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Crowd-shipping as a Service: Game-based Operating Strategy Design and Analysis

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Abstract

Crowd-shipping as a Service (CSaaS), a novel concept proposed in this study for the Online-to-Offline (O2O) market, integrates different kinds of shipping services provided by individuals and public transport (PT) operators and enables booking and payment through a single CSaaS platform. It largely increases the shipping capacities and provides a flexible shipping mode for consignees with parcel delivery requests. Focusing on the role of the CSaaS platform, we design the commission-based and integrator-based operating strategies in the presence of CSaaS, where the CSaaS platform acts as an intermediary and a reseller, respectively. To explicitly depict the interactive relations among O2O players, i.e., the CSaaS platform, the individual-based crowd-shipping (I-CS) platform, the PT operator, the conventional logistics (CL) platform, and consignees, we adopt a game-theoretic approach to formulate the business models with and without CSaaS and derive the optimal behaviors of these players, i.e., the price decisions of platforms/operators and the choice decisions of consignees regarding which shipping mode (i.e., the I-CS, CSaaS, and CL modes) to choose. Analytical results show that the commission-based operating strategy outperforms the integrator-based strategy with a larger CSaaS platform's profit. In addition, the impact of CSaaS on O2O players is also identified by comparing the results of two business models, which is found to be closely related to the urban structure regarding PT accessibility. Managerial implications concerning launching the CSaaS service are proposed at last.

Keywords: crowd-shipping as a service; individual-based crowd-shipping; public transport-based crowd-shipping; game-theoretic analysis; commission-based operating strategy; integrator-based operating strategy

1. Introduction

Crowd-shipping (CS), an emerging urban logistics solution outsourcing shipping tasks to non-professionals from the crowd or public transport operators with spare capacities, plays a vital role in delivering small parcels with the booming of e-commerce (Le et al., 2019; Pourrahmani and Jaller, 2021). Innovations brought by digitalization and new technologies have enabled CS services to be implemented in recent years (Ahamed et al., 2021). Current online CS platforms, such as PiggyBee, Shopopop, and FlashEx, mainly provide individual-based CS (I-CS) service by recruiting self-equipped shippers using bikes, motorcycles, scooters, ride-hailing cars, etc. from the crowd (Punel and Stathopoulos, 2017). The wide adoption of public transport-based CS (PT-CS) service, relying on the stabilized and large shipping capacities provided by metro, light rails, buses, etc., however, was hindered by segmental shipping and parcel transfer obstacles (Gatta et al., 2019). PT vehicles are only available on scheduled routes and normally cannot access the origins and destinations (e.g., the warehouse/retailing shops and the residential buildings in the Online-to-Offline (O2O) market). Meanwhile, there is a lack of responsible laborers who are in charge of transferring parcels at stations from other shipping modes to the PT mode and vice versa. Facing the fast-rising small parcel delivery demands in the O2O market, one important solution direction, potentially contributing to providing flexible shipping options and increasing shipping capacities, is the integration of I-CS and PT-CS services.

In this study, we explore the potential integration of I-CS and PT-CS services under the Crowd-shipping as a Service (CSaaS) environment. CSaaS is a user-oriented service concept providing door-to-door shipping solutions for consignees with parcel delivery requests. It integrates the services of multiple providers with different kinds of shipping equipment owned by individuals and PT operators and enables booking and payment through a single CSaaS platform. Compared with the existing pure I-CS and CL services (Savelsbergh and van Woensel, 2016), the CSaaS service largely increases the shipping capacities, where the individual-based shippers are responsible for pick-up and last-leg deliveries while the PT-based shippers are in charge of deliveries among stations. As the operator of the CSaaS service, the CSaaS platform is supposed to target a profitable operating strategy. Therefore, how to design operating strategies and choose the profitable one becomes one of the pressing issues to be tackled by the CSaaS platform. Besides, it is also worthwhile to explore the impact of the newly introduced CSaaS on the existing O2O market, including each player's optimal choice, each shipping mode's market share, and each operator's profit.

1.1. Literature review

Recently, many studies have investigated I-CS and PT-CS services separately. The studies considering the integration of both, however, are still lacking. One line of research in the literature focused on the I-CS service provided by individuals, including the matching between shippers and consignees (Allahviranloo and Baghestani, 2019), vehicle routing optimization (Dayarian and Savelsbergh, 2020; Wang et al., 2023), service acceptance analysis (Wicaksono et al., 2021), etc. To further increase the shipping capacities with more alternative modes, another line of research focused on the PT-CS service provided by PT operators, including the PT-CS preferences (Gatta et al., 2019; Fessler et al., 2022) and the impact of the PT-CS service on congestions (Galkin et al., 2021) and environments (Oliveira et al., 2022). Nevertheless, these I-CS studies optimized the service typically at an operational planning level, while these PT-CS studies assessed the service typically at an empirical level. Few studies, to the best of our knowledge, have investigated CS with both two services at the strategic level.

From the operations management perspective, the players in the logistics market are selfish and concerned with how to increase their own interests. This warrants an in-depth exploration and a good understanding of complex interactions among different players in the market as well as their optimal behaviors. So far, only a few studies have investigated the logistics market from this angle. For example, Xu et al. (2015) addressed the B2B e-commerce logistics problem by considering the relationships among the e-commerce platform, third-party logistics providers, sellers, and consignees. This study, however, was not focused on the peer-to-peer CS services within the intra-city scope. Focusing on grocery deliveries, Kung and Zhong (2017) proposed three pricing strategies and compared them based on the profitable target, where the interactions among a monopolistic platform, consignees, and shippers are involved. The shipping mode considered in this work was a single I-CS mode, which overlooked other alternatives such as CL and PT-CS modes. Xiao et al. (2022a, 2022b) further investigated the relationship between the I-CS and CL modes but the PT-CS mode is not included. The players are thus limited to only the I-CS platform, the CL platform, and consignees. As a result, these works cannot delineate the competition among different kinds of available modes as well as the related participants' optimal behaviors. Very recently, Ma et al. (2022) proposed a game-theoretic model for the metro-integrated city logistics system that utilized the spare capacity of metros to deliver parcels. They designed two models of non-cooperative and cooperative games regarding the relationship between the metro company and the CL platform. Nevertheless, the consignees in this work had no shipping mode choices but can only place orders through the CL platform who was in charge of assigning pracels between the CL and PT-CS modes faced by the fee set by the metro company.

Inspired by these studies, it becomes necessary to investigate the integration of different CS services in the face of competition among pure I-CS and CL services. In this circumstance, new challenges will emerge in the field of business innovations and operating strategies for running the market, which has turned out to be key problems to be tackled in related markets such as Mobility-as-a-Service (Polydoropoulou et al., 2020; van den Berg et al., 2022).

1.2. *Objective and contributions*

To bridge the above gaps, this study explores the operations management of the O2O shipping market with both the novel CSaaS service and the original I-CS and CL services. CSaaS integrates all kinds of available shipping equipment owned by individuals and PT operators, which provides an alternative shipping mode and largely increases the shipping capacities. The CSaaS platform, the I-CS platform, the PT operator, the CL platform, and consignees are included in the market. Among these players, the CSaaS platform plays a vital role in connecting consignees and two CS service providers (i.e., the I-CS platform and the PT operator). We then design two operating strategies, namely, the commission-based and the integrator-based strategies, based on the CSaaS platform's role as an intermediary and a reseller, respectively. For comparison, we propose a game-theoretic approach to formulate two business models with and without CSaaS, where the two operating strategies are incorporated into the business model with CSaaS. The business models explicitly depict the interactive relations among players. Equilibrium results with respect to each player's optimal behaviors, i.e., the price decisions and profits of the platforms/operators and the choice decisions of consignees, are derived from the models. Based on these results, the choice of the operating strategy targeting profit enhancement and the impact of CSaaS on the players is analytically explored. A case study is further conducted to verify these findings and to derive managerial insights. The contributions of this study are fourfold:

- First, we propose a novel concept of CSaaS to integrate the I-CS and PT-CS services for alternative shipping options and large shipping capacities in the O2O market. CSaaS integrates services of multiple service providers with different kinds of equipment owned by individuals (e.g., bikes, motorcycles, and ride-hailing cars)and PT operators (e.g., metro, light rails, and buses), enabling booking and payment through a single CSaaS platform.
- Second, we design the commission-based and integrator-based operating strategies in the presence of CSaaS. The CSaaS platform acts as an intermediary and benefits from a certain proportion of the cooperator's profit in the commission-based strategy, while acts as a reseller and benefits from the difference between fees charged from consignees and costs to purchase two CS services in the integrator-based strategy.
- Third, we adopt a game-theoretic approach to formulate the interactions among multiple players for the two business models with and without CSaaS. Equilibrium results concerning each player's interdependent optimal selfish behaviors of each business model (with and without CSaaS) and each operating strategy (the commission-based and the integrator-based strategies) can be derived from the models.
- Fourth, we reveal the analytical results regarding the choice of operating strategy and the impact of CSaaS on O2O players. Comparing the equilibrium results of two operating strategies and two business models, the profitable operating strategy in the presence of CSaaS is identified as the commission-based strategy, and the impact of CSaaS on O2O players is found to be closely related to urban structure regarding PT accessibility.

