mechanisms through which parcel locker platforms may support the sustainable operation of last-mile delivery systems.

To provide readers with a clear and integrated understanding of the research framework and main contributions, Figure 2 presents an overview of the four strategic modes considered in this study.

The figure summarizes the key stakeholders, service structures, ownership of parcel lockers, advertising strategies, and decision variables in each mode. In addition, it highlights the comparative effects of platform delivery, advertising operations, and platform ownership on pricing decisions, market demand, profitability, and managerial insights as well as sustainability implications. This overview facilitates a holistic view of the subsequent analytical models and emphasizes the practical and potential environmental significance of adopting parcel lockers in last-mile delivery systems.

The remainder of this paper is organized as follows. Section 2 reviews related works. Section 3 outlines the research problem and explains notations and assumptions. Section 4 reports the Stackelberg models, and Section 5 presents the comparative analysis results. Section 6 extends the baseline model by considering capacity constraints. Section 7 concludes our key findings and further research directions.

	Mode a: Home delivery only	Mode b: Third-party platform cooperation	Mode c: Third-party platform + advertising	Mode d: Self-built platform
Stakeholders	express company, consumers	express company, third-party platform, customers	express company, third-party platform, customers, advertisers	express company, customers, advertisers
Service	home delivery only	home + platform delivery	home + platform delivery	home + platform delivery
Ownership	none	third-party platform	third-party platform	express company
Advertising	no	no	yes	yes
Decisions	express company sets home fees	express company sets home fees, platform sets platform fees	express company sets home fees, platform sets platform fees and ad fees	express company sets all fees
Comparisons	Platform delivery effect (Mode a vs Mode b) demand ↑ express company total profit ↑ Advertising effect (Mode b vs Mode c) service fees ↓ platform demand ↑ platform profit ↑ express company total profit ↑ Ownership effect (Mode c vs. Mode d) choose self-build based on key indicators			
Managerial Implications	- hybrid delivery expands the market - advertising can subsidize platform delivery - parcel lockers support sustainable operation of last-mile delivery			

Figure 2. Overview of the four strategic modes and key comparative insights. Note: “↑” indicates “increase”, “↓” indicates “decrease”.

2. Literature Review

Parcel lockers, also known as shared reception boxes or express cabinets, are a group of lockers sited in urban areas such as apartment blocks, workplaces, and railway stations. They have electronic locks with variable opening codes and provide temporary storage for parcels [31]. Parcel lockers are commonly used for self-service collection and the return of online purchases [32]. In addition, using parcel lockers can reduce the number of unsuccessful home deliveries [33], which significantly improves the effectiveness and efficiency of end deliveries [34] and potentially reduces carbon emissions in the last-mile delivery market, thereby enhancing the environmental sustainability of urban logistics [6]. Many researchers have studied the factors that affect customers’ willingness to use parcel lockers, such as age, convenience, reliability, privacy and security [17,29,35], and perceived behavioral control [22,34]. But technology anxiety and location inconvenience become major barriers for customers to use them [19–21,36]. These studies provide an important behavioral foundation for understanding parcel locker adoption. However, most of them focus on whether customers are willing to use parcel lockers, while paying less attention to how customers’ perceived convenience affects service pricing, demand allocation, and platform profitability in a strategic interaction setting.

Many scholars also pay attention to the comparison of platform delivery and home delivery. The advantages of using parcel lockers as an alternative to home delivery are investigated, which justifies that a parcel locker is a robust and has considerable potential for the reductions in carbon emission and damage costs [37]. Compared with home delivery, platform delivery service can reduce risks of theft or delays at the expense of extra travel to parcel locker points [33,38]. These studies have proved well that adopting parcel lockers and platform delivery can compensate for the shortcomings of home delivery. However, the existing literature does not provide sufficient conclusions about how the emerging platform delivery affects the pricing and operation strategies of home delivery. In particular, when home delivery and platform delivery coexist, the two services may simultaneously generate customer substitution and market expansion effects. Existing studies have not sufficiently clarified how these effects reshape the pricing decisions of express companies and parcel locker operators.

Regarding the operational aspects of parcel-locker-based delivery, a bi-level optimization model for the optimal location selection and operational capacity planning of parcel lockers is proposed, which simultaneously considered both the planner's strategic decisions and customer preferences [26]. The last-mile efficiency is studied based on an open-access locker network in Singapore, and it is found that the optimal nested network design aligned with the largest logistics service providers' operations is critical [39]. A solution to determine how much locker capacity to reserve for different ship-option packages is studied [40]. Machine learning techniques are used to predict locker demand and package dwell time with linear programming to maximize throughput in lockers. A quantitative approach to determine the optimal locker location is proposed to maximize the overall delivery service provided by the alliance of express companies [27]. The above research has offered valuable findings and suggestions for sustainable operations of parcel locker platforms. However, most studies emphasize location, capacity, assignment, and network efficiency, while the platform-based revenue mechanism of parcel locker operators remains insufficiently examined.

Another stream of related research concerns platform economics [41], two-sided markets [42,43], and advertising-supported platforms [44]. A platform's profitability depends not only on its overall price level but also on the price structure across sides: owing to cross-group network externalities, it is often optimal to charge one side a low or even below-cost price to attract participation and to recover profit from the other side, which is often referred to as side-subsidization, and this remains central in recent platform-pricing research [45–47]. However, these models are not developed for last-mile delivery and do not capture the customer-to-advertiser externality or the parcel locker ownership choices that are central to parcel locker platforms. In platform-based business models, the value created on one side of the market may depend on the participation of another side, and advertising revenue can be used to support user-side services [48,49]. This logic is highly relevant to parcel locker platforms because customers who use lockers not only generate delivery service demand but also create traffic value for advertisers through locker screens and online applications. Nevertheless, existing studies on parcel lockers have not sufficiently incorporated customer-to-advertiser network externality into the analysis of delivery pricing and ownership decisions. Therefore, this paper fills this gap by treating parcel locker operators as platforms that connect express companies, customers, and advertisers, examining how stakeholders transact, and analyzing the main decision-making factors that affect these transactions to realize the sustainable operation of the parcel locker platform ecosystem.

3. Problem Description

Parcel lockers have become an important infrastructure to supplement home delivery and support the operationally sustainable operation of the last-mile delivery market. In this study, it is assumed that only home and platform deliveries are considered. This assumption allows us to focus on the strategic interaction between traditional home delivery and platform delivery. In practice, customers may also choose convenience-store pickup, community collection stations, or other out-of-home delivery channels. These are not explicitly modeled in this study; this paper focuses on parcel lockers because they have clear platform features, automated service processes, and advertising-based revenue potential. Excluding these alternatives may affect the absolute demand allocation between delivery modes but it does not change the central mechanism examined in this paper, namely how platform delivery, advertising operation, and platform ownership affect pricing and profitability.

The sending service means that if a customer wants to send a parcel, the express company will directly or indirectly pick it up and complete the long-distance transporta-

tion. The receiving service means that if a customer wants to receive a parcel from someone else, the express company will first deliver the parcel to terminal logistics transfer centers and then deliver it to the customer's residential address or store it in a parcel locker. For modeling consistency, this study assumes that local customers pay the corresponding express fees in both sending and receiving processes. This assumption is used to derive comparable demand functions for the sending and receiving markets. In practice, the fee may be paid by the remote sender or receiver at the other end of the delivery process, but the cost can still be reflected in the overall logistics service fee or transferred through transaction arrangements. Therefore, the assumption does not change the basic pricing logic of the model.

When customers send or receive parcels, the earliest mode is home delivery, which is denoted as Mode a. As shown in Figure 3, customers pay the fees of home-sending and -receiving and long-distance transportation services to the express company.

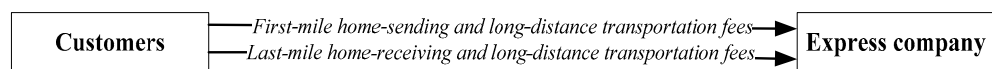


Figure 3. Home delivery service in Mode a.

With the emergence and popularization of platform delivery service, customers have new choices for their sending and receiving needs. Except for home delivery service, some customers can send parcels through the parcel locker platform, and some may ask the express company to store their parcels temporarily in the parcel lockers and pick them up later. This type of hybrid delivery service is denoted as Mode b. As shown in Figure 4, if the customer chooses platform delivery service in the parcel-sending process, they will put the parcel in a locker and pay for the express fee through the app or on the screen of the platform. If the customer chooses home delivery service, they will wait for the express company to pick up the parcel from their home address and pay for the express fee to the express company. In the former case, a part of the express fee will be kept by the parcel locker operator as the first-mile platform-sending fee, and the remaining part will be transferred to the express company as the long-distance transportation fee. It is similar for customers to receive parcels.

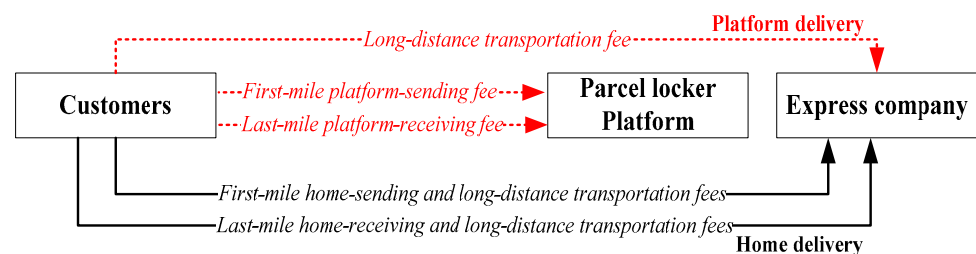


Figure 4. Home and platform delivery services in Mode b.

For Mode b, a Stackelberg game model is set up, and the decision sequence is as follows. First, the express company decides the fees of first-mile home-sending and last-mile home-receiving services. Then, the platform decides the fees of first-mile platform-sending and last-mile platform-receiving services. This decision sequence reflects the situation in which the express company controls the transportation network, parcel flow, and basic delivery service, while the parcel locker platform provides supplementary end-logistics infrastructure. Therefore, the express company is modeled as the Stackelberg leader and the parcel locker platform as the follower. In some markets, large e-commerce platforms or parcel locker operators may have stronger bargaining power. Such alternative game

structures, including platform-led Stackelberg games, simultaneous-move games, or bargaining models, are not the focus of this paper.

From an economic point of view, when the parcel locker platform operates advertising, the customers accumulated by the platform will bring considerable traffic value to advertisers. For example, advertisers can target customers with precision marketing and increase ad conversion rates. To examine the impact of customer traffic on the service pricing strategies of the platform and the express company, this type of hybrid delivery service is denoted as Mode c. As in Figure 5, the sending and receiving processes are similar to those of Mode b. A Stackelberg game model is set up for Mode c, and the decision sequence is as shown below. First, the express company decides the fees of first-mile home-sending and last-mile home-receiving services. Then, the platform decides the advertising fee and the fees of first-mile platform-sending and last-mile platform-receiving services. In this mode, the parcel locker platform is not only a delivery service provider but also an advertising-supported platform. The accumulated customer traffic generates customer-to-advertiser network externality, which means that more platform users increase the potential value of advertisements placed through locker screens or online applications. Following the common modeling treatment in the literature on ad-funded and two-sided platforms, this study focuses on the positive traffic value generated by platform users for advertisers and does not explicitly model the possible negative effect of advertising on customers' utility. This simplification allows us to highlight how advertising revenue affects platform delivery fees, advertising fees, and the profitability of stakeholders [48–51].

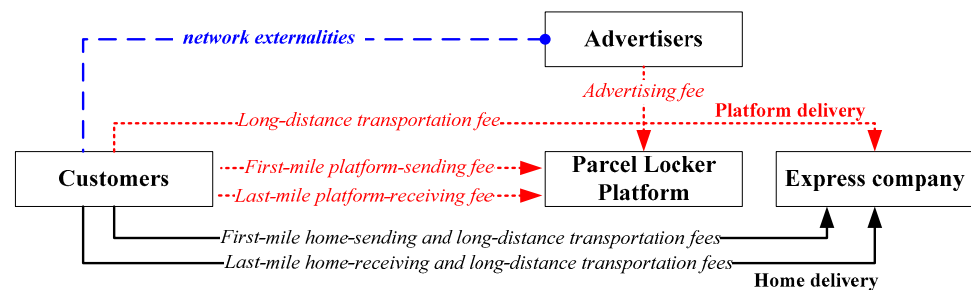


Figure 5. Home and platform delivery services in Mode c.

To reflect the reality that some parcel locker platforms are operated by express companies, Mode d is proposed. As in Figure 6, the delivery processes and advertising operations are similar to those of Mode c. The difference is that the costs and profits of the platform belong to the express company. The express company decides the fees of first-mile home-sending, last-mile home-receiving, first-mile platform-sending, and last-mile platform-receiving services and the advertising fee. Mode d captures the ownership decision of the express company. Compared with cooperation with a third-party platform, a self-built platform enables the express company to internalize platform delivery revenue, advertising revenue, and platform operating costs. Therefore, the comparison between Mode c and Mode d can reveal when cooperation with a third-party platform is preferable and when self-building becomes more profitable.

These models describe both customer substitution and market expansion effects. When home delivery and platform delivery coexist, some customers may switch from home delivery to platform delivery because of low waiting costs or higher perceived convenience. At the same time, the availability of platform delivery may also expand the total last-mile delivery demand by improving service accessibility and flexibility.

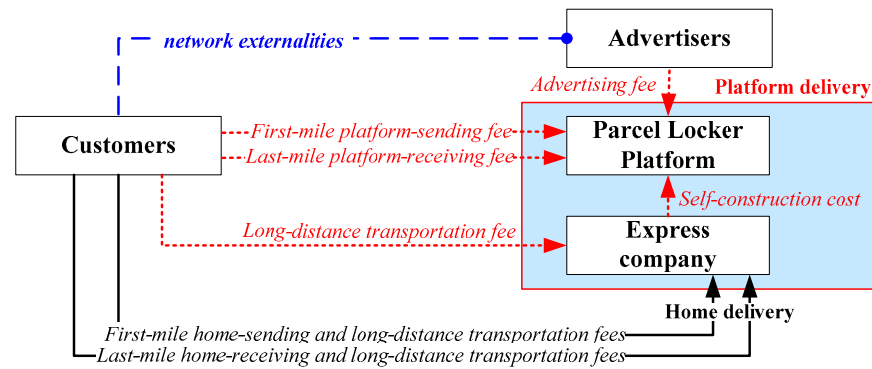


Figure 6. Home and platform delivery services in Mode d.

To facilitate problem description and model construction, the index, decision variables, and general parameters are shown in Table 3.

Table 3. Indexes.

Index	Explanation
i	Subscript $i = a, b, c$, and d indicates the modes, respectively.
p_i^{hs}	First-mile home-sending fee charged by the express company under Mode i ($i = a, b, c, d$) (Decision variable).
p_i^{hr}	Last-mile home-receiving fee charged by the express company under Mode i ($i = a, b, c, d$) (Decision variable).
p_i^{ps}	First-mile platform-sending fee charged by the platform under Mode i ($i = b, c, d$) (Decision variable).
p_i^{pr}	Last-mile platform-receiving fee charged by the platform under Mode i ($i = b, c, d$) (Decision variable).
p_i^{ad}	Advertising fee charged by the platform to the advertisers under Mode i ($i = b, c, d$) (Decision variable).
c	Customers' perceived convenience of using parcel lockers, $c > 0$.
v	Customers' willingness to send or receive parcels, $v \in U[0, \bar{v}]$.
w	Customers' waiting cost in home-receiving process, $w \geq 0$.
θ	Improved waiting efficiency of platform delivery service compared with home delivery service, $0 < \theta < 1$.
a	Cross-sensitivity of customers towards the not-selected service, $0 < a < 1$.
k	Approximate factor of path length in home delivery services.
n	Population base of customers requiring home delivery services in a certain area.
A	Service area of the express company.
C_0	Marginal cost of the home delivery service per unit distance.
C_e	Marginal cost of the long-distance transportation.
p_l	Long-distance transportation fee of the express company charged to customers.
C_s	Self-built and operating costs of the parcel locker platform.
C	Total operating cost of the parcel locker platform.
C_a	Production cost for an advertiser to place an ad on the platform.
γ	Customer-to-advertiser network externality (traffic value).