The remainder of this study is organized as follows. Section 2 presents the assumptions and problem descriptions. The business models with and without CSaaS for the O2O market are formulated in Section 3. Specifically, the commission-based and integrator-based operating strategies in the presence of CSaaS are designed in this section. Analytical discussions regarding the choice of CSaaS operating strategy and the impact of CSaaS on O2O players are presented in Section 4. Section 5 elaborates on a case study as well as policy implications. Conclusions and future research directions are presented in Section 6.

2. Assumptions and Problem Descriptions

2.1. Three shipping modes

To better focus on high-level CS development at the strategic level, we simplify the operational level aspects such as a single shipping line, linear service fee regarding the shipping distance, ignorance of service time and uncertainty demands. Some of the assumptions are at the micro-level and will not affect the macro-level results, while other assumptions will have a predictable influence on the macro-level results that will be discussed in Section 6. In this study, we consider an O2O shipping market with a specific OD pair from a warehouse/retailing area A to a residential area B. The consignees can shop online and place shipping orders for door-to-door on-demand deliveries. Focusing on small parcels, e.g, groceries and daily necessities, in the intra-city scope, the consignees have three shipping modes to choose from, namely, the I-CS, CSaaS, and CL modes, which are illustrated in Figure 1. In particular, the I-CS and CL modes are the current two shipping modes that involve three players of the I-CS platform, the CL platform, and consignees, while the CSaaS mode is a promising mode that involves two extra players of the PT operator and the CSaaS platform. All these players' strategies will be formulated in the proposed models in Section 3. For simplicity, we assume that CS shippers and PT vehicles on the supply side are sufficient to deliver the parcels, which corresponds to real-world cases since the current CS demands are not such large. We thus do not consider the strategies of the shippers on the supply side in this study. The three shipping modes will be first demonstrated as follows:

(i) The I-CS mode

The I-CS platform, without dedicated fleets and full-time employees, is in charge of operating this mode, which accepts orders from consignees and recruits nearby self-equipped shippers with any available types of shipping equipment (e.g., bikes, motorcycles, scooters, and ride-hailing cars) to deliver parcels from A to B.

(ii) The CSaaS mode

This mode makes it possible to utilize PT vehicles (e.g., metro, light rail, and bus) to deliver parcels. Considering that PT vehicles cannot access the original warehouse/retailing shop A and the final destination B, the PT service is only effective for the backbone chain from the stations C to D. The pick-up chain from A to C and the last-leg delivery chain from D to B rely on the I-CS service. In other words, this shipping mode can be regarded as a hybrid mode with both I-CS and PT-CS services. In particular, this mode is targeted for long-distance deliveries that PT vehicles can be utilized. Those deliveries with short shipping distances can be satisfied by the other two modes.

(iii) The CL mode

The CL platform, with a stable fleet and shipping schedule, is responsible for delivering parcels requested by consignees who choose the CL service. The dedicated fleets of the CL platform will be utilized to pick up parcels at A and ship them to the final destination B.

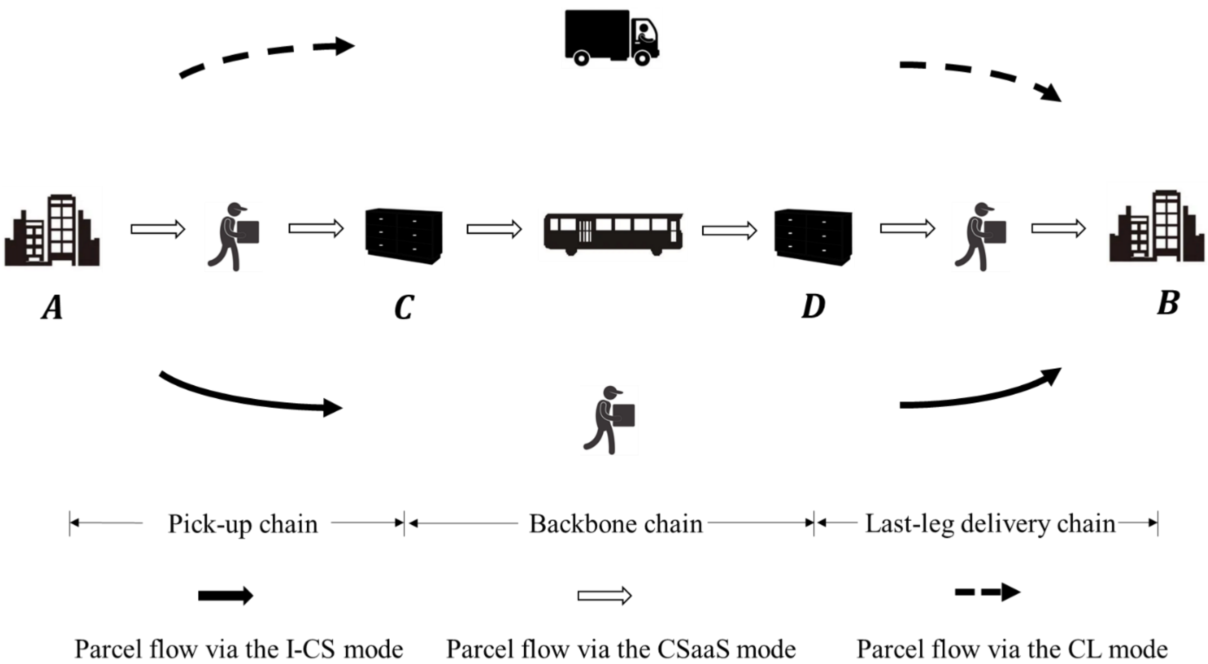


Figure 1. Parcel flows in the O2O market in the presence of CSaaS

Each shipping mode in the O2O market is operated by its corresponding platform.

Specifically, the CSaaS mode involves three operators, including the CSaaS platform, the I-CS platform, and the PT operator, where the CSaaS platform plays a vital role in operating this mode by connecting the I-CS service (provided by the I-CS platform in pick-up and last-leg delivery chains) and the PT-CS service (provided by the PT operator in the backbone chain) via a particular strategy. Different from travelers who can independently change travel modes (van den Berg et al., 2022), the parcels in the CSaaS mode should be passively transferred by staff recruited by the CSaaS platform at the connection points between two CS services, i.e., stations C and D in Figure 1.

2.2. Player interaction and Nash equilibrium

A game-theoretic approach will be employed in this study to investigate the interactions among O2O players with various objectives. Each player is assumed to be rational with selfish behaviors. These behaviors are specified as their optimal strategies and are contingent on the strategies implemented by other players. Different modeling frameworks result in different objectives for each player. We then elaborate on the player interactions as well as their optimal strategies for the business models with and without CSaaS.

(i) Business model without CSaaS

Only three kinds of players are involved in the market when CSaaS is unavailable, including the I-CS platform, the CL platform, and consignees. The I-CS platform charges F_{ics} measured by HK\$/km from each consignee and pays $(1-\tau)F_{ics}$ measured by HK\$/km as compensation to each shipper, where τ denotes the commission rate. It needs to decide F_{ics} to strive to maximize its profit. The CL platform, as the competitor of the I-CS platform, charges F_{cl} measured by HK\$/km from each consignee but suffers the operating cost C_{cl} of running the dedicated fleets. It needs to decide F_{cl} to maximize its profit. Given the two service fees of F_{ics} and F_{cl}, the consignees, with the total demands N and the average shipping distance L (the distance from A to B in Figure 1), make decisions about which modes, i.e., the I-CS vs. CL service, to choose for higher utilities. The price decisions made by the two platforms will affect the choice decisions of consignees, while the choice decisions, in turn, affect the price decisions of platforms. All players will continuously adjust their strategies until reaching the equilibrium state, where none of them can increase their profits or utilities by ultimately altering their strategies under the condition that other players' strategies keep unchanged.