In the following models, all cost parameters are assumed to be non-negative, and the basic market size and customers' willingness to send or receive parcels are assumed to be positive. The cross-sensitivity parameter satisfies ($0 < a < 1$), indicating that the price sensitivity of the unchosen service type is weaker than the price sensitivity of the chosen service type. Customers' perceived convenience of using parcel lockers (c) can be interpreted through practical indicators such as distance to lockers, ease of use, interface friendliness, and service accessibility. The improved waiting efficiency of platform delivery (θ) reflects the reduction in waiting cost compared with home delivery. To ensure the existence and economic feasibility of the equilibrium solutions, including non-negative service fees, non-

negative advertising fees, feasible customer and advertiser demands, and economically meaningful market allocations, the following conditions should be satisfied. Under the basic assumptions above, the second-order conditions for Modes a and b are satisfied, and no additional concavity condition is required. For Mode c, the optimal solution exists when $\bar{v} > \frac{\gamma^2(3-a^2)}{4-a^2}$, while for Mode d, the optimal solution exists when $\bar{v} > \frac{1}{2}\gamma^2$. In addition, the non-negativity conditions for Modes a, b, c, and d are denoted by $\mathcal{F}_a$, $\mathcal{F}_b$, $\mathcal{F}_c$, and $\mathcal{F}_d$, respectively, which are derived and reported in Appendix A. The equilibrium solutions and comparative analyses in the following sections are derived under these conditions.

In this study, from the perspective of cost composition, customers' express fee is divided into first-mile sending or last-mile receiving fee and the long-distance fee. The objective of such cost composition is to propose solid suggestions on service pricing for express companies and parcel locker operators through modeling and theoretical analysis, although in practice the express fee is a one-time payment.

4. Models

4.1. Modeling and Solutions of Mode a

In Mode a, in the process of home-receiving, the express company delivers parcels to customers' home addresses according to their delivery routes. Since the express company has to deliver parcels one by one, they cannot reserve an exact time for each customer. The customer needs to match the express company's delivery schedule and wait at home; sometimes, the customer cannot match the express company's time, which will cause secondary deliveries and extend the customer's receipt time. The customer's waiting time is denoted by a waiting cost (w), which captures customers' time loss and inconvenience caused by uncertain home-receiving schedules. Thus, the utility of customers choosing home-receiving service is Equation (1).

$$U_a^{hr} = v - (p^l + p_a^{hr}) - w \quad (1)$$

When a customer needs to send a parcel, he/she will designate an exact time frame for the express company to pick it up. As this time is given by the customer, the waiting cost in the home-sending process is neglected. Thus, the utility of customers choosing home-sending service is Equation (2).

$$U_a^{hs} = v - (p^l + p_a^{hs}) \quad (2)$$

Since $U_a^{hr} \geq 0$, the number of customers choosing home-receiving service is $n_a^{hr} = \frac{\bar{v} - (p^l + p_a^{hr}) - w}{\bar{v}}$. Since $U_a^{hs} \geq 0$, the number of customers choosing home-sending service is $n_a^{hs} = \frac{\bar{v} - (p^l + p_a^{hs})}{\bar{v}}$. The profit of the express company under Mode a is Equation (3).

$$\Pi_a^{courier} = \left[(p_a^{hr} - c_0 k \sqrt{nA}) + (p^l - c_e) \right] n_a^{hr} + \left[(p_a^{hs} - c_0 k \sqrt{nA}) + (p^l - c_e) \right] n_a^{hs} \quad (3)$$

On the right side of Equation (3), the first item is the profit of the home-receiving service, including profits from last-mile delivery and long-distance transportation, while the second item is the profit of home-sending service, including profits from first-mile delivery and long-distance transportation. The expression $k\sqrt{nA}$ denotes the distance that the express company has to travel in home delivery service within a certain home service area A [41]. Thus, $c_0 k \sqrt{nA}$ is the cost of home delivery service of the express company. A larger service area usually implies a longer delivery distance and higher home

delivery cost. Following the principle of profit maximization, Equation (3) is solved and Lemma 1 is given.

$$\textbf{Lemma 1: } p_a^{hr*} = \frac{\bar{v} - 2p^l + c_e + c_0 k \sqrt{nA} - w}{2}, \quad p_a^{hs*} = \frac{\bar{v} - 2p^l + c_e + c_0 k \sqrt{nA}}{2}.$$

4.2. Modeling and Solutions of Mode b

In Mode b, the express company cooperates with a third-party parcel locker platform to provide last-mile delivery services to customers. Customers choose between home and platform delivery in both sending and receiving processes. In the viewpoint of social comparison, the utility of a customer will be affected by the fee of the service type that they do not choose. Parameter a denotes customers' cross-price sensitivity of the unchosen service type. It reflects customers' perceived degree of substitutability between home delivery and platform delivery. It is assumed that the price sensitivity of the unchosen service type is weaker than the price sensitivity of the chosen one [42], namely, $0 < a < 1$. Hence, Mode b captures both the substitution between home delivery and platform delivery and the expansion of delivery service demand caused by the availability of an additional service option. In addition, parameter c denotes customers' perceived convenience of using parcel lockers. When $0 < c < 1$, customers are more likely to choose home delivery. When $c > 1$, customers are more likely to choose platform delivery. It is noted that using a parcel locker platform to pick up parcels can save time waiting at home or shorten the time to receive parcels, but it brings a hassle cost to customers, such as walking to parcel lockers and taking parcels home. The parameter θw is used to denote the hassle cost for customers who choose platform-receiving service. Thus, the utilities of customers choosing platform-receiving and home-receiving services are given in Equation (4) and Equation (5), respectively.

$$U_b^{pr} = cv - (p^l + p_b^{pr}) - \theta w + a(p^l + p_b^{hr}) \quad (4)$$

$$U_b^{hr} = v - (p^l + p_b^{hr}) - w + a(p^l + p_b^{pr}) \quad (5)$$

Since $U_b^{pr} > 0$, the number of customers choosing platform-receiving service is $n_b^{pr} = \frac{c\bar{v} - (p^l + p_b^{pr}) - \theta w + a(p^l + p_b^{hr})}{\bar{v}}$, while since $U_b^{hr} > 0$, the number of customers choosing home-receiving service is $n_b^{hr} = \frac{\bar{v} - (p^l + p_b^{hr}) - w + a(p^l + p_b^{pr})}{\bar{v}}$. These demand expressions indicate that customers are segmented between home-receiving and platform-receiving services according to their utility levels.

Customers can choose the time and route to deliver their parcels; similar to Mode a, it is assumed that there is no hassle cost or waiting cost in the platform-sending process. Thus, the utilities of customers choosing platform-sending and home-sending services are given in Equation (6) and Equation (7), respectively.

$$U_b^{ps} = cv - (p^l + p_b^{ps}) + a(p^l + p_b^{hs}) \quad (6)$$

$$U_b^{hs} = v - (p^l + p_b^{hs}) + a(p^l + p_b^{ps}) \quad (7)$$

Since $U_b^{ps} > 0$, the number of customers choosing platform-sending service is $n_b^{ps} = \frac{c\bar{v} - (p^l + p_b^{ps}) + a(p^l + p_b^{hs})}{\bar{v}}$, while since $U_b^{hs} > 0$, the number of customers choosing home-sending service is $n_b^{hs} = \frac{\bar{v} - (p^l + p_b^{hs}) + a(p^l + p_b^{ps})}{\bar{v}}$. Similar to the receiving

process, the sending demand is allocated between platform-sending and home-sending services according to customers' utility comparison.

Whether customers choose home or platform delivery, the long-distance transportation service is borne by the express company, and the profit belongs to the express company. Thus, the profit of the express company in Mode b is Equation (8).

$$\Pi_b^{courier}(p_b^{hs}, p_b^{hr}) = (p^l - c_e) \cdot n_b^{ps} + (p^l - c_e) \cdot n_b^{pr} + \left[(p^l - c_e) + (p_b^{hs} - c_0 k \sqrt{nA}) \right] \cdot n_b^{hs} + \left[(p^l - c_e) + (p_b^{hr} - c_0 k \sqrt{nA}) \right] \cdot n_b^{hr} \quad (8)$$

On the right side of Equation (8), the first and second items are profits from long-distance transportation when customers choose platform delivery to send and receive parcels. The third and fourth items are profits from home-sending and home-receiving services. Thus, the express company may benefit from platform delivery through long-distance transportation demand, even when some end-logistics demand is served by the third-party parcel locker platform.

The profit of the parcel locker platform is Equation (9), which includes profits from platform-sending and platform-receiving fees, as well as the fixed operating cost.

$$\Pi_b^p(p_b^{ps}, p_b^{pr}) = p_b^{ps} \cdot n_b^{ps} + p_b^{pr} \cdot n_b^{pr} - C \quad (9)$$

Following the principle of profit maximization, Equations (8) and (9) are solved and Lemma 2 is obtained.

Lemma 2: $p_b^{ps*} = \frac{a^2 M_1 + a M_2 + 2 M_3}{4 - a^2}$, $p_b^{pr*} = \frac{a^2 M_1 + a(M_2 - w) + 2(M_3 - \theta w)}{4 - a^2}$, $p_b^{hr*} = \frac{2aM_1 + 2(M_2 - w) + a(M_3 - \theta w)}{4 - a^2}$ and $p_b^{hs*} = \frac{2aM_1 + 2M_2 + aM_3}{4 - a^2}$; where $M_1 = p^l - c_e$, $M_2 = \bar{v} - 2p^l + ap^l + c_e + c_0 k \sqrt{nA}$ and $M_3 = c\bar{v} - p^l + ap^l$.

4.3. Modeling and Solutions of Mode c

In Mode c, the express company cooperates with a third-party parcel locker platform in the last-mile delivery market. To increase profit, the platform attracts advertisers to place ads on its lockers and the online system. The profit of an advertiser is Equation (10). It is affected by the benefit of customers accumulated by the platform, the advertising fee charged by the platform, and the cost of producing each ad. This setting reflects the customer-to-advertiser network externality of parcel locker platforms: more customers using platform delivery can increase advertisers' expected benefits from placing advertisements on the platform.

$$U_c^{ad} = \gamma(n_c^{ps} + n_c^{pr}) - p_c^{ad} - c_a \quad (10)$$

Since $U_c^{ad} \geq 0$, the number of advertisers who would like to place ads on the platform is $n_c^{ad} = \frac{\gamma}{v} \left[(2M_3 - \theta w) - (p_c^{pr} + p_c^{ps}) + a(p_c^{hr} + p_c^{hs}) \right] - p_c^{ad}$. Hence, the advertiser-side demand is endogenously related to the platform's customer traffic and the advertising fee. This mechanism distinguishes Mode c from Mode b.

The profit of the parcel locker platform is Equation (11), including profits of first-mile and last-mile platform delivery service fees, advertising fees, and operating costs.

$$\Pi_c^p(p_c^{ps}, p_c^{pr}, p_c^{ad}) = p_c^{ps} \cdot n_c^{ps} + p_c^{pr} \cdot n_c^{pr} + p_c^{ad} \cdot n_c^{ad} - C \quad (11)$$

Compared with Mode b, the platform in Mode c has an additional advertising revenue source. This enables the platform to adjust customer-facing platform delivery fees more flexibly in order to attract more users and increase advertising value. However, the baseline model assumes moderate and targeted advertising, so that advertising does not significantly reduce customers' utility from using parcel lockers.

The express company's profit is Equation (12), which is similar to Equation (8) in Mode c.

$$\begin{aligned} \Pi_c^{courier}(p_c^{hs}, p_c^{hr}) = & (p^l - c_e) \cdot n_c^{ps} + (p^l - c_e) \cdot n_c^{pr} + \left[(p^l - c_e) + (p_c^{hs} - c_0 k \sqrt{nA}) \right] \cdot n_c^{hs} \\ & + \left[(p^l - c_e) + (p_c^{hr} - c_0 k \sqrt{nA}) \right] \cdot n_c^{hr} \end{aligned} \quad (12)$$

Following the principle of profit maximization, Equations (11) and (12) are solved and Lemma 3 is obtained.

Lemma 3: When $\bar{v} > \frac{\gamma^2(3-a^2)}{4-a^2}$, $p_c^{ps*} = p_b^{ps*} - \frac{2\gamma}{4-a^2} p_c^{ad*}$, $p_c^{pr*} = p_b^{pr*} - \frac{2\gamma}{4-a^2} p_c^{ad*}$, $p_c^{ad*} = \frac{\gamma[2a^2M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{2\gamma(4-a^2) - 2\gamma^2(2-a^2)}$, $p_c^{hs*} = p_b^{hs*} - \frac{\gamma a}{4-a^2} p_c^{ad*}$, and $p_c^{hr*} = p_b^{hr*} - \frac{\gamma a}{4-a^2} p_c^{ad*}$.

4.4. Modeling and Solutions of Mode d

In Mode d, the express company constructs and operates a parcel locker platform by itself. Thus, the profit of the express company is Equation (13). It includes profits of sending and receiving parcels by both platform and home delivery, the benefit from operating advertising, and the self-built and operating costs of the platform.

$$\begin{aligned} \Pi_d^{courier}(p_d^{ps}, p_d^{pr}, p_d^{ad}, p_d^{hs}, p_d^{hr}) = & (p^l + p_d^{ps} - c_e) \cdot n_d^{ps} + (p^l + p_d^{pr} - c_e) \cdot n_d^{pr} + p_d^{ad} \cdot n_d^{ad} \\ & + \left[(p^l - c_e) + (p_d^{hs} - c_0 k \sqrt{nA}) \right] \cdot n_d^{hs} + \left[(p^l - c_e) + (p_d^{hr} - c_0 k \sqrt{nA}) \right] \cdot n_d^{hr} - C_s \end{aligned} \quad (13)$$

Different from Mode c, the express company in Mode d internalizes the platform delivery revenue, advertising revenue, and self-built and operating costs. Thus, the comparison of Modes c and d allows us to examine whether the express company should cooperate with a third-party platform or build and operate its own one. Following the principle of profit maximization, Equation (13) is solved and Lemma 4 is given.

Lemma 4: When $\bar{v} > \frac{1}{2}\gamma^2$, $p_d^{ps*} = \frac{a(M_2 - w) + a^2M_1 + (M_3 - M_1 - \theta w) + a(M_1 - c_0 k \sqrt{nA})}{2(1-a^2)} - \frac{\gamma}{2} p_d^{ad*}$, $p_d^{pr*} = \frac{aM_2 + a^2M_1 + (M_3 - M_1) + a(M_1 - c_0 k \sqrt{nA})}{2(1-a^2)} - \frac{\gamma}{2} p_d^{ad*}$, $p_d^{ad*} = \frac{(M_2 - w) + aM_1 + a(M_3 - M_1 - \theta w) + a^2(M_1 - c_0 k \sqrt{nA})}{2(1-a^2)}$, $p_d^{hs*} = \frac{M_2 + aM_1 + a(M_3 - M_1) + a^2(M_1 - c_0 k \sqrt{nA})}{2(1-a^2)}$, $p_d^{hr*} = \frac{\gamma}{2\gamma - \gamma^2} \left[\frac{1}{2}(M_3 - \theta w) + M_1 - a(M_1 - c_0 k \sqrt{nA}) \right]$.