(ii) Business models with CSaaS

The introduction of CSaaS makes it possible to provide PT-CS service. Five players of the CSaaS platform, the I-CS platform, the PT operator, the CL platform, and consignees are involved in the market. Among these players, the CSaaS platform plays a vital role in integrating the two CS services. In this study, we propose two operating strategies based on the role of the CSaaS platform, namely, the commission-based and integrator-based strategies.

(a) The commission-based operating strategy

The CSaaS platform in this strategy acts as an intermediary to offer intermediation services between consignees and service providers, i.e., the I-CS platform and the PT operator. It provides a convenient channel for consignees to access both I-CS (in pick-up and last-leg delivery chains) and PT-CS (in the backbone chain) services. The consignees can book and pay for these services with their preferred shipping equipment at each chain through a single CSaaS platform. In particular, the fees are collected by the CSaaS platform and will finally be transferred to the I-CS platform and the PT operator. The CSaaS platform can benefit from this strategy through a certain proportion of profits of the two operators through negotiation, which can be regarded as commissions. The PT operator will be pleased to share its profit with the CSaaS platform because it is incorporated into the market and earns extra benefits due to CSaaS. The I-CS platform, however, may or may not benefit from CSaaS, considering the market share of the pure I-CS mode will bound to reduce and the profit gained from the CSaaS mode may not make up for the profit loss in I-CS mode. For simplicity, we consider the CSaaS platform only benefits from a certain proportion of the PT operator's profit in this strategy. In other words, the CSaaS platform and the PT operator are cooperators to accomplish the shipping task in the backbone chain and share the profit.

In this strategy, the I-CS and CL platforms still make price decisions F'_{ics} and F'_{cl} measured by HK$/km, respectively, to maximize their profits. The PT operator charges F'_{pt} measured by HK$/km for the deliveries in the backbone chain with the average distance $L_b\left(0 \le L_b \le L\right)$ (the distance from C to D in Figure 1). It needs to decide F'_{pt} for profit maximization. The CSaaS platform, however, has no price decision but suffers the transshipment cost C_t regarding transferring parcels at stations. It collects fees charged from consignees and gains profit from the PT operator with a negotiated profit share rate ρ. Facing three choices of the I-CS, CSaaS, and CL modes, the consignees make decisions about which modes to choose for higher utilities. All players, except for the CSaaS platform, will continuously adjust their strategies until reaching the equilibrium state that has been explained in this section.

(b) The integrator-based operating strategy

The CSaaS platform in this strategy acts as a reseller to provide an integrated service with a lump-sum charge. It purchases the I-CS service in pick-up and last-leg delivery chains from the I-CS platform and the PT-CS service in the backbone chain from the PT operator and resells these services through a uniform fee to consignees. The CSaaS platform in this strategy must make price decisions for profit maximization rather than negotiating with the PT operator for profit share. The consignees in this strategy can directly book and pay for the shipping services from the origin to the destination provided by the CSaaS platform rather than access services chain by chain. In other words, the CSaaS platform in the integrator-based strategy uses a "visible hand" to operate the CSaaS mode compared with that of the commission-based strategy.

In this strategy, the I-CS platform, the PT operator, and the CL platform still make price decisions F''_{ics}, F''_{pt}, and F''_{cl} measured by HK$/km, respectively, to maximize their profits. The CSaaS platform charges F''_{css} measured by HK$/km for profit maximization. Facing the three shipping modes, the consignees make decisions about which modes to choose for higher utilities. All players will continuously adjust their strategies until reaching the equilibrium state that has been explained in this section.

3. Model Formulation

For comparison, we first formulate the business model of the O2O market without CSaaS in Subsection 3.1. The business models with CSaaS concerning the commission-based and integrator-based operating strategies are formulated in Subsection 3.2.

3.1. Business model without CSaaS

The business model without CSaaS only includes the I-CS platform, the CL platform, and consignees.

(i) Formulation of players' profits/utilities

Recall that the I-CS platform gains profits from commissions, i.e., the difference between the fees charged from consignees and the compensations paid to shippers, which is given by

$$\Pi_{ics} = \tau LF_{ics} \lambda N \tag{1}$$

where τ denotes the commission rate set by the I-CS platform and λ denotes the ratio of the I-CS orders requested by consignees to all shipping orders and is referred to as the I-CS market share. Here, τLF_{ics} represents the profit per delivery request and λN denotes the total I-CS demands.

The CL platform gains profits from the fees charged from consignees but suffers the operating costs related to running the fleet, which is given by

$$\Pi_{cl} = LF_{cl} \omega N - C_{cl} \tag{2}$$

where $\omega(\omega = 1 - \lambda)$ denotes the ratio of the CL orders requested by consignees to all shipping orders and is referred to as the CL market share, and C_{cl} denotes the operating cost concerning running the fleet.

Facing the I-CS and CL services, the consignees make choice decisions regarding which shipping mode to choose based on their utilities. The consignees' utilities for choosing the I-CS and CL services are formulated by Eqs. (3)-(4), respectively, as follows:

$$U_{ics} = u - LF_{ics} + \varepsilon_{ics} \tag{3}$$

$$U_{cl} = u - LF_{cl} + \varepsilon_{cl} \tag{4}$$

where u denotes the basic benefit of consignees obtained from receiving parcels; ε_{ics} and ε_{cl} characterize the attribute regarding the flexibility of I-CS and CL services, respectively, which will further affect consignees' preferences. In view of flexibility, the I-CS mode outperforms the CL mode because the I-CS platform can recruit shippers from the crowd and deliver the parcels instantly. Without the consideration of fees, the consignees will prefer the flexible I-CS mode according to the dominance rule. To allow the establishment of the relationship between the attribute terms and the market shares of different modes, we follow the operations management studies (Zhu et al., 2019; Benjaafar et al., 2019; Pei et al., 2021) to normalize the attribute term for simplicity.

(ii) Market equilibrium analysis

The game among the I-CS platform, the CL platform, and consignees, is solved by backward induction. The consignees' optimal decision is thus given by

$$\begin{cases} \text{I-CS service, if } \varepsilon \geq \sigma \\ \text{CL service, if } \varepsilon < \sigma \end{cases} \tag{5}$$

where $\sigma = \dfrac{1 - F_{cl}L + F_{ics}L}{2}$ in Eq. (5) can be regarded as the threshold derived from the relationship of $U_{ics} = U_{cl}$, in which case there is no difference between the two services. Based on the recognized relationship between the two services regarding flexibility, the consignee will thus choose the I-CS mode if his/her attribute term is greater than σ while will choose the CL mode otherwise. Further, according to the relationship between market share and corresponding attribute term identified by Zhu et al. (2019), the I-CS market share λ and the CL market share ω are given by Eq. (6) with the relationship of $\lambda = 1 - \sigma$ and $\omega = 1 - \lambda$ as follows:

$$\begin{cases} \lambda\left(F_{ics}, F_{cl}\right) = \dfrac{1 + F_{cl}L - F_{ics}L}{2} \\ \omega\left(F_{ics}, F_{cl}\right) = \dfrac{1 - F_{cl}L + F_{ics}L}{2} \end{cases} \tag{6}$$

where price decisions of the two platforms F_{ics} and F_{cl} are variables affecting λ and ω.