4.5. Model Analysis

It can be seen that the express company's service area (A), customers' perceived convenience of using parcel lockers (c), and customer-to-advertiser network externality (γ) can influence the optimal equilibrium solutions of the proposed models. Therefore, the impacts of the above factors are examined. These three factors also correspond to important managerial variables in practice. The service area reflects the spatial cost of home delivery; perceived convenience captures customers' acceptance of parcel locker services;

and customer-to-advertiser network externality measures the traffic value generated by platform users for advertisers.

Corollary 1: (i) $\frac{\partial p_i^{hr*}}{\partial A} > 0, (i = a, b, c, d)$; (ii) $\frac{\partial p_i^{hs*}}{\partial A} > 0 (i = a, b, c, d)$.

Corollary 1 indicates that with the increase in the express company's service area (A), the optimal home-receiving and home-sending fees charged by the express company will increase. The reason is that the increase in the service area will increase the delivery cost of the express companies (including transportation and time expenses), which will bring high last-mile delivery service costs to express companies. As a result, last-mile delivery service fees charged by the express company to customers will increase. For example, in some remote villages, due to the small population density and relatively dispersed residents, the service area covered by a certain population will be relatively broad. In this case, the express company's delivery cost will increase, and the service fees are often higher. This finding is consistent with real-world observations. Thus, the service area can be regarded as an important operational factor when express companies design differentiated home delivery fees.

Corollary 2: $\frac{\partial p_i^{ps*}}{\partial c} > 0, \frac{\partial p_i^{pr*}}{\partial c} > 0 (i = b, c)$; when $\frac{\gamma^2(3-a^2)}{4} > \frac{1}{v}$, $\frac{\partial p_d^{ps*}}{\partial c} > 0, \frac{\partial p_d^{pr*}}{\partial c} > 0$.

Corollary 2 shows that with the increase in customers' perceived convenience of using parcel lockers (c), the optimal fees of first-mile platform-sending service and last-mile platform-receiving service increase. The reason is that the increase in c can reflect the parcel locker platform's input or investment in improving the service quality of platform delivery, which will increase customers' willingness to pay for platform delivery services. From the perspective of revenue management, the platform has the motivation to increase the service fees charged to customers. This result also suggests that parcel locker operators can improve perceived convenience through better locker locations, higher locker density, easier-to-use interfaces, clearer pickup instructions, safer storage, and more flexible service availability.

Corollary 3: (i) $\frac{\partial p_i^{ad*}}{\partial c} > 0, (ii) \frac{\partial p_i^{ad*}}{\partial \gamma} > 0 (i = c, d)$.

Corollary 3(i) shows that with the increase in customers' perceived convenience of using parcel lockers (c), the advertising fee charged to advertisers increases. The reason is that the increased c will increase the number of customers choosing platform delivery services. Due to the network externality theory and the characteristics of platform economy, more customers choosing platform delivery will produce a higher advertising conversion rate and will attract more advertisers to the platform. In this case, the platform has an incentive to increase the advertising fee. Moreover, the increased advertising fee will further help the platform to screen ads with high quality, which will provide additional value for customers. In doing so, the customer-to-advertiser network externality will be improved, and the platform's profit will be maintained and increased, contributing to the sustainable operation of the platform ecosystem.

The customer-to-advertiser network externality (γ) can be used to describe the extent to which customers using platform delivery read ads placed on lockers and apps and complete payment for goods. In other words, it refers to the benefits that customer traffic brings to advertisers. Therefore, Corollary 3(ii) indicates that with the increase in γ , the

platform will increase the advertising fee. The reasons are twofold. First, if advertisers can get more ad conversion rates from customers, they will have higher willingness to pay a higher advertising fee to the platform. Second, the advertising fee becomes a new profit source for the platform, which enables the platform to improve the service quality and customer satisfaction and accumulate more customers, which will further improve the bilateral network externality between customers and advertisers.

5. Comparative Analysis

This paper investigates the optimal delivery decision of the express company related to the use of parcel lockers and the optimal pricing and advertising decision of the parcel locker operators. By comparing the four modes proposed previously, the following questions have been answered. First, how does the existence of platform delivery service affect the optimal pricing strategy and market performance of the express company (as shown in Section 5.1)? Second, how does the platform's strategy of operating advertising affect the optimal pricing strategy and market performance of the express company (as shown in Section 5.2)? Lastly, should the express company cooperate with the third-party parcel locker platform or build its own platform (as shown in Section 5.3)?

5.1. Comparisons Between Modes a and b: Effects of the Existence of Platform Delivery Service

In Mode a, the express company provides home delivery to customers. In Mode b, the express company provides home delivery and also cooperates with the third-party parcel locker platform to provide platform delivery to customers. The comparison between Modes a and b is used to examine how the existence of platform delivery service affects the pricing decisions of the express company and whether it only diverts customers from home delivery or also expands the total delivery service demand.

First of all, the express company's home-sending fee and home-receiving fee in Mode b are compared with those in Mode a, and the result is Proposition 1.

Proposition 1: $p_b^{hr*} > p_a^{hr*}$, $p_b^{hs*} > p_a^{hs*}$.

Proposition 1 indicates that the home-sending fee and home-receiving fee of the express company in Mode b are higher than those in Mode a. In practice, with the emergence and popularity of platform delivery service, parcel locker platforms become the competitors of express companies in the last-mile delivery market. Counter-intuitively, instead of reducing fees of home delivery service, Proposition 1 suggests that the express company should raise fees of home delivery when platform delivery and home delivery coexist. This is because when express companies provide home and platform delivery simultaneously, customers choosing home delivery may have higher requirements for home-sending and -receiving. For instance, some customers want to inspect parcels in person, and some may expect fast delivery. As a result, customers choosing home delivery are willing to accept a premium fee to meet their needs. This result also reflects a customer segmentation effect: after platform delivery becomes available, some price-sensitive or convenience-oriented customers may switch to parcel lockers, while customers who continue to choose home delivery may have stronger preferences for personalized or premium home services.

Next, the express company's market demand in Mode b is compared with that in Mode a, and the result is Proposition 2.

Proposition 2: (i) $n_a^{hs} < n_b^{hs} + n_b^{ps}$, (ii) $n_a^{hr} < n_b^{hr} + n_b^{pr}$.

Proposition 2 shows that the market demand for home-sending service in Mode a is lower than the demands for home-sending and platform-sending services in Mode b. Similarly, the market demand for home-receiving service in Mode a is lower than the demands for home-receiving and platform-receiving services in Mode b. This is because with the emergence of platform delivery, the delivery service capacity of the express company will be improved, which will expand customers' demands for last-mile delivery services. Therefore, for express companies or third-party logistics enterprises such as parcel locker operators, the development of various delivery service modes will enlarge their market sizes. Thus, Proposition 2 indicates a market expansion effect. Although some customers may substitute platform delivery for home delivery, the coexistence of the two options can improve service accessibility and generate a larger total demand.

At last, the profits of the express company in Modes a and b are compared in a numerical example. A unified set of standardized benchmark parameters is adopted for this comparison and for all subsequent numerical analyses, $\bar{v}=20$, $p^l=6$, $C_e=2.5$, $k=1.2$, $n=1$, $A=3.14$, $C_0=0.94$, $c=1.10$, $w=6$, $\theta=0.60$, $a=0.40$; these parameters are calibrated to China's express delivery market and the literature, as reported in the Appendix A (Table A1).

The influences of some important factors (c , w , A , and a) on the profits of the express companies in Mode a and Mode b are shown in Figure 7 and Observation 1.

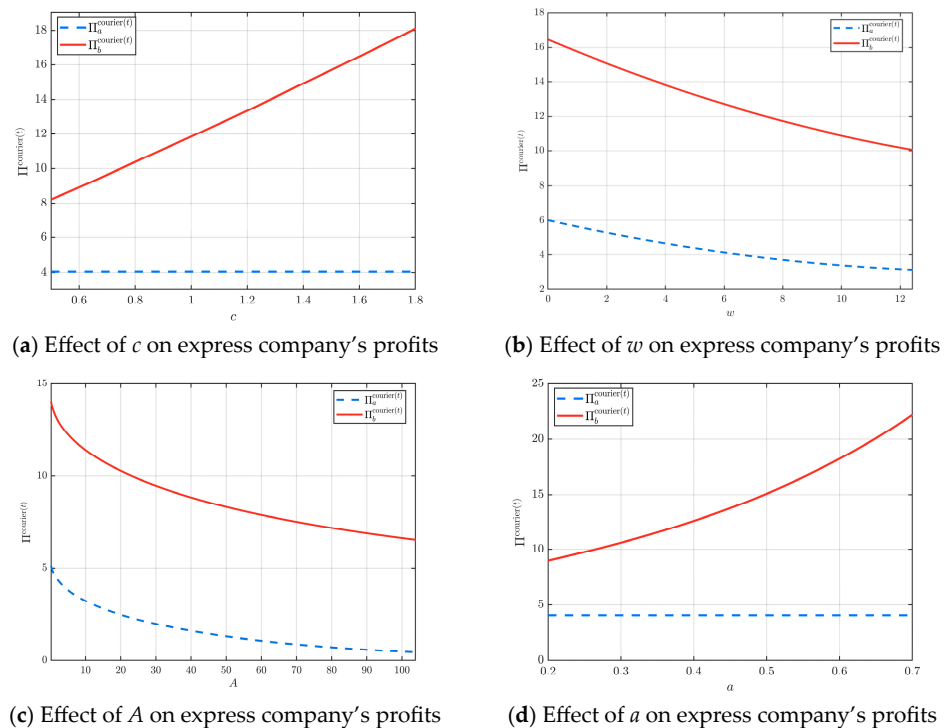


Figure 7. Comparisons of the express company's profits under Mode a and b.

Observation 1. Comparing the express company's profits in Mode a and b, the following results are obtained:

- (i) As customers' perceived convenience of using parcel lockers c increases, the express company's profit under Mode b increases significantly, whereas that under Mode a remains almost unchanged.

- (ii) As customers' waiting cost w increases, the express company's profits under both modes decrease. However, within the feasible parameter range of the model, the profit under Mode b remains higher than that under Mode a.
- (iii) As the service area A expands, the express company's profits under both modes decline, mainly because longer delivery distances increase last-mile service costs. Nevertheless, Mode b still maintains a relatively higher profit level.
- (iv) As the substitutability between platform service and home delivery service a increases, the express company's profit under Mode b rises markedly, while that under Mode a is almost unaffected.

Observation 1(i) indicates that Mode b can convert customers' recognition of parcel locker convenience into firm profit. Observation 1(ii) suggests that the third-party parcel locker platform can partly mitigate the negative effect of higher waiting costs on the express company's profit. Observation 1(iii) implies that the platform can share part of the last-mile service burden. Observation 1(iv) implies that when the substitutability between the two services becomes stronger, the express company can obtain greater demand-shifting benefits through platform cooperation.

Overall, Mode b generates higher profits across different parameter changes. This shows that cooperation with a third-party platform can improve the express company's profitability, especially when customers place greater value on locker convenience, waiting costs are high, the service area is large, or service substitutability is strong.

5.2. Comparisons of Modes b and c: Impacts of Operating Advertising

In this section, the express company cooperates with a third-party parcel locker platform to provide platform delivery to customers in the last-mile delivery market. In reality, there are two scenarios of the parcel locker platform: the platform does not operate advertising (Mode b) and the platform operates advertising (Mode c). The objective of comparing Modes b and c is to analyze the business value of the number of customers accumulated by the platform and the impact of operating advertising on the pricing strategies and market performance of the stakeholders.

First, the platform-sending and platform-receiving fees and the home-sending and home-receiving fees of Modes b and c are compared in Proposition 3, respectively.

Proposition 3: (i) $p_c^{ps*} < p_b^{ps*}$, $p_c^{pr*} < p_b^{pr*}$; (ii) $p_c^{hs*} < p_b^{hs*}$, $p_c^{hr*} < p_b^{hr*}$.

Proposition 3(i) shows that the platform-sending and platform-receiving fees of Mode c are lower than those of Mode b. This is because in Mode c, the advertising fee becomes a new profit source of the platform. In order to attract more customers and increase customer-to-advertiser network externality, the platform has an incentive to lower the fees of platform delivery charged to customers, and, consequently, it will attract more advertisers, bringing continuous advertising profit to the platform. Proposition 3(ii) shows that the home-sending and home-receiving fees under Mode c are lower than those under Mode b. Based on Proposition 3(i), if the platform operates advertising, the number of customers choosing home delivery will be decreased. Therefore, to compete for the price-sensitive customers in the last-mile delivery market, the express company may lower the fees of home delivery services in Mode c. This result indicates that advertising revenue can be used as an indirect subsidy for customer-side platform delivery fees. However, this conclusion is based on the assumption that advertising is moderate and does not significantly reduce customers' experience or willingness to use parcel lockers.

Next, $\Delta_{bc}^{ps} = p_b^{ps*} - p_c^{ps*}$ denotes the price difference of platform-sending fees between Modes b and c; $\Delta_{bc}^{pr} = p_b^{pr*} - p_c^{pr*}$ denotes the price difference of platform-receiv-

ing fees between Modes b and c; $\Delta_{bc}^{hs} = p_b^{hs*} - p_c^{hs*}$ denotes the price difference of home-sending fees between Modes b and c; and $\Delta_{bc}^{hr} = p_b^{hr*} - p_c^{hr*}$ denotes the price difference of home-receiving fees between Modes b and c. By comparing the above price differences, the influences of advertising on the pricing strategies of the express company and the platform are investigated. The results are shown in Proposition 4 and Figure 8.

Proposition 4: (i) $\Delta_{bc}^{ps} = \Delta_{bc}^{pr} > \Delta_{bc}^{hs} = \Delta_{bc}^{hr}$; (ii) $\frac{\partial \Delta_{bc}^{ps}}{\partial c} = \frac{\partial \Delta_{bc}^{pr}}{\partial c} > 0$, $\frac{\partial \Delta_{bc}^{hs}}{\partial c} = \frac{\partial \Delta_{bc}^{hr}}{\partial c} > 0$; (iii) $\frac{\partial \Delta_{bc}^{ps}}{\partial \gamma} = \frac{\partial \Delta_{bc}^{pr}}{\partial \gamma} > 0$, $\frac{\partial \Delta_{bc}^{hs}}{\partial \gamma} = \frac{\partial \Delta_{bc}^{hr}}{\partial \gamma} > 0$.

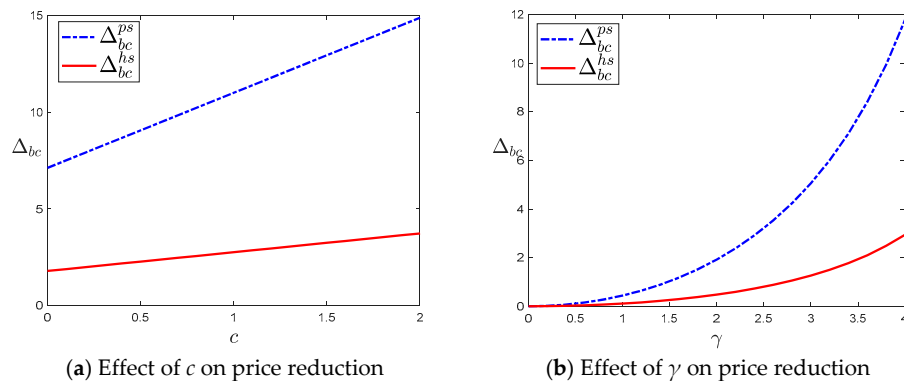


Figure 8. Effects of c and γ on price reductions of the platform and the express company in Modes b and c.

Proposition 4 further compares the magnitude of price reductions induced by advertising operation. Proposition 4(i) shows that the reduction in the platform-sending fee is equal to that in the platform-receiving fee, and the reduction in the home-sending fee is equal to that in the home-receiving fee. More importantly, the price reduction in platform delivery is larger than that in home delivery. This indicates that advertising operation mainly affects customer-side pricing through the parcel locker platform. Once the platform operates advertising, platform users generate not only delivery service revenue but also advertising traffic value. Thus, the platform has a stronger incentive to reduce platform delivery fees in order to attract more users and enlarge the customer base for advertisers. By contrast, the express company does not obtain advertising revenue from home delivery customers. Its reduction in home delivery fees is mainly a competitive response to the lower platform delivery fees.

Proposition 4(ii) and 4(iii) also show that both customers' perceived convenience of using parcel lockers (c) and customer-to-advertiser network externality (γ) strengthen the price-reduction effect of advertising operation. When perceived convenience increases, customers become more willing to choose platform delivery, so lowering platform delivery fees can more effectively expand platform demand. As a result, the platform further reduces platform delivery fees, and the price difference between Modes b and c becomes larger. The home delivery price difference also increases with perceived convenience, but this effect is weaker because it is transmitted indirectly through customer substitution and competitive pressure. Similarly, a higher γ means that each platform user creates greater advertising value for advertisers. This increases the marginal benefit of attracting additional platform users, thereby encouraging the platform to rely more on advertising revenue and further reduce platform delivery fees. The express company may also lower home

delivery fees as γ increases, but this adjustment is still an indirect response to the platform's stronger price competition.

Moreover, the number of customers choosing platform delivery in Modes b and c is compared; the profits of the platform in Modes b and c are compared as well. The results are shown in Proposition 5 and Figure 9.

Proposition 5: (i) $n_c^{ps*} > n_b^{ps*}$, $n_c^{pr*} > n_b^{pr*}$; (ii) $\Pi_c^p(p_c^{ps}, p_c^{pr}, p_c^{ad}) > \Pi_b^p(p_b^{ps}, p_b^{pr})$; (iii) $\frac{\partial \Pi_c^p(p_c^{ps}, p_c^{pr}, p_c^{ad})}{\partial c} > 0$; (iv) $\frac{\partial \Pi_c^p(p_c^{ps}, p_c^{pr}, p_c^{ad})}{\partial \gamma} > 0$.

Proposition 5 further examines how advertising operation affects platform demand and platform profitability. Proposition 5(i) indicates that the number of customers choosing platform delivery in Mode c is higher than that in Mode b. Proposition 5(ii) indicates that the platform's profit in Mode c is higher than that in Mode b. These results indicate that the lower platform delivery fees identified in Proposition 3 do not necessarily damage the platform's profitability. On the contrary, once the platform introduces advertising, the platform can attract more customers to use parcel lockers by reducing platform delivery fees. The enlarged customer base then increases the platform's advertising value and brings additional advertising revenue. Therefore, although the platform earns less delivery revenue from each individual customer, the loss can be offset by two sources: the increase in platform delivery demand and the newly generated advertising revenue. This explains why Mode c leads to both a larger platform delivery market and a higher platform profit than Mode b.

Propositions 5(iii) and (iv) and Figure 9 indicate that with the increase in c and γ , the platform's profit increases in Mode c. A higher perceived convenience (c) directly improves customers' willingness to use platform delivery, thereby expanding the user base that can be monetized through advertising. At the same time, as shown in Proposition 4, a higher c strengthens the platform's incentive to reduce customer-facing delivery fees, which further accelerates customer accumulation. Therefore, customers' perceived convenience improves platform profit through both a demand-expansion effect and a price-subsidization effect. Similarly, a higher customer-to-advertiser network externality (γ) means that each platform user creates greater traffic value for advertisers. This increases the marginal advertising revenue generated by platform users and gives the platform a stronger incentive to attract customers through lower delivery fees. Hence, γ improves platform profit through both a monetization effect and a customer-base expansion effect.

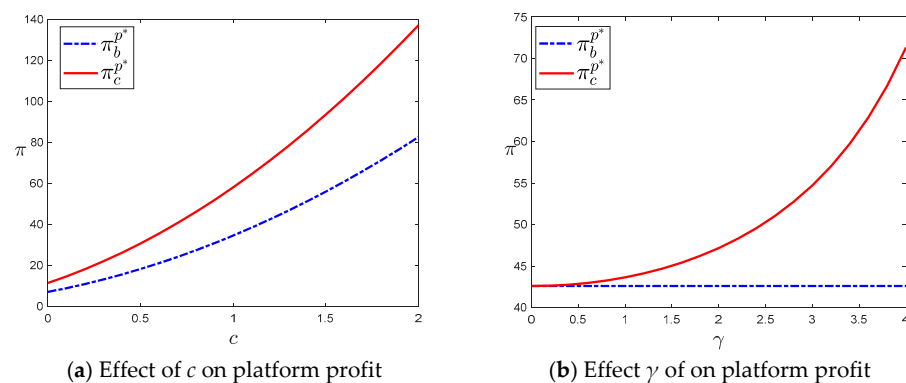


Figure 9. Effects of c and γ on the platform's profit in Modes b and c.

At last, the market size of the express company, the profit of home delivery, the profit of long-distance transportation related to home delivery, the profit of long-distance transportation related to platform delivery, and the total profit of the express company in Modes b and c are compared. The results are shown in Proposition 6 and Figure 10.

Proposition 6: (i) $n_c^{hs*} < n_b^{hs*}$, $n_c^{hr*} < n_b^{hr*}$; (ii) $\Pi_c^{courier(h)}(p_c^{hs}, p_c^{hr}) < \Pi_b^{courier(h)}(p_b^{hs}, p_b^{hr})$; (iii) $\Pi_c^{courier(hl)}(p_c^{hs}, p_c^{hr}) < \Pi_b^{courier(hl)}(p_b^{hs}, p_b^{hr})$; (iv) $\Pi_c^{courier(pl)}(p_c^{hs}, p_c^{hr}) > \Pi_b^{courier(pl)}(p_b^{hs}, p_b^{hr})$; (v) $\Pi_c^{courier(t)}(p_c^{hs}, p_c^{hr}) > \Pi_b^{courier(t)}(p_b^{hs}, p_b^{hr})$.

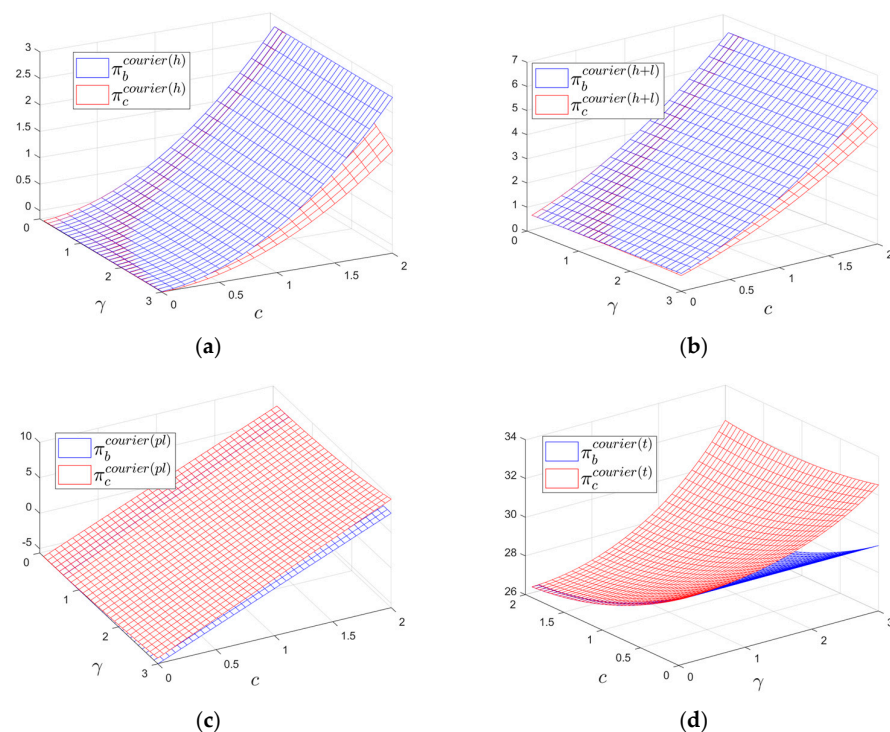


Figure 10. Comparisons of the express company's profits in Modes b and c: (a) profit of home delivery; (b) profit of long-distance transportation related to home delivery; (c) profit of long-distance transportation related to platform delivery; (d) total profit.

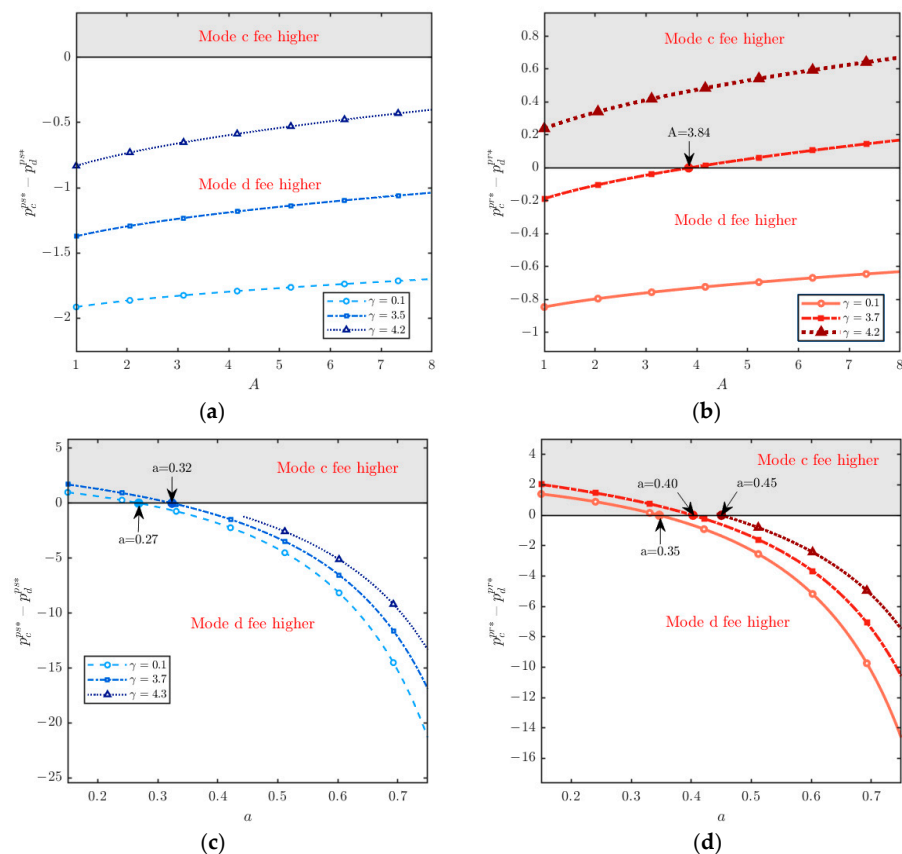
Proposition 6(i) indicates that the number of customers choosing home delivery in Mode c is lower than that in Mode b. Proposition 6(ii) and Figure 10a indicate that the express company's profit from home delivery in Mode c is lower than that in Mode b. Proposition 6(iii) and Figure 10b indicate that the profit that the express company makes from long-distance transportation related to home delivery in Mode c is lower than that in Mode b. Proposition 6(iv) and Figure 10c indicate that the profit that the express company makes from long-distance transportation related to platform delivery in Mode c is higher than that in Mode b. Proposition 6(v) and Figure 10d indicate that the total profit of the express company in Mode c is higher than that in Mode b. The reasons for Propositions 6(i)–(iii) are that, according to Proposition 3(i), the platform will reduce service fees charged for customers after it operates advertising, which will attract more customers to use platform delivery. As a result, the number of customers choosing home delivery decreases, and the profits that the express company makes from home delivery and long-distance transportation related to home delivery decrease as well. The reason for Proposition 6(iv) is that the number of customers choosing platform delivery increases in Mode

c, which brings a higher profit for the express company in long-distance transportation related to platform delivery. Proposition 6(v) implies that the increased profit from the express company's long-distance transportation related to platform delivery can offset their decreased profits from home delivery in Mode c. This finding explains why advertising can benefit not only the platform but also the express company, even though the express company loses some home delivery demand.

Therefore, it is concluded by comparing Modes b and c that operating advertising can increase the profits of the express company and the parcel locker platform. By lowering the price of platform delivery, the platform can attract more customers to use platform delivery. This interaction of customer-to-advertiser network externality can make the platform's delivery service and advertising business enter a virtuous sustainable operation circle. Nevertheless, managers should also control advertising intensity and improve advertising relevance. If advertising becomes intrusive, excessive, or poorly targeted, it may reduce customer satisfaction and weaken the positive customer-to-advertiser network externality assumed in the baseline model.

5.3. Comparisons of Mode c and Mode d: Impact of Platform Ownership

In this section, whether the express company should build a parcel locker platform by itself is discussed. On the premise that operating advertising always brings more profit to the platform (the results in Section 5.2), Modes c and d are compared in a numerical example. The values of parameters are the same as those in Section 5.1. Observation 2 and Figure 11 provide advice on the pricing strategies of platform owners. Observation 3 and Figure 12 provide advice on platform ownership determination.



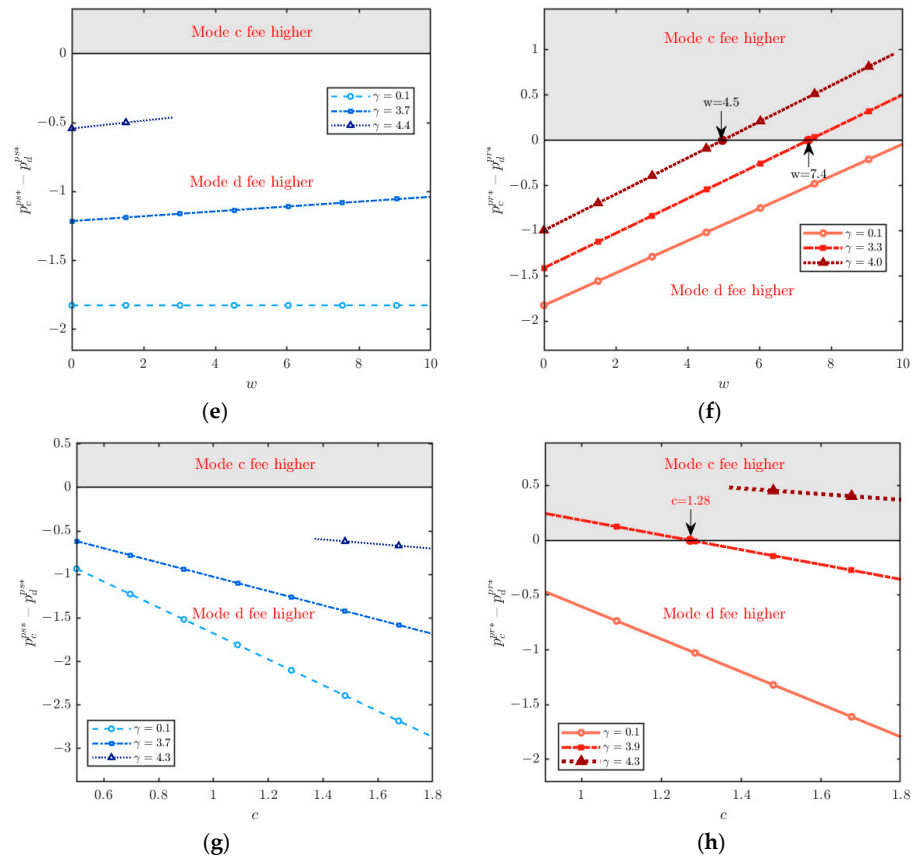


Figure 11. Effects of key parameters on platform fee differences in Modes c and d. (a) Effect of A on platform-sending fee difference. (b) Effect of A on platform-receiving fee difference. (c) Effect of a on platform-sending fee difference. (d) Effect of a on platform-receiving fee difference. (e) Effect of w on platform-sending fee difference. (f) Effect of w on platform-receiving fee difference. (g) Effect of c on platform-sending fee difference. (h) Effect of c on platform-receiving fee difference.