By substituting Eq. (6) into Eqs. (1)-(2), the two platforms' profits with respect to their price decisions are given by

$$\begin{cases} \Pi_{ics}\left(F_{ics}, F_{cl}\right) = \dfrac{\tau F_{ics}LN\left(1 + F_{cl}L - F_{ics}L\right)}{2} \\ \Pi_{cl}\left(F_{ics}, F_{cl}\right) = \dfrac{F_{ics}F_{cl}L^2N + F_{cl}LN - F_{cl}^2L^2N - 2C_{cl}}{2} \end{cases} \tag{7}$$

The first and second derivatives of $\Pi_{ics}\left(F_{ics}, F_{cl}\right)$ in Eq. (7) with respect to F_{ics} and $\Pi_{cl}\left(F_{ics}, F_{cl}\right)$ in the same equation with respect to F_{cl} are given by Eqs. (8)-(9), respectively, as follows:

$$\begin{cases} \dfrac{\partial \Pi_{ics}}{\partial F_{ics}} = \dfrac{\tau NL\left(1 + F_{cl}L - F_{ics}L\right) - \tau NL^2F_{ics}}{2} \\ \dfrac{\partial \Pi_{cl}}{\partial F_{cl}} = \dfrac{LN - 2F_{cl}L^2N + F_{ics}L^2N}{2} \end{cases} \tag{8}$$

$$\begin{cases} \dfrac{\partial^2 \Pi_{ics}}{\partial F_{ics}^2} = -\tau NL^2 < 0 \\ \dfrac{\partial^2 \Pi_{cl}}{\partial F_{cl}^2} = -NL^2 < 0 \end{cases} \tag{9}$$

It can be easily deduced that both $\dfrac{\partial^2 \Pi_{ics}}{\partial F_{ics}^2}$ and $\dfrac{\partial^2 \Pi_{cl}}{\partial F_{cl}^2}$ in Eq. (9) are negative, indicating that both Π_{ics} and Π_{cl} have the maximum value under the price decisions derived from $\dfrac{\partial \Pi_{ics}}{\partial F_{ics}} = 0$ and $\dfrac{\partial \Pi_{cl}}{\partial F_{cl}} = 0$ in Eq. (8) as follows:

$$\begin{cases} F_{ics}\left(F_{cl}\right)=\dfrac{1+F_{cl}L}{2L} \\ F_{cl}\left(F_{ics}\right)=\dfrac{1+F_{ics}L}{2L} \end{cases} \tag{10}$$

Considering that F_{ics} and F_{cl} are the two platforms' independent price decisions, we can deduce the equilibrium price decisions of F_{ics}^* and F_{cl}^* by combining $F_{ics}\left(F_{cl}\right)$ and $F_{cl}\left(F_{ics}\right)$ in Eq. (10), which is given by

$$F_{ics}^* = F_{cl}^* = \frac{1}{L} \tag{11}$$

By substituting Eq. (11) into Eqs. (6)-(7), the equilibrium two market shares (λ^* and ω^*) and the equilibrium profits of the two platforms (Π_{ics}^* and Π_{cl}^*) are given by

$$\lambda^* = \omega^* = \frac{1}{2} \tag{12}$$

$$\begin{cases} \Pi_{ics}^* = \dfrac{\tau N}{2} \\ \Pi_{cl}^* = \dfrac{N-2C_{cl}}{2} \end{cases} \tag{13}$$

We now prove the existence and uniqueness of equilibrium results characterized by Eqs. (11)-(13). To prove the existence of the equilibrium solution, we apply the theorem proposed by Debreu (1952), in which there exists at least one equilibrium solution if the strategy space for each platform is compact and convex, and the profit function is continuous and quasi-concave with respect to the strategy of each platform. According to Eq. (10), we can deduce that the price decisions of the platforms are bounded, indicating that the strategy space of the two platforms is compact and convex, so is their Cartesian product Ω. We then verify that the two profit functions of the platforms are concave with respect to their price decisions because $\partial^2 \Pi_{ics} / \partial F_{ics}^2 < 0$ and $\partial^2 \Pi_{cl} / \partial F_{cl}^2 < 0$, indicating that the functions are quasi-concavity and the existence of equilibrium results is thus proved. The proof of the uniqueness of the market equilibrium is equivalent to proving that the solution of the variational inequality problem derived from the profits functions $\mathbf{F}\left(F_{ics}, F_{cl}\right)$ is strictly monotone on their Cartesian product Ω. It can be readily seen that the Jacobian matrix of $\mathbf{F}\left(F_{ics}, F_{cl}\right)$ is negative definite, which means the derived equilibrium solution is unique.

3.2. Business models with CSaaS

The business model with CSaaS includes the CSaaS platform, the I-CS platform, the PT operator, the CL platform, and consignees. Among these players, the CSaaS platform plays a vital role in operating the market. We will propose two operating strategies based on the role of the CSaaS platform in this section.

3.2.1. Commission-based operating strategy

(i) Formulation of players' profits/utilities

Recall that the CSaaS platform in this strategy benefits from a certain proportion of the PT operator's profit ρ. The profit of the CSaaS platform is thus given by

$$\Pi'_{css} = \rho L_b F'_{pt} \upsilon' N - C_t \tag{14}$$

where υ' denotes the CSaaS market share and C_t denotes the operating costs of the CSaaS platform concerning transferring parcels at stations.

The I-CS platform gains profits from the difference between the fees charged from consignees and the compensations paid to shippers, which is given by

$$\Pi'_{ics} = \tau L F'_{ics} \lambda' N + \tau\left(L - L_b\right) F'_{ics} \upsilon' N \tag{15}$$

where the first term of Eq. (15) $\tau L F'_{ics} \lambda' N$ denotes the profits gained from the I-CS mode and the second term $\tau\left(L - L_b\right) F'_{ics} \upsilon' N$ denotes the profits gained from pick-up and last-leg delivery chains of the CSaaS mode.

The PT operator benefits from the fees charged from the backbone chain of CSaaS mode but has to share a proportion of profit with the CSaaS platform, which is given by

$$\Pi'_{pt} = (1-\rho) L_b F'_{pt} \upsilon' N \tag{16}$$

The CL platform also gains profits from the fees charged from consignees but suffers the operating costs related to running the fleet, which is given by

$$\Pi'_{cl} = LF'_{cl} \omega' N - C_{cl} \tag{17}$$

where $\omega' (\omega' = 1 - \lambda' - \upsilon')$ denotes the CL market share.

Facing the above three shipping modes, the consignees make choice decisions regarding which mode to choose based on their utilities. The consignees' utilities for choosing the I-CS, CSaaS, and CL modes are formulated by Eqs. (18)-(20), respectively, as follows:

$$U'_{ics} = u - LF'_{ics} + \varepsilon'_{ics} \tag{18}$$

$$U'_{css} = u - (L - L_b) F'_{ics} - L_b F'_{pt} + \varepsilon'_{ccs} \tag{19}$$

$$U'_{cl} = u - LF'_{cl} + \varepsilon'_{cl} \tag{20}$$

where ε'_{ics}, ε'_{css}, and ε'_{cl} characterize the attribute regarding the flexibility of I-CS, CSaaS, and CL services, respectively, which will further affect consignees' preferences. Note that the consignees who choose the CSaaS mode (see Eq. (19)) endure the fees concerning the I-CS service in pick-up and last-leg delivery chains $(L - L_b) F'_{ics}$ and the PT-CS service in the backbone chain $L_b F'_{pt}$.

(ii) Market equilibrium analysis

Again, the game among the CSaaS platform, the I-CS platform, the PT operator, the CL platform, and the consignees is solved by backward induction. The consignees' optimal decision is given by Eq. (21) based on the recognized relationship between the three services regarding flexibility, where the I-CS mode outperforms the CSaaS mode and CL mode because the I-CS platform can recruit shippers from the crowd and deliver the parcels instantly while the CL platform has to deliver parcels according to fixed schedules:

$$\begin{cases} \text{I-CS service, if } \varepsilon' \geq \phi \\ \text{PT-CS service, if } \phi' \leq \varepsilon' < \phi \\ \text{CL service, if } \varepsilon' < \phi' \end{cases} \tag{21}$$

where $\phi = \dfrac{1 + F'_{ics}L_b - F'_{pt}L_b}{2}$ and $\phi' = \dfrac{1 - F'_{cl}L + F'_{ics}L - F'_{ics}L_b + F'_{pt}L_b}{2}$ in Eq. (21) can be regarded as the threshold derived from $U'_{ics} = U'_{pt}$ and $U'_{pt} = U'_{cl}$, respectively. Similar to the methods applied in the business model without CSaaS, three market shares, i.e., λ', υ', and ω' are given by Eq. (22) with the relationship of $\lambda' = 1 - \phi$, $\upsilon' = \phi - \phi'$, and $\omega' = 1 - \lambda' - \upsilon'$, respectively, as follows:

$$\begin{cases} \lambda'\left(F'_{ics}, F'_{pt}\right) = \dfrac{1 - F'_{ics}L_b + F'_{pt}L_b}{2} \\ \upsilon'\left(F'_{ics}, F'_{pt}, F'_{cl}\right) = \dfrac{F'_{cl}L - F'_{ics}L + 2F'_{ics}L_b - 2F'_{pt}L_b}{2} \\ \omega'\left(F'_{ics}, F'_{pt}, F'_{cl}\right) = \dfrac{1 - F'_{cl}L + F'_{ics}L - F'_{ics}L_b + F'_{pt}L_b}{2} \end{cases} \tag{22}$$

where the price decisions F'_{ics}, F'_{pt}, and F'_{cl} are variables affecting λ', υ', and ω'.