Observation 2. Comparing the platform delivery fee differences between Mode c and d, the following results are obtained:

- As the service area A expands, the third-party platform gains a higher pricing advantage in receiving services, especially when γ is strong. However, the self-built platform always charges higher prices in sending services.
- As the substitutability a increases, the pricing advantage shifts from the third-party platform to the self-built platform. A stronger γ delays this shift.
- The waiting cost w has little effect on sending prices but strengthens the third-party platform's pricing advantage in receiving services. A stronger γ lowers the waiting-cost threshold required for this advantage.
- As customers' perceived convenience c increases, the self-built platform's pricing advantage in sending services becomes more stable. In receiving services, the pricing advantage depends on both c and γ . When γ is strong, the third-party platform is more likely to maintain higher receiving prices.

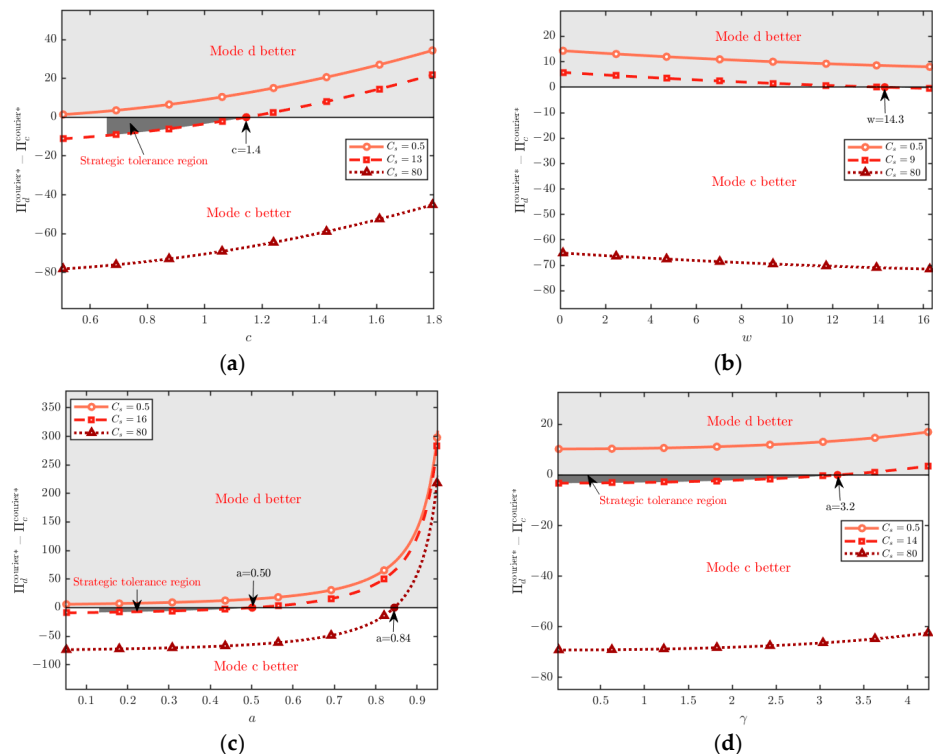
It should be noted that the price comparison in this study is conducted only within the parameter ranges where both modes satisfy the common feasibility conditions, including the equilibrium existence conditions, non-negative optimal price conditions, and non-negative demand conditions. Therefore, when a change in a parameter causes either mode to violate the feasibility requirements, the corresponding curve is no longer plotted. This is reflected in the figures as truncated curves.

Observation 2(i) and Figure 11a,b show that the expansion of the service area mainly strengthens the pricing power of the third-party platform on the receiving side. As A increases, the consumer coverage and traffic value improve. The third-party platform can therefore better convert user demand into advertising revenue and platform pricing power. This effect is particularly evident when the customer-to-advertiser network externality γ is strong. However, in sending services, the self-built platform maintains a relatively stable pricing advantage because it relies on the express company's own transportation and last-mile service system.

Observation 2(ii) and Figure 11c,d indicate that stronger substitutability compresses the independent pricing space of the third-party platform. As a result, the pricing advantage shifts to the self-built platform. Nevertheless, a higher γ enhances the advertising revenue and traffic value of the third-party platform, which partly offsets the pricing pressure caused by stronger substitutability.

Observation 2(iii) and Figure 11e,f show that waiting cost mainly affects the receiving side rather than the sending side. As w increases, customers attach greater importance to the time-saving and convenience benefits of platform-receiving services. The third-party platform can therefore increase the receiving service price by leveraging user traffic and customer-to-advertiser network externality. When γ is strong, the third-party platform can more effectively convert user scale into advertising revenue and platform value.

Observation 2(iv) and Figure 11g,h show that the effect of perceived convenience c differs across service types. For platform-sending services, the self-built platform still maintains strong pricing power as c increases, suggesting that sending-side prices are more closely related to the express company's integrated operational capability. For platform-receiving services, the effect of c is moderated by γ . When γ is weak, the self-built platform is more likely to obtain a pricing advantage. When γ is strong, the third-party platform can maintain a higher receiving-side price through traffic aggregation and advertising revenue.



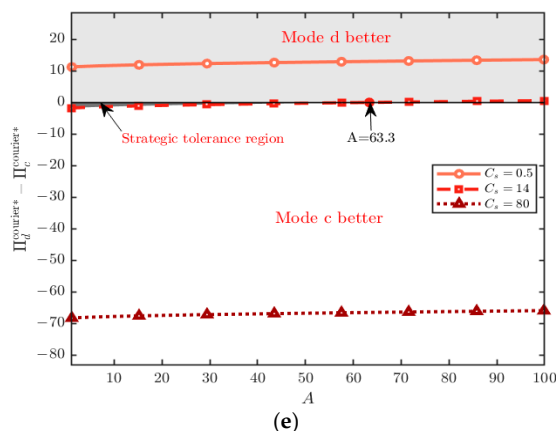


Figure 12. Effect of key parameters on the express company's profit difference between Mode d and Mode c. (a) Effect of c on express company's profit difference. (b) Effect of w on express company's profit difference. (c) Effect of a on express company's profit difference. (d) Effect of γ on express company's profit difference. (e) Effect of A on express company's profit difference.

Observation 3. Comparing the express company's profit difference in Mode c and d, the following results are obtained:

- (i) As customers' perceived convenience c increases, Mode d becomes more profitable relative to Mode c. When the self-built and operating cost C_s is low, Mode d always dominates; when C_s is moderate, Mode d becomes superior once c exceeds a certain threshold; and when C_s is high, Mode c remains preferable.
- (ii) As customers' waiting cost w increases, the profit advantage of Mode d weakens. Mode d still dominates under a low C_s , while Mode c becomes superior when w exceeds a threshold. If C_s is high, Mode c always dominates.
- (iii) As the substitutability between platform services and home services a increases, Mode d gains a stronger profit advantage. When a is low, Mode c is more likely to dominate; when a becomes sufficiently high, Mode d becomes preferable.
- (iv) As the customer-to-advertiser network externality γ increases, Mode d performs better than Mode c. Under a low C_s , Mode d always dominates; under a moderate C_s , Mode d becomes superior once γ exceeds a threshold. When C_s is high, Mode c still dominates, although the profit gap narrows.
- (v) As the service area A expands, Mode d's relative profit advantage increases slightly. Mode d dominates when C_s is low and may become superior after A exceeds a threshold. However, Mode c remains preferable when C_s is high.

Observation 3(i) and Figure 12a show that a higher c improves the profitability of Mode d. Under Mode d, the express company can coordinate platform services, last-mile delivery, and advertising revenue within the same system. Hence, a higher c makes the self-built platform more likely to gain a profit advantage. However, C_s remains a key constraint. When C_s is low, Mode d is more likely to dominate; when C_s is high, the benefit from higher convenience may be insufficient to offset the self-building and operating cost. The strategic tolerance region in the figure indicates that even when Mode d generates lower profit than Mode c, it can still be an acceptable option for entering the parcel locker platform market as long as its own profit remains non-negative.

Observation 3(ii) and Figure 12b indicate that a higher w weakens the profit advantage of Mode d over Mode c. A higher w makes customers more dependent on the parcel locker platform. Mode d requires the express company to bear self-built and operating costs. Thus, when w is high and C_s cannot be effectively reduced, Mode c is more likely to be the better choice for short-term profit maximization.

Observation 3(iii) and Figure 12c show that a higher a strengthens the profit advantage of Mode d. As a increases, decentralized decisions by the third-party platform and the express company under Mode c make it difficult to fully coordinate service prices. By contrast, Mode d allows the express company to jointly manage platform services and home services within the same system, thereby improving overall profit easily. The strategic tolerance region also suggests that even before Mode d reaches the switching threshold, it may still be a feasible option.

Observation 3(iv) and Figure 12d indicate that a higher γ improves the relative profitability of Mode d. A higher γ enables platform user scale to be more effectively converted into advertising revenue and traffic value, helping the self-built platform cover its construction and operating costs. Therefore, under a moderate C_s , Mode d may shift from being inferior to being superior as γ increases. However, when C_s is excessively high, advertising revenue is insufficient to fully offset the high C_s , and Mode c remains preferable.

Observation 3(v) and Figure 12e show that a higher A affects the profits of both modes, but its effect on the profit difference is relatively limited. This is because A mainly enters the model through the last-mile delivery cost, which affects both Mode c and Mode d and is therefore partly offset in the profit comparison. Nevertheless, when C_s is moderate, a larger A may still enhance the scale value and channel-control benefits of the self-built platform, allowing Mode d to gradually gain a profit advantage. The strategic tolerance region suggests that even before the service area reaches the critical scale, the express company may still consider self-building for long-term platform development, as long as Mode d itself remains profitable.

Overall, C_s is the core factor affecting the choice between Mode c and Mode d. A low C_s helps Mode d maintain a profit advantage, whereas a high C_s weakens or even offsets the benefits of self-building. In addition, a high c , a , γ , and A improve the relative performance of Mode d, while a high w weakens its advantage. The strategic tolerance region indicates that Mode d is meaningful not only when it outperforms Mode c. As long as its own profit is non-negative, the express company may still choose self-building for last-mile channel control, user-resource accumulation, and long-term platform development.

6. Extensions

Since the previous analyses have shown that Mode b outperforms Mode a and that Mode c further outperforms Mode b, the key remaining strategic issue is not whether parcel lockers or advertising should be adopted but whether the express company should cooperate with a third-party advertising-supported platform or build and operate its own platform. Therefore, the extension focuses on Modes c and d, which both involve advertising-supported parcel locker services but differ in platform ownership.

In the baseline model, parcel locker capacity is assumed to be sufficient to satisfy platform delivery demand. However, in real-world operations, parcel lockers may face capacity shortages, especially during peak delivery periods or in densely populated communities. Limited locker capacity may affect service pricing, platform-demand allocation, advertising traffic, and the ownership choice between cooperation with a third-party platform and self-construction. Therefore, to further examine the operational implications of the comparison between Mode c and Mode d, we extend the baseline model by introducing a capacity constraint for platform delivery.

Since platform-sending and platform-receiving services both occupy parcel locker resources, the effective capacity constraint is formulated as follows:

$$\tau_s n_i^{ps} + \tau_r n_i^{pr} \leq K_i, i = c, d$$

Here, the parameter K_i denotes the effective parcel locker capacity under Mode i . The parameters τ_s and τ_r represent the capacity occupation intensities of platform-sending and platform-receiving services, respectively. Since receiving parcels usually remain in lockers for a longer period before being collected by customers, platform-receiving demand is assumed to occupy more capacity than platform-sending demand, namely, $\tau_r \geq \tau_s > 0$. This formulation captures the effects of capacity occupation intensity and locker turnover rate. A larger τ_r indicates that platform-receiving parcels occupy lockers for a longer time, resulting in a tighter capacity constraint. For Mode c, the third-party platform determines the platform-sending fee, platform-receiving fee, and advertising fee after observing the home delivery fees decided by the express company. With the capacity constraint, the platform's optimization problem becomes

$$\max_{p_c^{ps}, p_c^{pr}, p_c^{ad}} \Pi_c^p$$

Subject to

$$\begin{aligned} \tau_s n_c^{ps} + \tau_r n_c^{pr} &\leq K_c, \\ p_c^{ps} \geq 0, \quad p_c^{pr} \geq 0, \quad p_c^{ad} \geq 0, \\ n_c^{ps} \geq 0, \quad n_c^{pr} \geq 0, \quad n_c^{ad} \geq 0. \end{aligned}$$

The express company then chooses p_c^{hs} and p_c^{hr} to maximize its profit, taking into account the capacity-constrained response of the platform.

For Mode d, the express company constructs and operates the parcel locker platform by itself. Thus, it jointly determines platform delivery fees, home delivery fees, and the advertising fee. The capacity-constrained optimization problem is given by

$$\max_{p_d^{ps}, p_d^{pr}, p_d^{ad}, p_d^{hs}, p_d^{hr}} \Pi_d^p$$

Subject to

$$\begin{aligned} \tau_s n_d^{ps} + \tau_r n_d^{pr} &\leq K_d, \\ p_d^{ps} \geq 0, \quad p_d^{pr} \geq 0, \quad p_d^{ad} \geq 0, \quad p_d^{hs} \geq 0, \quad p_d^{hr} \geq 0, \\ n_d^{ps} \geq 0, \quad n_d^{pr} \geq 0, \quad n_d^{ad} \geq 0, \quad n_d^{hs} \geq 0, \quad n_d^{hr} \geq 0. \end{aligned}$$

The above constrained models are solved numerically because the capacity constraint changes the feasible region and may become binding under limited locker availability. To measure the degree of the capacity sufficiency ratio, we first calculate the unconstrained platform-capacity demand:

$$\widehat{K}_i = \tau_s n_i^{ps*} + \tau_r n_i^{pr*}, \quad i = c, d.$$

Then, the capacity sufficiency ratio is defined as

$$\rho_i = \frac{K_i}{\widehat{K}_i}.$$

When $\rho_i < 1$, parcel locker capacity is insufficient; when $\rho_i = 1$, capacity just satisfies the unconstrained optimal platform delivery demand; and when $\rho_i > 1$ capacity is sufficient. In the numerical analysis, we set $\tau_s = 1$ and $\tau_r = 2$ and vary ρ from 0.2 to 1.2 to simulate different levels of capacity shortage and sufficiency.

Based on the above capacity-constrained models, we conduct numerical simulations to examine how the capacity sufficiency ratio affects the express company's profit difference and platform delivery prices. The parameters follow Table A1, and the additional parame-

ters introduced in the capacity-constrained extension are reported in Table A2 in Appendix A. The results are summarized in Observations 4–6 and illustrated in Figures 13–15.

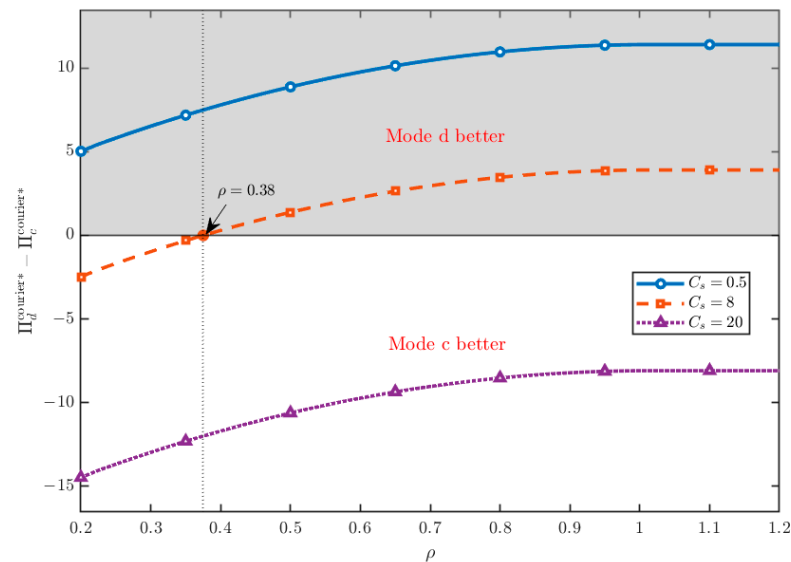


Figure 13. Effect of capacity sufficiency ratio on the express company's profit difference between Mode d and Mode c.

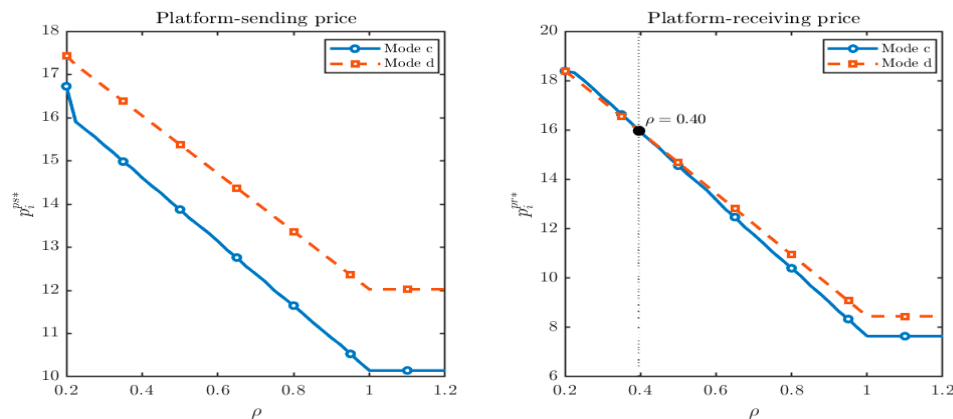


Figure 14. Effect of capacity sufficiency ratio on platform delivery fees.

Observation 4. The profit difference between Mode d and Mode c increases with the capacity sufficiency ratio. When the self-building cost is low, Mode d always outperforms Mode c. When the self-building cost is high, Mode c remains preferable. When the self-building cost is moderate, there exists a capacity threshold: Mode c performs better under insufficient capacity, whereas Mode d becomes superior once capacity is sufficiently high.

This result indicates that the capacity sufficiency ratio helps the express company realize the value of self-building. In Mode d, the express company can internalize platform delivery revenue and advertising traffic value, but these benefits cannot be fully captured when locker capacity is limited. As capacity becomes sufficient, more platform delivery demand can be served and monetized, strengthening Mode d's profit advantage. However, if the self-building cost is too high, the capacity improvement is still insufficient to offset the cost burden, so Mode c remains more profitable.

Observation 5. The platform delivery fees generally decrease as the capacity sufficiency ratio increases and then gradually stabilize when capacity becomes sufficient. This

pattern appears in both Modes c and d. In addition, the effect of the capacity sufficiency ratio differs between platform-sending and platform-receiving services. For platform-sending, Mode d charges a higher fee than Mode c in the examined range. For platform-receiving, the price difference between the two modes changes as the capacity sufficiency ratio increases.

The result suggests that limited locker capacity restricts the platform's ability to attract demand through lower prices. When capacity is insufficient, the platform or express company has less incentive to reduce fees because excessive demand cannot be fully served. As capacity becomes sufficient, the capacity constraint is relaxed, allowing lower prices to attract more platform users and advertising traffic. The receiving fee is more sensitive to capacity changes because receiving parcels usually occupy lockers for a longer time, making capacity availability more important for platform-receiving services.

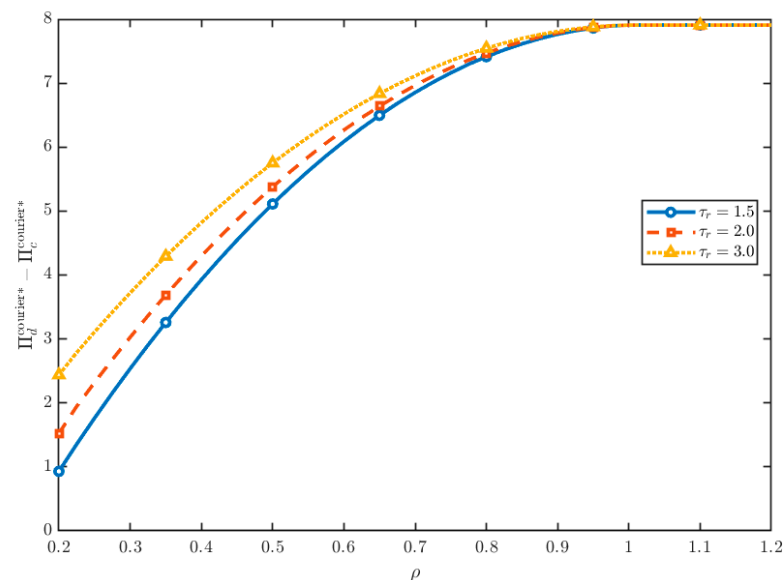


Figure 15. The impact of capacity occupation intensity and the capacity sufficiency ratio on the express company's profit difference under Mode d and Mode c.

Observation 6. For a given capacity occupation intensity, the profit difference between Mode d and Mode c increases with the increase in the capacity sufficiency ratio. For a given capacity sufficiency ratio, a higher capacity occupation intensity leads to a higher profit difference between Mode d and Mode c, especially when capacity is insufficient.

This result can be explained by two aspects. On the one hand, as capacity becomes more sufficient, the express company in Mode d can serve more platform delivery demand and better internalize platform delivery revenue and advertising traffic value, thereby improving its relative profitability. On the other hand, a larger capacity occupation intensity means that receiving parcels stay in lockers for a longer time and occupy more locker resources. This makes capacity allocation more important. Compared with Mode c, Mode d allows the express company to coordinate platform delivery pricing, home delivery pricing, and advertising revenue within the same system. Therefore, when capacity is tighter, the integrated decision-making advantage of Mode d becomes more valuable, leading to a larger profit difference. Overall, capacity occupation intensity affects the magnitude of the profit difference but does not change the main conclusion that a greater capacity sufficiency ratio strengthens the attractiveness of self-building.

7. Conclusions

This paper examines the operational strategies of express companies in the last-mile delivery market in the presence of parcel lockers and offers sound pricing and advertising suggestions for parcel locker operators from the perspective of platform economics. The main findings are summarized below.

First, the comparison between Modes a and b shows that, compared with offering home delivery only, an express company can gain higher profit by cooperating with a third-party parcel locker platform and providing both home and platform delivery. The comparison between Modes b and c indicates that cooperating with a platform that operates advertising brings greater benefits to the express company than cooperating with one that does not. The comparison between Modes c and d reveals that the decision to self-build a parcel locker platform depends on various factors, such as self-built and operating costs, customers' perceived convenience, waiting cost, service substitutability, customer-to-advertiser network externality, service area, and capacity sufficiency. The capacity-constrained extension further shows that sufficient locker capacity strengthens the relative attractiveness of self-building, especially when the self-built and operating cost is moderate and high.

Second, the comparison between Modes a and b demonstrates that the introduction of platform delivery leads the express company to charge higher home-sending and home-receiving fees than when no platform delivery exists. The comparison between Modes b and c suggests that both the express company and the parcel locker platform operating advertising can charge lower service fees to customers. Moreover, the advertising-induced price reduction is larger for platform delivery than for home delivery, and this effect is strengthened by customers' perceived convenience and customer-to-advertiser network externality. The comparison between Modes c and d further shows that the relative platform delivery fees depend on service type and key parameters. For platform-sending services, the self-built platform tends to charge higher fees; for platform-receiving services, the relative pricing relationship changes with perceived convenience, customer-to-advertiser network externality, and capacity sufficiency. This differential pricing strategy can improve the financial viability and operational adaptability of both third-party and self-built platforms in the competitive market.

Lastly, the express company's home-sending and home-receiving fees increase with its service coverage area, while the platform delivery fee charged to customers increases with customers' perceived convenience of using lockers and the advertising fee charged to advertisers increases with both perceived convenience and customer-to-advertiser network externality. In addition, stronger customer-to-advertiser network externality amplifies the advertising-induced reduction in platform delivery fees. As perceived convenience and customer-to-advertiser network externality increase, both express companies and platforms can achieve higher profits and strengthen the financial viability of parcel-locker-based delivery services. This finding also confirms the importance of the customer-to-advertiser network externality in platform delivery: more platform users can increase advertising value, while advertising revenue can support more flexible customer-side pricing. Under capacity constraints, higher capacity sufficiency increases the profit difference between Mode d and Mode c, while a higher capacity occupation intensity of platform-receiving demand further enlarges this profit difference, especially when capacity is insufficient.

This study provides the following managerial and operational insights for stakeholders in the last-mile delivery market to improve the financial viability and operational performance of parcel-locker-based delivery systems. For express companies, (1) pricing strategies should fully account for the service area covered by a given population; (2) home delivery fees can be raised to meet personalized and premium demands of such customers; (3) cooperation with parcel locker platforms can help satisfy more last-mile

delivery demand; and (4) if intending to self-build a platform, companies should reduce self-built and operating costs, while enhancing customers' perceived convenience of using lockers, lowering customers' waiting time, increasing the substitutability between platform services and home services, increasing the customer-to-advertiser network externality, and ensuring sufficient locker capacity and efficient locker turnover. For third-party parcel locker platforms, (1) improving perceived convenience, e.g., through convenient locations and elderly friendly interfaces, can strengthen the advantage of platform delivery; (2) lowering platform delivery fees can attract and retain more customers, which in turn draws more advertisers and boosts profit via customer traffic; and (3) raising advertising fees can compensate for the profit loss from lower delivery fees. Such a fee increase can serve as a screening mechanism for high-quality ads, leading to more ad views, higher conversion rates, and greater long-term profitability, thereby supporting the financial viability and stable operation of the platform ecosystem.

In summary, the above results and managerial insights provide important guidance for stakeholders in determining economically viable and operationally effective strategies in the last-mile delivery market and lay a theoretical foundation for the platform-based last-mile delivery industry. Nevertheless, this study has limitations and leaves room for future improvement. First, the model assumes that the sending/receiving fees charged by parcel locker platforms and express companies remain constant. In reality, these fees may vary across peak and off-peak periods, customer segments, and locker sizes. Future research may therefore examine dynamic or discriminatory pricing strategies under heterogeneous customer preferences. Second, this study assumes that advertising creates positive traffic value for advertisers without reducing customers' utility. Future research may consider advertising disutility, privacy concerns, or advertising fatigue to identify the boundary conditions of advertising-supported parcel locker platforms. Finally, although this paper discusses the potential environmental sustainability implications of adopting parcel lockers in the last-mile delivery market, future studies may explicitly include environmental-performance measures, such as carbon emissions, failed delivery rates, and locker electricity use, to examine whether and under what conditions the economic and operational advantages identified in this study translate into environmental improvements.

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Appendix A

Benchmark Parameter Settings for the Numerical Analysis

Table A1 reports the benchmark parameter values used in the numerical example that compares Mode a and Mode b, as well as in all subsequent numerical analyses.

Table A1. Benchmark parameter values.

Parameter	Symbol	Value
Customers' willingness to send or receive parcels (basic market size)	$\bar{v}$	20
Unit price of long-distance transportation	p^l	6
Unit transportation cost of the express company	C_e	2.5
Cost coefficient in the home delivery cost term	k	1.2
Scale parameter in the home delivery cost term	n	1
Service area of the express company	A	3.14
Marginal cost coefficient of the home delivery service per unit distance	C_0	0.94
Customers' perceived convenience of using parcel lockers	c	1.10
Customers' waiting cost in the home-receiving process	w	6
Improved waiting efficiency of platform delivery relative to home delivery	θ	0.60
Customers' cross-price sensitivity (substitutability)	a	0.40

The transportation-related parameters p^l and C_e are selected with reference to the operating scale and revenue characteristics of China's express delivery market, where the express sector handled 174.5 billion parcels and generated about 1.4 trillion yuan in revenue in 2024 [52]. The home delivery cost term $C_0 k \sqrt{nA} = 2$ is assumed in the benchmark case, reflecting the cost pressure of last-mile delivery, and is also consistent with the models in [53,54]. Under $k = 1.2$, $n = 1$, and $A = 3.14$, this setting yields $C_0 = 0.94$. The settings of parameters c , w , θ and a are supported by [27,30]. These values are not direct estimates from a single firm but standardized benchmark parameters constructed from industry and the prior literature. This setting is used consistently in the following numerical analyses.

Table A2. Additional parameter settings for the capacity-constrained extension.

Parameter	Symbol	Value
Capacity sufficiency ratio	ρ	[0.20,1.20]
Capacity occupation intensity of platform-sending demand	τ_s	1
Capacity occupation intensity of platform-receiving demand	τ_r	2
Robustness values of platform-receiving capacity occupation intensity	τ_r	1.5, 2.0, 3.0
Self-construction cost levels in the capacity analysis	C_s	0.5, 8, 20
Self-construction cost in the robustness analysis	C_s	4

Table A2 reports the additional parameter settings used in the capacity-constrained extension. The benchmark parameters not listed in this table follow Table A1. Since firm-level data on the capacity occupation intensity, turnover rate, and effective locker capacity are difficult to obtain, these capacity-related parameters are set as standardized scenario

parameters. Specifically, $\tau_s = 1$ is used as the normalized capacity occupation intensity of platform-sending demand, while $\tau_r = 2$ reflects that receiving parcels usually occupy locker cells for a longer time. The values $\tau_r = 1.5, 2.0$, and 3.0 are used for robustness checks. The range of ρ represents different levels of capacity shortage and sufficiency, and the values of C_s represent low, moderate, and high self-construction cost levels.