By substituting Eq. (22) into Eqs. (14)-(17), the four players' profits with respect to their price decisions are given by

$$\begin{cases} \Pi'_{css}\left(F'_{ics}, F'_{pt}, F'_{cl}\right) = \dfrac{\rho N F'_{pt}L_b\left(F'_{cl}L - F'_{ics}L + 2F'_{ics}L_b - 2F'_{pt}L_b\right)}{2} - C_t \\ \Pi'_{ics}\left(F'_{ics}, F'_{pt}, F'_{cl}\right) = \dfrac{\tau F'_{ics}N\left[L + \left(F'_{cl} - F'_{ics}\right)L^2 - 2L_b^2\left(F'_{ics} - F'_{pt}\right) - LL_b\left(F'_{cl} - 2F'_{ics} + F'_{pt}\right)\right]}{2} \\ \Pi'_{pt}\left(F'_{ics}, F'_{pt}, F'_{cl}\right) = \dfrac{(\rho - 1)F'_{pt}L_bN\left(F'_{ics}L - F'_{cl}L - 2F'_{ics}L_b + 2F'_{pt}L_b\right)}{2} \\ \Pi'_{cl}\left(F'_{ics}, F'_{pt}, F'_{cl}\right) = \dfrac{F'_{cl}LN\left(1 - F'_{cl}L + F'_{ics}L - F'_{ics}L_b + F'_{pt}L_b\right)}{2} - C_{cl} \end{cases}$$

(23)

Note that the CSaaS platform in this strategy has no price decision but a preset profit share rate ρ negotiated with the PT operator, while the I-CS platform, the PT operator, and the CL platform have their own price decisions F'_{ics}, F'_{pt}, and F'_{cl}. Similar to the business model without CSaaS, each player in this strategy, i.e., the I-CS platform, the PT operator, and the CL platform, chooses a price that maximizes its own profit while taking the prices of other players as a given. Therefore, the equilibrium fees set by the three players, the equilibrium market shares of the three shipping modes, and the equilibrium profits of the four operators/platforms are given by Eqs. (24)-(26), respectively, as follows:

$$\begin{cases} F'^{*}_{ics} = \dfrac{5L - L_b}{5L^2 - 9LL_b + 10L_b^2} \\ F'^{*}_{pt} = \dfrac{L + L_b}{5L^2 - 9LL_b + 10L_b^2} \\ F'^{*}_{cl} = \dfrac{5L^2 - 7LL_b + 6L_b^2}{L\left(5L^2 - 9LL_b + 10L_b^2\right)} \end{cases} \tag{24}$$

$$\begin{cases} \lambda'^{*} = \dfrac{5L^2 - 13LL_b + 12L_b^2}{2\left(5L^2 - 9LL_b + 10L_b^2\right)} \\ \upsilon'^{*} = \dfrac{L_b\left(L + L_b\right)}{5L^2 - 9LL_b + 10L_b^2} \\ \omega'^{*} = \dfrac{5L^2 - 7LL_b + 6L_b^2}{2\left(5L^2 - 9LL_b + 10L_b^2\right)} \end{cases} \tag{25}$$

$$\begin{cases} \Pi'^{*}_{css} = \dfrac{\rho N L_b^2 \left(L + L_b\right)^2}{\left(5L^2 - 9LL_b + 10L_b^2\right)^2} - C_t \\ \Pi'^{*}_{ics} = \dfrac{\tau N \left(L_b - 5L\right)^2 \left(L^2 - 2LL_b + 2L_b^2\right)}{2\left(5L^2 - 9LL_b + 10L_b^2\right)^2} \\ \Pi'^{*}_{pt} = \dfrac{\left(1 - \rho\right) L_b^2 N \left(L + L_b\right)^2}{\left(5L^2 - 9LL_b + 10L_b^2\right)^2} \\ \Pi'^{*}_{cl} = \dfrac{N\left(5L^2 - 7LL_b + 6L_b^2\right)^2}{2\left(5L^2 - 9LL_b + 10L_b^2\right)^2} - C_{cl} \end{cases} \tag{26}$$

Applying the same analysis method presented in Subsection 3.1, the existence and uniqueness of equilibrium results characterized by Eqs.(24)-(26) can be readily proved. It can be also found that the equilibrium results from Eqs. (24)-(26) are closely related to the total shipping distance

L and the backbone chain distance L_b. We thus introduce a notation of the PT accessibility rate regarding the two distances in Eq. (27), which is given by

$$\theta = \frac{L_b}{L} \tag{27}$$

Obviously, this rate should range from 0 to 1 considering that L_b run by the PT vehicles cannot be larger than L. If the ratio approaches zero, PT accessibility is at a low level, which can happen in some specific rural areas. If the ratio approaches one, PT accessibility is at a high level, which can happen in downtown with well-developed PT plans. Other value ranges of the ratio can be regarded as at a medium level, which can happen in suburbs. In general, different values of PT accessibility will stand for different urban structures. Based on the three kinds of equilibrium results, we have the following observation:

Observation 1. *The equilibrium results of the O2O shipping market concerning shipping fees and market shares under the commission-based operating strategy are only affected by the total shipping distance* L *and the backbone distance* L_b*. The equilibrium results concerning operators' profits are additionally affected by the market size* N *and the related commission rates (*ρ *for the CSaaS platform and the PT operator,* τ *for the I-CS platform) and costs (*C_t *for the CSaaS platform and* C_{cl} *for the CL platform).*

This observation demonstrates that the equilibrium results under the commission-based strategy in the presence of CSaaS are closely related to the urban PT structure, i.e., the value of θ, where a large value of θ stands for a high PT accessibility and a small value of θ denotes a low PT accessibility.

3.2.2. Integrator-based operating strategy

(i) Formulation of players' profits/utilities

Recall that the CSaaS platform in this strategy benefits from the difference between the fees charged from consignees and the costs to purchase two CS services. The profit of the CSaaS platform is thus given by

$$\Pi''_{css} = \left[LF''_{css} - L_b F''_{pt} - \left(L - L_b\right) F''_{ics}\right] \upsilon'' N - C_t \tag{28}$$

where LF''_{css} denotes the fees charged from consignees per delivery, $L_b F''_{pt} + \left(L - L_b\right) F''_{ics}$ denotes the costs concerning getting the CS services from the PT operator and the I-CS platform, and $\upsilon'' N$ denotes the number of consignees who choose the CSaaS mode.

Similar to the commission-based strategy, the I-CS platform gains profits from the difference between the fees charged from consignees and the compensations paid to shippers, which is given by

$$\Pi''_{ics} = \tau LF''_{ics} \lambda'' N + \tau \left(L - L_b\right) F''_{ics} \upsilon'' N \tag{29}$$

The PT operator benefits from the fees charged from consignees in the backbone chain of the CSaaS mode, which is given by

$$\Pi''_{pt} = L_b F''_{pt} \upsilon'' N \tag{30}$$

The CL platform's profit in this strategy has the same formulation structure compared with that in the commission-based strategy as follows:

$$\Pi''_{cl} = LF''_{cl} \omega'' N - C_{cl} \tag{31}$$

where $\omega'' N \left(\omega'' = 1 - \lambda'' - \upsilon''\right)$ denotes the number of consignees who choose the CL service.

Facing the three shipping modes, the consignees make choice decisions based on their utilities. The consignees' utilities for choosing the I-CS, CSaaS, and CL modes are formulated by Eqs. (32)-(34), respectively, as follows:

$$U''_{ics} = u - LF''_{ics} + \varepsilon''_{ics} \tag{32}$$

$$U''_{css} = u - LF''_{css} + \varepsilon''_{ccs} \tag{33}$$

$$U''_{cl} = u - LF''_{cl} + \varepsilon''_{cl} \tag{34}$$

where ε''_{ics}, ε''_{css}, and ε''_{cl} characterize the attribute regarding the flexibility of I-CS, CSaaS, and CL services, respectively, which will further affect consignees' preferences.