Proof of Non-negativity restrictions of equilibrium solutions. To guarantee the economic feasibility of the equilibrium solutions, the equilibrium service fees, advertising fees, customer demands, and advertiser-side demands should be non-negative. This appendix derives the corresponding non-negativity conditions for Modes a–d. For notational simplicity, define the following auxiliary terms: $H = C_0 k \sqrt{nA}$, $M_1 = p^l - C_e$, $M_2 = \bar{v} - 2p^l + ap^l + C_e + H$, $M_3 = c\bar{v} - p^l + ap^l$, $R = \bar{v} - p^l - w + ap^l$, $\Delta = 4 - a^2$. In Mode a, the equilibrium service fees and demands should satisfy $p_a^{hr*} \geq 0$, $p_a^{hs*} \geq 0$, $n_a^{hr*} \geq 0$ and $n_a^{hs*} \geq 0$. By substituting the equilibrium solutions in Lemma 1 into these non-negativity requirements, the non-negativity conditions for Mode a can be summarized as $\mathcal{F}_a = \{A_1 \geq 0, A_2 \geq 0\}$, where $A_1 = \bar{v} - 2p^l + C_e + H - w$, $A_2 = \bar{v} - C_e - H - w$. Thus, Mode a is economically feasible when the conditions in $\mathcal{F}_a$ hold. In Mode b, the equilibrium service fees and demands should be non-negative. Define $P^{pr} = a^2 M_1 + a(M_2 - w) + 2(M_3 - \theta w)$, $P^{ps} = a^2 M_1 + aM_2 + 2M_3$, $P^{hr} = 2aM_1 + 2(M_2 - w) + a(M_3 - \theta w)$, $P^{hs} = 2aM_1 + 2M_2 + aM_3$. By substituting the equilibrium solutions in Lemma 2 into the non-negativity requirements of prices and demands, the non-negativity conditions for Mode b can be summarized as $\mathcal{F}_b = \{B_1 \geq 0, B_2 \geq 0, B_3 \geq 0\}$, where $B_1 = P^{pr}$, $B_2 = P^{hr}$, $B_3 = \Delta R - P^{hr} + aP^{pr}$. Here, $B_1 \geq 0$, $B_2 \geq 0$ and $B_3 \geq 0$ respectively ensure the non-negativity of the retained equilibrium platform-receiving fee, home-receiving fee, and home-receiving demand in Mode b. Therefore, Mode b is economically feasible when the conditions in $\mathcal{F}_b$ hold. In Mode c, the equilibrium service fees, advertising fee, customer demands, and advertiser-side demand should be non-negative. In addition to the existence condition of Mode c, define $K_c = \bar{v}\Delta - \gamma^2(2 - a^2)$, $Q_c = 2a^2 M_1 + a(M_2 - w) + 2(M_3 - \theta w)$, $S_c^{pr} = K_c P^{pr} - \gamma^2 Q_c$, $S_c^{ps} = K_c P^{ps} - \gamma^2 Q_c$, $S_c^{hr} = 2K_c P^{hr} - a\gamma^2 Q_c$, $S_c^{hs} = 2K_c P^{hs} - a\gamma^2 Q_c$. By substituting the equilibrium solutions in Lemma 3 into the non-negativity requirements, the non-negativity conditions for Mode c can be summarized as $\mathcal{F}_c = \{C_1 \geq 0, C_2 \geq 0, C_3 \geq 0, C_4 \geq 0, C_5 \geq 0, C_6 \geq 0\}$, where $C_1 = S_c^{pr}$, $C_2 = S_c^{hr}$, $C_3 = \gamma Q_c$, $C_4 = 2\Delta K_c(M_3 - \theta w) - 2S_c^{pr} + aS_c^{hr}$, $C_5 = 2\Delta K_c R - S_c^{hr} + 2aS_c^{pr}$, $C_6 = \gamma[2\Delta K_c(2M_3 - \theta w) - 2(S_c^{pr} + S_c^{ps}) + a(S_c^{hr} + S_c^{hs}) - \bar{v}\Delta Q_c]$. Here, $C_1 \geq 0$, $C_2 \geq 0$, $C_3 \geq 0$, $C_4 \geq 0$, $C_5 \geq 0$, and $C_6 \geq 0$ correspond to the non-negativity requirements of p_c^{pr*} , p_c^{hr*} , p_c^{ad*} , n_c^{pr*} , n_c^{hr*} , and n_c^{ad*} , respectively. Therefore, Mode c is economically feasible when the conditions in $\mathcal{F}_c$ hold. In Mode d, the equilibrium service fees, advertising fee, customer demands, and advertiser-side demand should be non-negative. In addition to the existence condition of Mode d, define $K_d = 2\bar{v} - \gamma^2$, $L = 1 - a^2$, $Q_d = \frac{1}{2}(M_3 - \theta w) + M_1 - a(M_1 - H)$, $T_d^{pr} = a(M_2 - w) + a^2 M_1 + (M_3 - M_1 - \theta w) + a(M_1 - H)$, $T_d^{ps} = aM_2 + a^2 M_1 + (M_3 - M_1) + a(M_1 - H)$, $T_d^{hr} = M_2 - w + aM_1 + a(M_3 - M_1 - \theta w) + a^2(M_1 - H)$.

$T_d^{hs} = M_2 + aM_1 + a(M_3 - M_1) + a^2(M_1 - H)$, $S_d^{pr} = K_d T_d^{pr} - \gamma^2 L Q_d$, $S_d^{ps} = K_d T_d^{ps} - \gamma^2 L Q_d$.
 By substituting the equilibrium solutions in Lemma 4 into the non-negativity requirements, the non-negativity conditions for Mode d can be summarized as $\mathcal{F}_d = \{D_1 \geq 0, D_2 \geq 0, D_3 \geq 0, D_4 \geq 0, D_5 \geq 0, D_6 \geq 0\}$, where $D_1 = S_d^{pr}$, $D_2 = T_d^{hr}$, $D_3 = \gamma Q_d$,
 $D_4 = 2LK_d(M_3 - \theta w) - S_d^{pr} + aK_d T_d^{hr}$, $D_5 = 2LK_d R - K_d T_d^{hr} + aS_d^{pr}$,
 $D_6 = \gamma[2LK_d(2M_3 - \theta w) - (S_d^{pr} + S_d^{ps}) + aK_d(T_d^{hr} + T_d^{hs}) - 2\gamma L Q_d]$. Here, $D_1 \geq 0$, $D_2 \geq 0$,
 $D_3 \geq 0$, $D_4 \geq 0$, $D_5 \geq 0$, and $D_6 \geq 0$ correspond to the non-negativity requirements of p_d^{pr*} , p_d^{hr*} , p_d^{ad*} , n_d^{pr*} , n_d^{hr*} , and n_d^{ad*} , respectively. Therefore, Mode d is economically feasible when the conditions in $\mathcal{F}_d$ hold. $\square$

Proof of Lemma 1. In Mode a, we take the first-order derivative of the express company's profit function $\Pi_a^{courier}$ in Equation (3) with respect to p_a^{hr} and p_a^{hs} , and we have $\frac{\partial \Pi_a^{courier}}{\partial p_a^{hr}} = \frac{1}{v}(\bar{v} - 2p^l - 2p_a^{hr} - w + c_e + c_0 k \sqrt{nA})$, $\frac{\partial \Pi_a^{courier}}{\partial p_a^{hs}} = \frac{1}{v}(\bar{v} - 2p^l - 2p_a^{hs} - w + c_e + c_0 k \sqrt{nA})$. Next, we take the second-order derivative of the express company's profit function $\Pi_a^{courier}$ with respect to p_a^{hr} and p_a^{hs} , and we have $\frac{\partial^2 \Pi_a^{courier}}{\partial (p_a^{hr})^2} = -\frac{2}{v} < 0$, $\frac{\partial^2 \Pi_a^{courier}}{\partial (p_a^{hs})^2} = -\frac{2}{v} < 0$. Let $\frac{\partial \Pi_a^{courier}}{\partial p_a^{hr}} = 0$, $\frac{\partial \Pi_a^{courier}}{\partial p_a^{hs}} = 0$, and we have $p_a^{hr*} = \frac{\bar{v} - 2p^l + c_e + c_0 k \sqrt{nA} - w}{2}$, $p_a^{hs*} = \frac{\bar{v} - 2p^l + c_e + c_0 k \sqrt{nA}}{2}$. Since the determinant of the Hessian matrix with respect to p_a^{hr} and p_a^{hs} is negative, we can say that $\Pi_a^{courier}$ is a jointly concave function of p_a^{hr} and p_a^{hs} . Thus, $\Pi_a^{courier}(p_a^{hr}, p_a^{hs})$ is the unique global optimal solution for the express company when it determines its home delivery service fee. $\square$

Proof of Lemma 2. In Mode b, we take the first-order derivative of the platform's profit function Π_b^p in Equations (8) and (9) with respect to p_b^{ps} and p_b^{pr} , and we have $\frac{\partial \Pi_b^p}{\partial p_b^{ps}} = \frac{1}{v}(M_3 - 2p_b^{ps} + ap_b^{hs})$, $\frac{\partial \Pi_b^p}{\partial p_b^{pr}} = \frac{1}{v}[(M_3 - \theta w) - 2p_b^{pr} + ap_b^{hr}]$. We make $M_1 = p^l - c_e$, $M_2 = \bar{v} - 2p^l + ap^l + c_e + c_0 k \sqrt{nA}$, $M_3 = c\bar{v} - p^l + ap^l$. Next, we take the second-order derivative of the platform's profit function Π_b^p with respect to p_b^{ps} and p_b^{pr} , and we have $\frac{\partial^2 \Pi_b^p}{\partial (p_b^{ps})^2} = -\frac{2}{v} < 0$, $\frac{\partial^2 \Pi_b^p}{\partial (p_b^{pr})^2} = -\frac{2}{v} < 0$. Since the determinant of the Hessian matrix with respect to p_b^{pr} and p_b^{ps} is negative, we can say that Π_b^p is a jointly concave function of p_b^{pr} and p_b^{ps} . Thus, Π_b^p is the unique global optimal solution for the platform. Similarly, for express companies we have $\frac{\partial \Pi_b^{courier}}{\partial p_b^{hs}} = \frac{a}{v} M_1 + \frac{1}{v}(M_2 - 2p_b^{hs} + ap_b^{ps})$, $\frac{\partial \Pi_b^{courier}}{\partial p_b^{hr}} = \frac{a}{v} M_1 + \frac{1}{v}(M_2 - w - 2p_b^{hr} + ap_b^{pr})$. Next, we take the second-order derivative of the express company's profit function $\Pi_b^{courier}$ with respect to p_b^{hs} and p_b^{hr} , and we have $\frac{\partial^2 \Pi_b^{courier}}{\partial (p_b^{hs})^2} = -\frac{2}{v} < 0$, $\frac{\partial^2 \Pi_b^{courier}}{\partial (p_b^{hr})^2} = -\frac{2}{v} < 0$. Since the determinant of the Hessian matrix with respect to p_b^{hs} and p_b^{hr} is negative, we can say that $\Pi_b^{courier}$ is a jointly concave func-

tion of p_b^{hs} and p_b^{hr} . Thus, $\Pi_b^{courier}$ is the unique global optimal solution for the express company. We brought it into the solution, and Lemma 2 can be obtained. $\square$

Proof of the Lemma 3. In Mode c, we take the first-order derivative of the platform's profit function Π_c^p in Equations (11) and (12) with respect to p_c^{ps} and p_c^{pr} , and we

$$\text{have } \frac{\partial \Pi_c^p}{\partial p_c^{ps}} = \frac{1}{v} (M_3 - 2p_c^{ps} + ap_c^{hs}) - \gamma p_c^{ad},$$

$$\frac{\partial \Pi_c^p}{\partial p_c^{pr}} = \frac{1}{v} [(M_3 - \theta w) - 2p_c^{pr} + ap_c^{hr}] - \gamma p_c^{ad},$$

$$\frac{\partial \Pi_c^p}{\partial p_c^{ad}} = \frac{\gamma}{v} (2M_3 - \theta w - p_c^{pr} - p_c^{ps} + ap_c^{hr} + ap_c^{hs}) - 2p_c^{ad}.$$

Next, we take the second-order derivative of the platform's profit function Π_c^p with respect to p_c^{ps} , p_c^{pr} and p_c^{ad} ,

$$\text{and we have } \frac{\partial^2 \Pi_c^p}{\partial (p_c^{ps})^2} = -\frac{2}{v} < 0, \quad \frac{\partial^2 \Pi_c^p}{\partial (p_c^{pr})^2} = -\frac{2}{v} < 0, \quad \frac{\partial^2 \Pi_c^p}{\partial (p_c^{ad})^2} = -2 < 0.$$

Since the determinant of the Hessian matrix with respect to p_c^{ps} , p_c^{pr} and p_c^{ad} is negative, we can say that

when $\bar{v} > \frac{1}{2} \gamma^2$, Π_c^p is a jointly concave function of p_c^{ps} , p_c^{pr} and p_c^{ad} . Thus, Π_c^p

is the unique global optimal solution for the platform. Similarly, for express companies

$$\text{we have } \frac{\partial \Pi_c^{courier}}{\partial p_c^{hs}} = \frac{a}{v} M_1 + \frac{1}{v} (M_2 - 2p_c^{hs} + ap_c^{ps}), \quad \frac{\partial \Pi_c^{courier}}{\partial p_c^{hr}} = \frac{a}{v} M_1 + \frac{1}{v} (M_2 - w - 2p_c^{hr} + ap_c^{pr}).$$

Next, we take the second-order derivative of the express company's profit function

$$\Pi_c^{courier} \text{ with respect to } p_c^{hs} \text{ and } p_c^{hr}, \text{ and we have } \frac{\partial^2 \Pi_c^{courier}}{\partial (p_c^{hs})^2} = -\frac{2}{v} < 0, \quad \frac{\partial^2 \Pi_c^{courier}}{\partial (p_c^{hr})^2} = -\frac{2}{v} < 0.$$

Since the determinant of the Hessian matrix with respect to p_c^{hs} and p_c^{hr} is negative,

we can say that $\Pi_c^{courier}$ is a jointly concave function of p_c^{hs} and p_c^{hr} . Thus, $\Pi_c^{courier}$

is the unique global optimal solution for the express company. We brought it into the solution, and Lemma 3 can be obtained. $\square$

Proof of the Lemma 4. In Mode d, we take the first-order derivative of the express company's profit function $\Pi_d^{courier}$ in Equation (13) with respect to p_d^{ps} , p_d^{pr} , p_d^{hs} , p_d^{hr} ,

$$p_d^{ad}, \quad \text{and we have } \frac{\partial \Pi_d^{courier}}{\partial p_d^{ps}} = \frac{a}{v} (M_1 + p_d^{ps}) + \frac{1}{v} (M_2 - 2p_d^{ps} + ap_d^{hs}) + \frac{\alpha \gamma}{v} p_d^{ad},$$

$$\frac{\partial \Pi_d^{courier}}{\partial p_d^{pr}} = \frac{a}{v} (M_1 + p_d^{pr}) + \frac{1}{v} (M_2 - w - 2p_d^{pr} + ap_d^{hr}) + \frac{\alpha \gamma}{v} p_d^{ad}, \quad \frac{\partial \Pi_d^{courier}}{\partial p_d^{hs}} = \frac{1}{v} (M_3 - M_1 - 2p_d^{hs} + ap_d^{ps}) + \frac{a}{v} (M_1 + p_d^{hs} - c_b k \sqrt{nA}) - \frac{\gamma}{v} p_d^{ad},$$

$$\frac{\partial \Pi_d^{courier}}{\partial p_d^{hr}} = \frac{1}{v} (M_3 - M_1 - \theta w - 2p_d^{hr} + ap_d^{pr}) + \frac{a}{v} (M_1 + p_d^{hr} - c_b k \sqrt{nA}) - \frac{\gamma}{v} p_d^{ad},$$

$$\frac{\partial \Pi_d^{courier}}{\partial p_d^{ad}} = \frac{\gamma}{v} (2M_3 - \theta w - p_d^{ps} - p_d^{pr} + ap_d^{hr} + ap_d^{hs}) - 2p_d^{ad}.$$

Next, we take the second-order derivative of the express company's profit function $\Pi_d^{courier}$ with respect to p_d^{ps} , p_d^{pr} , p_d^{hs} ,

$$p_d^{hr}, \quad p_d^{ad}, \quad \text{and we have } \frac{\partial^2 \Pi_d^{courier}}{\partial (p_d^{ps})^2} = -\frac{2}{v} < 0, \quad \frac{\partial^2 \Pi_d^{courier}}{\partial (p_d^{pr})^2} = -\frac{2}{v} < 0, \quad \frac{\partial^2 \Pi_d^{courier}}{\partial (p_d^{hs})^2} = -\frac{2}{v} < 0,$$

$$\frac{\partial^2 \Pi_d^{courier}}{\partial (p_d^{hr})^2} = -\frac{2}{v} < 0, \quad \frac{\partial^2 \Pi_d^{courier}}{\partial (p_d^{ad})^2} = -2 < 0.$$

Since the determinant of the Hessian matrix with respect to p_d^{ps} , p_d^{pr} , p_d^{hs} , p_d^{hr} , p_d^{ad} is negative, we can say that when $\bar{v} > \frac{1}{4} \gamma^2$,

$\Pi_d^{courier}$ is a jointly concave function of p_d^{ps} , p_d^{pr} , p_d^{hs} , p_d^{hr} , p_d^{ad} . Thus, $\Pi_d^{courier}$ is the unique global optimal solution for the express company. We brought it into the solution, and Lemma 4 can be obtained. $\square$