(ii) Market equilibrium analysis

Adopting the same method presented in Subsection 3.2.1, we can further derive the final equilibrium results concerning the shipping fees, market shares, and profits under this strategy. The detailed derivative process is presented in Appendix A and the final equilibrium results under this strategy are listed in Table 1. Again, the existence and uniqueness of equilibrium results characterized by Table 1 can be readily proved with the analysis presented in Subsection 3.1. In particular, we have two pairs of equilibrium results here, which is illustrated in the following observation:

Observation 2. *The equilibrium results of the O2O shipping market under the integrator-based operating strategy in the presence of CSaaS are divided into two pairs based on PT accessibility* θ.

The results listed in Table 1 are divided into two pairs because there has a quadratic term with regard to a shipping fee. Once the equilibrium shipping fees have two results, the derived two pairs of equilibrium market shares and profits are also found here. We also emphasize that the two pairs of results are closely related to the value of PT accessibility θ, which is constrained by the nonnegative value of υ''^{*}. Specifically, the result in the first column should be constrained by $\frac{C_t L\left(L^2-9L_b^2\right)}{\sqrt{C_t N\left(L^3-9LL_b^2\right)^2}}\geq 0$, e.g., $0\leq\theta\leq 1/3$, while the result in the second column should be constrained by $\frac{C_t L\left(9L_b^2-L^2\right)}{\sqrt{C_t N\left(L^3-9LL_b^2\right)^2}}\geq 0$, i.e., $1/3<\theta\leq 1$.

Table 1. Equilibrium results under the integrator-based operating strategy

Equilibrium results	Notations	$0 \le \theta \le 1/3$	$1/3 < \theta \le 1$
Shipping fee	$F_{css}''^{*}$	$\frac{3L^4N + L^3L_bN - 27L^2L_b^2N}{L^2N(L-3L_b)(L+3L_b)^2} - \frac{9LL_b^3N + 8L_b\sqrt{C_tN(L^3-9LL_b^2)^2}}{L^2N(L-3L_b)(L+3L_b)^2}$	$\frac{3L^4N + L^3L_bN - 27L^2L_b^2N}{L^2N(L-3L_b)(L+3L_b)^2} - \frac{9LL_b^3N - 8L_b\sqrt{C_tN(L^3-9LL_b^2)^2}}{L^2N(L-3L_b)(L+3L_b)^2}$
	$F_{ics}''^{*}$	$\frac{4}{L+3L_b} + \frac{2C_t(L-3L_b)^2}{\sqrt{C_tN(L^3-9LL_b^2)^2}}$	$\frac{4}{L+3L_b} - \frac{2C_t(L-3L_b)^2}{\sqrt{C_tN(L^3-9LL_b^2)^2}}$
	$F_{pt}''^{*}$	$\frac{5L^4L_bN + 9L^3L_b^2N - 45NL^2L_b^3 - L^5N}{L^2L_bN(L-3L_b)(L+3L_b)^2} - \frac{(3LL_b + 6L_b^2 + 3L^2)\sqrt{C_tN(L^3-9LL_b^2)^2}}{L^2L_bN(L-3L_b)(L+3L_b)^2}$	$\frac{5L^4L_bN + 9L^3L_b^2N - 45NL^2L_b^3 - L^5N}{L^2L_bN(L-3L_b)(L+3L_b)^2} + \frac{(3LL_b + 6L_b^2 + 3L^2)\sqrt{C_tN(L^3-9LL_b^2)^2}}{L^2L_bN(L-3L_b)(L+3L_b)^2}$

	$F_{cl}''^{*}$	$\frac{2\left(L^4N+L^3L_bN-9L^2L_b^2N-9LL_b^3N\right)}{L^2N\left(L-3L_b\right)\left(L+3L_b\right)^2}-\frac{4L_b\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}}{L^2N\left(L-3L_b\right)\left(L+3L_b\right)^2}$	$\frac{2\left(L^4N+L^3L_bN-9L^2L_b^2N-9LL_b^3N\right)}{L^2N\left(L-3L_b\right)\left(L+3L_b\right)^2}+\frac{4L_b\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}}{L^2N\left(L-3L_b\right)\left(L+3L_b\right)^2}$
Market share	λ''^{*}	$\frac{2L_b}{L+3L_b}-\frac{C_tL\left(L-3L_b\right)\left(L+L_b\right)}{\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}}$	$\frac{2L_b}{L+3L_b}+\frac{C_tL\left(L-3L_b\right)\left(L+L_b\right)}{\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}}$
	υ''^{*}	$\frac{C_tL\left(L^2-9L_b^2\right)}{\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}}$	$\frac{C_tL\left(9L_b^2-L^2\right)}{\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}}$
	ω''^{*}	$\frac{L+L_b}{L+3L_b}-\frac{2C_tLL_b\left(L^2-9L_b^2\right)}{\left(L+3L_b\right)\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}}$	$\frac{L+L_b}{L+3L_b}+\frac{2C_tLL_b\left(L^2-9L_b^2\right)}{\left(L+3L_b\right)\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}}$
Profit	$\Pi_{ccs}''^{*}$	0	0
	$\Pi_{ics}''^{*}$	$\frac{2\tau L_b\left[C_t\left(L-3L_b\right)^2\left(L+3L_b\right)+2\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}\right]^2}{C_tL\left(L-3L_b\right)^2\left(L+3L_b\right)^4}$	$\frac{2\tau L_b\left[C_t\left(L-3L_b\right)^2\left(L+3L_b\right)-2\sqrt{C_tN\left(L^3-9LL_b^2\right)^2}\right]^2}{C_tL\left(L-3L_b\right)^2\left(L+3L_b\right)^4}$

	$\Pi_{pt}^{\prime\prime *}$	$\frac{(5L_b - L)\sqrt{C_t N(L^3 - 9LL_b^2)^2}}{L(L-3L_b)(L+3L_b)^2} - \frac{3C_t(L-3L_b)(L+3L_b)(L^2+LL_b+2L_b^2)}{L(L-3L_b)(L+3L_b)^2}$	$\frac{(L - 5L_b)\sqrt{C_t N(L^3 - 9LL_b^2)^2}}{L(L-3L_b)(L+3L_b)^2} - \frac{3C_t(L-3L_b)(L+3L_b)(L^2+LL_b+2L_b^2)}{L(L-3L_b)(L+3L_b)^2}$
	$\Pi_{cl}^{\prime\prime *}$	$\frac{-8L_b(L+L_b)\sqrt{C_t N(L^3 - 9LL_b^2)^2}}{L(L-3L_b)(L+3L_b)^3} + \frac{2(L+L_b)(L^4N + L^3L_bN - 9L^2L_b^2N - 9LL_b^3N)}{L(L-3L_b)(L+3L_b)^3} + \frac{-C_{cl}L(L-3L_b)(L+3L_b)^3 + 8C_tLL_b^2(L^2-9L_b^2)}{L(L-3L_b)(L+3L_b)^3}$	$\frac{8L_b(L+L_b)\sqrt{C_t N(L^3 - 9LL_b^2)^2}}{L(L-3L_b)(L+3L_b)^3} + \frac{2(L+L_b)(L^4N + L^3L_bN - 9L^2L_b^2N - 9LL_b^3N)}{L(L-3L_b)(L+3L_b)^3} + \frac{-C_{cl}L(L-3L_b)(L+3L_b)^3 + 8C_tLL_b^2(L^2-9L_b^2)}{L(L-3L_b)(L+3L_b)^3}$

2

4. Analytical Discussions

In this section, we focus on two concerns regarding which operating strategy to choose for the CSaaS platform and whether CSaaS can benefit all players in the O2O market. The choice of two operating strategies, i.e., the commission-based and integrator-based strategies, is discussed in Subsection 4.1. Followed by the discussions regarding the impact of CSaaS on O2O players in Subsection 4.2.

4.1. Discussions regarding the choice of CSaaS operating strategy

As the key player in providing CSaaS service, the CSaaS platform is requested to choose a profitable strategy. Comparing the profit of the CSaaS platform under the two strategies, we have the following proposition.