Proof of Corollary 1. (i) According to Lemmas 1, 2, 3, and 4, we have $\frac{\partial p_a^{hr*}}{\partial A} = \frac{1}{4}c_0k\sqrt{\frac{n}{A}} > 0$,

$$\frac{\partial p_b^{hr*}}{\partial A} = \frac{1}{2(4-a^2)}c_0k\sqrt{\frac{n}{A}} > 0, \quad \frac{\partial p_c^{hr*}}{\partial A} = \frac{1}{2(4-a^2)}\left[\frac{2\bar{v}(4-a^2)-2\gamma^2\left(2-\frac{1}{2}a^2\right)}{2\bar{v}(4-a^2)-2\gamma^2(2-a^2)}\right]c_0k\sqrt{\frac{n}{A}} > 0, \quad \frac{\partial p_d^{hr*}}{\partial A} = \frac{a}{8(1-a^2)}c_0k\sqrt{\frac{n}{A}} > 0.$$

(ii) According to Lemma 1, Lemma 2, Lemma 3, and Lemma 4, we have

$$\frac{\partial p_a^{hs*}}{\partial A} = \frac{1}{4}c_0k\sqrt{\frac{n}{A}} > 0, \quad \frac{\partial p_b^{hs*}}{\partial A} = \frac{1}{2(4-a^2)}c_0k\sqrt{\frac{n}{A}} > 0, \quad \frac{\partial p_c^{hs*}}{\partial A} = \frac{1}{2(4-a^2)}\left[\frac{2\bar{v}(4-a^2)-2\gamma^2\left(2-\frac{1}{2}a^2\right)}{2\bar{v}(4-a^2)-2\gamma^2(2-a^2)}\right]c_0k\sqrt{\frac{n}{A}} > 0, \\ \frac{\partial p_d^{hs*}}{\partial A} = \frac{a}{8(1-a^2)}c_0k\sqrt{\frac{n}{A}} > 0. \quad \square$$

Proof of Corollary 2. For platform fees, according to Lemmas 1, 2, 3, and 4, we have

$$\frac{\partial p_b^{ps*}}{\partial c} = \frac{2\bar{v}}{4-a^2} > 0, \quad \frac{\partial p_b^{pr*}}{\partial c} = \frac{2\bar{v}}{4-a^2} > 0, \quad \frac{\partial p_c^{ps*}}{\partial c} = \frac{2\bar{v}}{4-a^2}\left[\frac{2\bar{v}(4-a^2)-2\gamma^2(3-a^2)}{2\bar{v}(4-a^2)-2\gamma^2(2-a^2)}\right] > 0, \\ \frac{\partial p_c^{pr*}}{\partial c} = \frac{2\bar{v}}{4-a^2}\left[\frac{2\bar{v}(4-a^2)-2\gamma^2(3-a^2)}{2\bar{v}(4-a^2)-2\gamma^2(2-a^2)}\right] > 0, \quad \frac{\partial p_d^{ps*}}{\partial c} = \frac{\bar{v}}{2}\left[\frac{1}{1-a^2} - \frac{\gamma^2}{2(2\bar{v}-\gamma^2)}\right]; \text{ when } \bar{v} > \frac{\gamma^2(3-a^2)}{4}, \text{ we} \\ \text{have } \frac{\partial p_d^{ps*}}{\partial c} > 0. \text{ Similarly, it can be concluded that } \frac{\partial p_d^{pr*}}{\partial c} > 0. \quad \square$$

Proof of Corollary 3. For advertising fees, according to Lemmas 3 and 4, we have (i)

$$\frac{\partial p_c^{ad*}}{\partial c} = \frac{2\gamma\bar{v}}{2\bar{v}(4-a^2)-2\gamma^2(2-a^2)} > 0, \quad \frac{\partial p_d^{ad*}}{\partial c} = \frac{\gamma\bar{v}}{2(2\bar{v}-\gamma^2)} > 0; \quad \text{(ii)} \\ \frac{\partial p_c^{ad*}}{\partial \gamma} = \frac{[2a^2M_1 + a(2M_2 - w) + 2(M_3 - \theta w)][2\bar{v}(4-a^2) + 2\gamma^2(2-a^2)]}{[2\bar{v}(4-a^2) - 2\gamma^2(2-a^2)]^2} > 0; \\ \frac{\partial p_d^{ad*}}{\partial \gamma} = \frac{2\bar{v} + \gamma^2}{(2\bar{v} - \gamma^2)^2}\left[\frac{1}{2}(M_3 - \theta w) + M_1 - a(M_1 - c_0k\sqrt{nA})\right] > 0. \quad \square$$

Proof of Proposition 1. According to Lemmas 1 and 2, we have

$$p_b^{hr*} - p_a^{hr*} = \frac{1}{2(4-a^2)}[4aM_1 + 4ap^l + a^2(\bar{v} - 2p^l + c_e + c_0k\sqrt{nA} - w) + 2a(M_3 - \theta w)] > 0, \\ p_b^{hs*} - p_a^{hs*} = \frac{1}{2(4-a^2)}[4aM_1 + 4ap^l + a^2(\bar{v} - 2p^l + c_e + c_0k\sqrt{nA}) + a^2M_2 + 2aM_3] > 0,$$

so we have $p_b^{hr*} > p_a^{hr*}$, $p_b^{hs*} > p_a^{hs*}$. $\square$

Proof of Proposition 2. Bringing $p_a^{hr*} = \frac{\bar{v} - 2p^l + c_e + c_0k\sqrt{nA} - w}{2}$ and

$$p_a^{hs*} = \frac{\bar{v} - 2p^l + c_e + c_0k\sqrt{nA}}{2} \text{ into the demand function } n_a^{hr} = \frac{\bar{v} - (p^l + p_a^{hr}) - w}{\bar{v}},$$

$n_a^{hs} = \frac{\bar{v} - (p^l + p_a^{hs})}{\bar{v}}$, we have $n_a^{hr} = \frac{1}{2} \frac{(\bar{v} - w - c_e - c_0 k \sqrt{nA})}{\bar{v}}$, $n_a^{hs} = \frac{1}{2} \frac{(\bar{v} - c_e - c_0 k \sqrt{nA})}{\bar{v}}$. Bring-
 ing $p_b^{ps*} = \frac{a^2 M_1 + a M_2 + 2 M_3}{4 - a^2}$, $p_b^{ps*} = \frac{a^2 M_1 + a(M_2 - w) + 2(M_3 - \theta w)}{4 - a^2}$, $p_b^{hr*} = \frac{2a M_1 + 2(M_2 - w) + a(M_3 - \theta w)}{4 - a^2}$
 and $p_b^{hs*} = \frac{2a M_1 + 2 M_2 + a M_3}{4 - a^2}$ into $n_b^{pr} = \frac{c\bar{v} - (p^l + p_b^{pr}) - \theta w + a(p^l + p_b^{hr})}{\bar{v}}$,
 $n_b^{hr} = \frac{\bar{v} - (p^l + p_b^{hr}) - w + a(p^l + p_b^{pr})}{\bar{v}}$, $n_b^{ps} = \frac{c\bar{v} - (p^l + p_b^{ps}) + a(p^l + p_b^{hs})}{\bar{v}}$,
 $n_b^{hs} = \frac{\bar{v} - (p^l + p_b^{hs}) + a(p^l + p_b^{ps})}{\bar{v}}$, we have
 $n_b^{hr} + n_b^{pr} = \frac{1}{\bar{v}} \left\{ \bar{v} - p^l + a p^l - w + (M_3 - \theta w) + \frac{1}{4 - a^2} \left[a(a - 2 + a^2) M_1 + (a - 2 + a^2)(M_2 - w) + (a - 2 + a^2)(M_3 - \theta w) \right] \right\}$
 $(n_b^{hr} + n_b^{pr}) - n_a^{hr} = \frac{1}{\bar{v}(4 - a^2)} \left[a \left(a + \frac{a^2}{2} \right) p^l + a(1 - a)(2 + a)c_e + \left(a + \frac{a^2}{2} \right) (M_2 - w) + (2 + a)(M_3 - \theta w) \right] > 0$.
 So, we have $n_b^{hr} + n_b^{pr} > n_a^{hr}$. Similarly, we have
 $(n_b^{hs} + n_b^{ps}) - n_a^{hs} = \frac{1}{\bar{v}(4 - a^2)} \left[a \left(a + \frac{a^2}{2} \right) p^l + a(1 - a)(2 + a)c_e + \left(a + \frac{a^2}{2} \right) M_2 + (2 + a)M_3 \right] > 0$, so we
 have $(n_b^{hs} + n_b^{ps}) > n_a^{hs}$. $\square$

Proof of Proposition 3. According to Lemma 3 and Lemma 4, we have

$$\begin{aligned}
 p_b^{ps*} - p_c^{ps*} &= \frac{2\gamma^2 [2a^2 M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\gamma^2(2 - a^2)]} > 0, & p_b^{pr*} - p_c^{pr*} &= \frac{2\gamma^2 [2a^2 M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\gamma^2(2 - a^2)]} > 0, \\
 p_b^{hs*} - p_c^{hs*} &= \frac{a\gamma^2 [2a^2 M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\gamma^2(2 - a^2)]} > 0, & p_b^{hr*} - p_c^{hr*} &= \frac{a\gamma^2 [2a^2 M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\gamma^2(2 - a^2)]} > 0.
 \end{aligned}$$

$\square$

Proof of Proposition 4. According to Proposition 5, we have

$$\begin{aligned}
 \Delta_{bc}^{ps} &= p_c^{ps*} - p_b^{ps*} = p_c^{pr*} - p_b^{pr*} = \frac{2\gamma^2 [2a^2 M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\gamma^2(2 - a^2)]} > 0, \\
 \Delta_{bc}^{hs} &= p_c^{hs*} - p_b^{hs*} = p_c^{hr*} - p_b^{hr*} = \frac{a\gamma^2 [2a^2 M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\gamma^2(2 - a^2)]} > 0, \\
 \Delta_{bc}^{ps} - \Delta_{bc}^{hs} &= \frac{\gamma^2(2 - a) [2a^2 M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\gamma^2(2 - a^2)]} > 0.
 \end{aligned}$$

(ii) According to Proposition 6(i), we have

$$\frac{\partial \Delta_{bc}^{ps}}{\partial c} = \frac{4\gamma^2 \bar{v}}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\gamma^2(2 - a^2)]} > 0, \quad \frac{\partial \Delta_{bc}^{hs}}{\partial c} = \frac{2a\gamma^2 \bar{v}}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\gamma^2(2 - a^2)]} > 0.$$

(iii) According to Proposition 6(i), we have

$$\begin{aligned}
 \frac{\partial \Delta_{bc}^{ps}}{\partial \gamma} &= \frac{8\gamma \bar{v} (4 - a^2) [2a^2 M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\alpha\gamma^2(2 - a^2)]^2} > 0, \\
 \frac{\partial \Delta_{bc}^{hs}}{\partial \gamma} &= \frac{4a\gamma \bar{v} (4 - a^2) [2a^2 M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{(4 - a^2) [2\bar{v}(4 - a^2) - 2\alpha\gamma^2(2 - a^2)]^2} > 0. \quad \square
 \end{aligned}$$

Proof of Proposition 5. (i) According to Lemmas 2 and 3, by subtracting the n_c^{ps*} and

n_c^{pr*} , we have $n_c^{ps*} - n_b^{ps*} = \frac{\gamma^2(2-a^2)[2a^2M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{\bar{v}(4-a^2)[2\bar{v}(4-a^2) - 2\gamma^2(2-a^2)]} > 0$; similarly, we

have $n_c^{pr*} - n_b^{pr*} = \frac{\gamma^2(2-a^2)[2a^2M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{\bar{v}(4-a^2)[2\bar{v}(4-a^2) - 2\gamma^2(2-a^2)]} > 0$.

(ii) According to Lemmas 2 and 3, by subtracting the Π_c^p and Π_b^p , we have $\Pi_c^p(p_c^{ps}, p_c^{pr}, p_c^{ad}) - \Pi_b^p(p_b^{ps}, p_b^{pr}) = (p_c^{ps} \cdot n_c^{ps} + p_c^{pr} \cdot n_c^{pr} + p_c^{ad} \cdot n_c^{ad} - C) - (p_b^{ps} \cdot n_b^{ps} + p_b^{pr} \cdot n_b^{pr} - C)$

$$= \left\{ 4a^2\gamma(2-a^2) - 2a^2\gamma \frac{2\gamma^2(2-a^2) + (4-a^2)}{(4-a^2)[2\bar{v}(4-a^2) - 2\gamma^2(2-a^2)]} \right\} M_1 + \left\{ 2a\gamma(2-a^2) - a\gamma \frac{2\gamma^2(2-a^2) + (4-a^2)}{(4-a^2)[2\bar{v}(4-a^2) - 2\gamma^2(2-a^2)]} \right\} (2M_2 - w) + \left\{ \frac{a^2\gamma}{4-a^2} + a^2\gamma(2-a^2) - \gamma \frac{2\gamma^2(2-a^2) + (4-a^2)}{(4-a^2)[2\bar{v}(4-a^2) - 2\gamma^2(2-a^2)]} \right\} (2M_3 - \theta w) + 2\gamma \frac{2\gamma^2(2-a^2) + (4-a^2)}{(4-a^2)[2\bar{v}(4-a^2) - 2\gamma^2(2-a^2)]} \theta w$$

So, we have $\Pi_c^p(p_c^{ps}, p_c^{pr}, p_c^{ad}) > \Pi_b^p(p_b^{ps}, p_b^{pr})$. $\square$

Proof of Proposition 6. (i) According to Lemmas 2 and 3, by subtracting the n_c^{hs*} and

n_c^{hr*} , we have $n_c^{hs*} - n_b^{hs*} = -\frac{a\gamma^2[2a^2M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{\bar{v}(4-a^2)[2\bar{v}(4-a^2) - 2\gamma^2(2-a^2)]} < 0$;

similarly, we have $n_c^{hr*} - n_b^{hr*} = -\frac{a\gamma^2[2a^2M_1 + a(2M_2 - w) + 2(M_3 - \theta w)]}{\bar{v}(4-a^2)[2\bar{v}(4-a^2) - 2\gamma^2(2-a^2)]} < 0$.

(ii) According to Propositions 3 and 5, we have $p_c^{hs*} < p_b^{hs*}$, $p_c^{hr*} < p_b^{hr*}$, $n_c^{hs*} < n_b^{hs*}$, $n_c^{hr*} < n_b^{hr*}$. Comparing the express company's profit from home delivery services in Mode b and Mode c, we have $\Pi_c^{courier(h)}(p_c^{hs}, p_c^{hr}) < \Pi_b^{courier(h)}(p_b^{hs}, p_b^{hr})$.

(iii) Comparing the profit that the express company makes from long-distance shipments of home delivery services in Mode b and Mode c, we have $\Pi_b^{courier(h+l)}(p_b^{hs}, p_b^{hr}) = (p^l - c_e)(n_b^{hs} + n_b^{hr})$, $\Pi_c^{courier(h+l)}(p_c^{hs}, p_c^{hr}) = (p^l - c_e)(n_c^{hs} + n_c^{hr})$; so, we have $\Pi_c^{courier(h+l)}(p_c^{hs}, p_c^{hr}) < \Pi_b^{courier(h+l)}(p_b^{hs}, p_b^{hr})$.

(iv) Comparing the profit that the express company makes from long-distance shipments of platform delivery services in Mode b and Mode c, we have $\Pi_b^{courier(pl)} = (p^l - c_e)(n_b^{ps} + n_b^{pr})$, $\Pi_c^{courier(pl)} = (p^l - c_e)(n_c^{ps} + n_c^{pr})$; according to Proposition 6 $n_c^{ps*} > n_b^{ps*}$, $n_c^{pr*} > n_b^{pr*}$, so we have $\Pi_c^{courier(pl)}(p_c^{ps}, p_c^{pr}) > \Pi_b^{courier(pl)}(p_b^{ps}, p_b^{pr})$. $\square$

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