Proposition 1. *The CSaaS platform should adopt the commission-based strategy considering that it always outperforms the integrator-based strategy with a larger profit.*

It can be found in Table 1 that the profit of the CSaaS platform is zero under the integrator-based strategy in both two domains, i.e., $0 \le \theta \le 1/3$ and $1/3 < \theta \le 1$. Therefore, the CSaaS platform should choose the commission-based strategy for a profitable target. Although it is easy for the CSaaS platform to make a decision by comparing the profits under the two strategies, we still need to clarify why the profit of the CSaaS platform under the integrator-based strategy is zero. Adopting the same method demonstrated in Subsection 3.1, the first derivative of the PT operator's profit Π''_{pt} with respect to its price decision F''_{pt} under the integrator-based strategy is given by

$$\frac{\partial \Pi''_{pt}}{\partial F''_{pt}} = \frac{NL_b\left(F''_{cl}L - 2F''_{css}L + F''_{ics}L\right)}{2} \tag{35}$$

which is independent of F''_{pt}. This indicates that the PT operator will have the maximum profit when F''_{pt} is set as the boundary point, either zero or the maximum PT fee, depending on the value of Eq. (35). However, a rational PT operator will not provide free service for consignees, F''_{pt} must be set as the maximum PT fee. Considering that the CSaaS platform gains nonnegative profit, the value range of F''_{pt} can be obtained as follows:

$$0 \le F''_{pt} \le \frac{F''_{css}L + F''_{ics}\left(L_b - L\right)}{L_b} - \frac{2C_t}{LL_bN\left(F''_{cl} - 2F''_{css} + F''_{ics}\right)} \tag{36}$$

where the right side of F''_{pt} ($\frac{F''_{css}L + F''_{ics}\left(L_b - L\right)}{L_b} - \frac{2C_t}{LL_bN\left(F''_{cl} - 2F''_{css} + F''_{ics}\right)}$) will lead to zero CSaaS platform's profit. This indicates that regardless of whatever the shipping fee set by the CSaaS platform, the PT operator can always set a special F''_{pt} to maximize its own profit and resulting in zero CSaaS platform's profit.

4.2. Discussions regarding the effects of CSaaS on O2O players

Both the PT operator and the CSaaS platform will benefit from the introduction of CSaaS because they are newly incorporated into the market with nonnegative profits. The effect of CSaaS on the original two operators, i.e., the I-CS and CL platforms, becomes one of the pressing tasks to be tackled for O2O operations. By comparing the shipping fees and market shares of the I-CS and CL platforms with CSaaS (under the commission-based strategy) and without CSaaS, we have the following two propositions.

Proposition 2. *The introduction of CSaaS results in an increase in the shipping fee of the I-CS platform when* $0 \le \theta \le \frac{4}{5}$ *and a decrease in the fee otherwise, it also results in a decrease in the I-CS market share all the time.*

Detailed proof of this proposition is presented in Appendix B. This proposition demonstrates that the introduction of CSaaS will prompt the I-CS platform to raise its shipping fee when PT accessibility is at a low or medium level while decreasing the fee otherwise. Meanwhile, the introduction of CSaaS will naturally take share from the I-CS service. Considering the I-CS platform's profit is the product of the commissions charged and the number of consignees who choose this service (equivalent to the I-CS market share), the introduction of CSaaS will first result in an increase in the I-CS platform's profit and then a decrease in this profit with the increase of θ from 0 to 1. In particular, the changing point regarding the profit is obtained by setting a specific θ in value ranging from 0 to 4/5.

Proposition 3. *The introduction of CSaaS results in an increase in the shipping fee of the CL platform and the CL market share when* $0 \le \theta \le \frac{1}{2}$ *and a decrease in the two results otherwise.*

Detailed proof of this proposition is presented in Appendix C. This proposition demonstrates that the introduction of CSaaS will prompt the CL platform to raise its shipping fee and expand the CL market share when PT accessibility is at low or medium level (θ is lower than $1/2$) while decreasing the fee and market share otherwise. Considering that the profit of the CL platform is the product of the shipping fee charged from consignees per complete delivery and the number of consignees who choose the CL service (equivalent to the CL market share), the introduction of CSaaS will also result in an increase in the CL platform's profit when $0 \le \theta \le \frac{1}{2}$ and a decrease in the profit otherwise.

With the findings from Propositions 2-3, we conclude that the introduction of CSaaS will benefit the original two players, i.e., the I-CS and CL platforms, when PT accessibility is not such large. This finding is useful to provide significant implications regarding launching CSaaS in a targeted market, where a profitable service benefiting all players will not suffer resistance.

5. Case Study and Policy Implications

We conduct a case study in this section based on the available data from Hong Kong. Focusing on the equilibrium shipping fees, market shares, and profits, the impact of CSaaS on four O2O players, i.e., the CSaaS platform, the I-CS platform, the PT operator, and the CL platform, are presented in Subsection 5.1. A sensitivity analysis of the profit share rate negotiated between the CSaaS platform and the PT operator under the commission-based strategy is conducted in Subsection 5.2. Extension regarding consignees' budget is performed in Subsection 5.3. Policy implications are last proposed accordingly in Subsection 5.4.

Figure 2 illustrates the layout of typical residential and warehouse/retailing areas in Hong Kong. The average O2O shipping distance from warehouse/retailing areas (e.g., Tsing Yi, Causeway Bay) to residential areas (e.g., Tuen Mun, Hung Hom) is estimated at around 10km, i.e., $L = 10\text{km}$. The average number of shipping parcels to be delivered per day in each OD pair (e.g., from Tsing Yi to Hung Hom) is estimated at around 80,000, i.e., $N = 80{,}000$. Given the hourly minimum wage in Hong Kong, i.e., HK$37.5, the CSaaS platform is assumed to bear HK$1,200 for hiring employees per day who are in charge of transferring parcels in stations, i.e., $C_t = \text{HK\$1,200}$. Similarly, the CL platform is assumed to bear HK$10,000 per day in each OD pair regarding running the CL fleet, i.e., $C_{cl} = \text{HK\$10,000}$. Following the application of Pickupp (https://hk.pickupp.io/en/), an I-CS platform marketed in Hong Kong, we set the commission rate of this platform to be 20%, i.e., $\tau = 20\%$. Furthermore, we assume that the profit share rate negotiated between the CSaaS platform and the PT operator is 50%, i.e., $\rho = 50\%$, indicating that the PT operator will share its half profit with the CSaaS platform to reward this profitable opportunity.

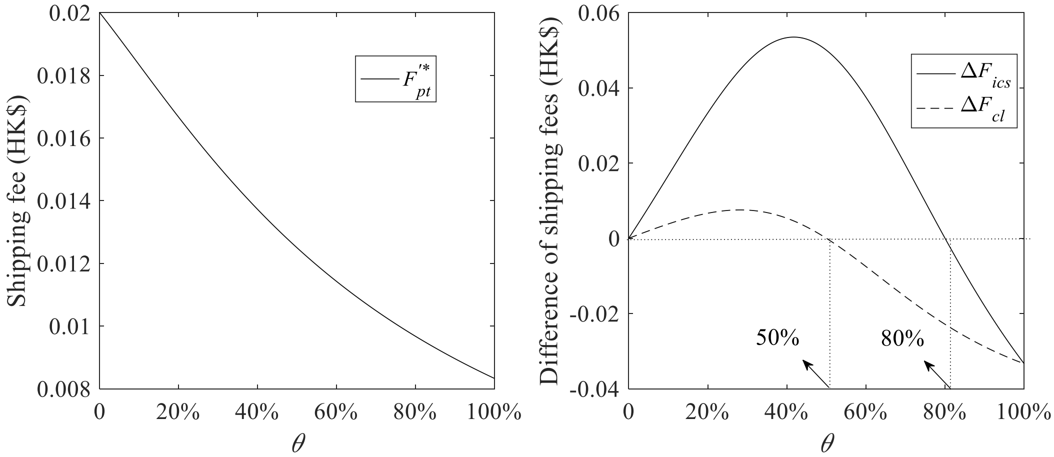
Source: Lands Department and Transport Department, Hong Kong SAR

Figure 2. The layout of typical residential and warehouse/retailing areas in Hong Kong

5.1. Basic results

Recall that the equilibrium results of shipping fees, market shares, and profits are affected by the urban PT structure θ. Without loss of generality, we regard θ as the independent variable ranging from zero to one to cover all levels of urban PT structures. In these regards, we simulate the effects of CSaaS on the equilibrium results of the four players, i.e., the CSaaS platform, the I-CS platform, the PT operator, and the CL platform, in this subsection.

The effect of CSaaS on O2O players regarding shipping fees is presented in Figure 3, where only the shipping fees of the I-CS platform, the PT operator, and the CL platform are included. The CSaaS platform has no price decision under the commission-based operating strategy. Subfigure 3(a) illustrates the relationship between θ and the shipping fee of the new player due to CSaaS, i.e., the PT operator's shipping fee $F_{pt}'^{*}$. A decreasing trend of $F_{pt}'^{*}$ can be found in this subfigure with the increase of θ, which indicates that the PT operator will reduce its shipping fee with the increase of PT accessibility. Subfigure 3(b) illustrates the relationship between θ and the shipping fees of original players, i.e., the I-CS and CL platforms. In particular, we present the differences regarding two shipping fees between the business models with and without CSaaS, i.e., ΔF_{ics} and ΔF_{cl}, to figure out the impact of CSaaS. It can be found from Subfigure 3(b) that the I-CS shipping fee is positively affected by CSaaS when $0 \le \theta \le 80\%$ and is negatively affected otherwise, while the CL shipping fee is positively affected by CSaaS when $0 \le \theta \le 50\%$ and is negatively affected otherwise. Consistent with Propositions 1-2, this finding illustrates that the undeveloped urban structure with a low or medium PT accessibility contributes to raising the shipping fees of original players.

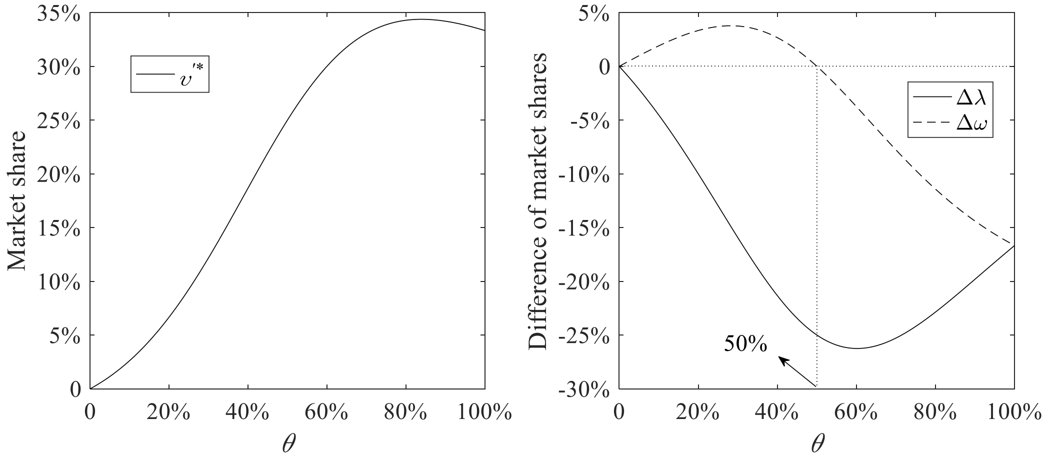


(a) The effect of CSaaS on the shipping fee of the new player

(b) The effect of CSaaS on the shipping fee of the original players

Figure 3. The effect of CSaaS on the O2O players regarding shipping fees

The effect of CSaaS on O2O players regarding market shares is presented in Figure 4, where three shipping modes are included. Subfigure 4(a) illustrates the relationship between the θ and the CSaaS market share υ'^{*}. It can be found that υ'^{*} will gradually increase with the increase of θ and will mildly decrease when θ is at a relatively high level. This is rational considering that high PT accessibility will make it convenient to ship parcels via CSaaS and increase the market share of this mode consequently. Subfigure 4(b) illustrates the relationship between θ and the market shares of original players, i.e., the I-CS and CL platforms. Similar to the analysis for the shipping fee, we focus on the differences regarding two market shares between the business models with and without CSaaS, i.e., $\Delta\lambda$ and $\Delta\omega$. It can be found from Subfigure 4(b) that the I-CS market share is always negatively affected by CSaaS, while the CL market share is positively affected by CSaaS when $0 \leq \theta \leq 50\%$ and is negatively affected otherwise. This finding is also consistent with Propositions 1-2, which indicates that the developed urban structure with a high PT accessibility contributes to decreasing the market shares of original O2O players, due to the convenient access to CSaaS.



(a) The effect of CSaaS on the market share of the new shipping mode

(b) The effect of CSaaS on the market share of the original shipping modes

Figure 4. The effect of CSaaS on the O2O players regarding market shares

The effect of CSaaS on the O2O players regarding profits is presented in Figure 5, where the profits of the CSaaS platform, the I-CS platform, the PT operator, and the CL platform are included. Subfigure 5(a) illustrates the relationship between θ and the profits of the CSaaS platform Π'^*_{css} and the PT operator Π'^*_{pt}. Both the two profits will gradually increase with the increase of θ and will mildly decrease when θ is at a relatively high level. In particular, the CSaaS platform can only yield positive profit when and only when $\theta > 38\%$ considering it should keep a minimum profit to offset its operating cost. Subfigure 5(b) illustrates the relationship between θ and the profits of original players, i.e., the I-CS and CL platforms. It can be found from this figure that the profit of the I-CS platform is positively affected by CSaaS when $0 \le \theta \le 58.9\%$ and is negatively affected otherwise, while the profit of the CL platform is positively affected by CSaaS when $0 \le \theta \le 50\%$ and is negatively affected otherwise. Recall that an accepted operating strategy for the O2O shipping market under CSaaS should not only benefit the new players but also without harming the original players. In this specific case, we notice that the feasible value of θ should range from 38% to 50%, indicating that PT accessibility should be at a proper level, no more and no less, to benefit all players.

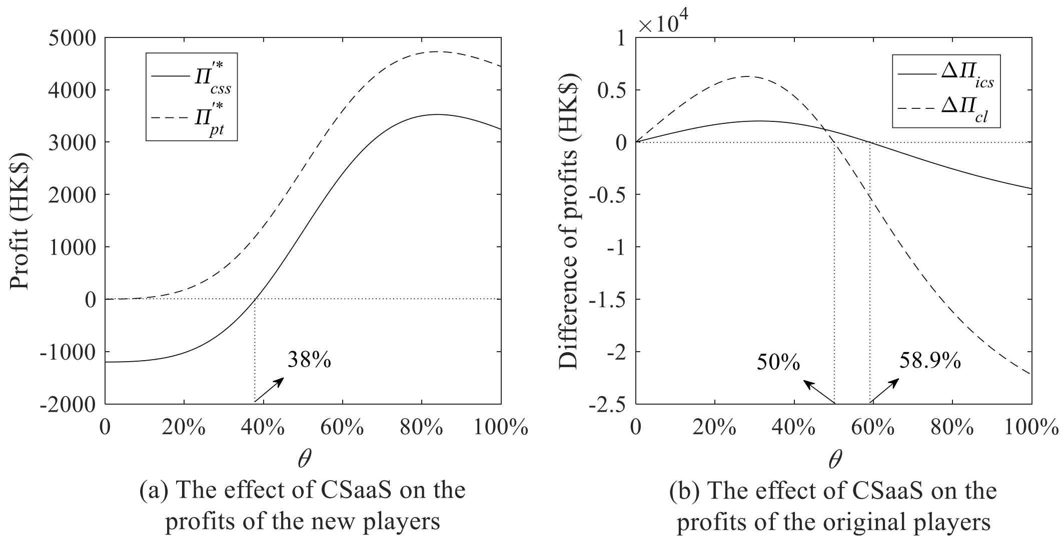


Figure 5. The effect of CSaaS on the O2O players regarding profits

5.2. Sensitivity analysis

This subsection investigates the pathways to further boost the profit of the CSaaS platform. Apart from the PT accessibility θ, the profit of the CSaaS platform is also affected by the profit share rate negotiated between the CSaaS platform and the PT operator ρ. We then conduct the sensitivity analysis of this parameter. Without loss of generality, the value of ρ is set to range from 0 to 1. Other parameters are set the same as the basic simulation, i.e., $L = 10\text{km}$, $N = 80{,}000$, $C_t = 1{,}200\text{HK\$}$, $C_{cl} = 10{,}000\text{HK\$}$, and $\tau = 20\%$. In particular, θ is assumed to be 45% considering that the operating strategy can only benefit all players when $38\% \le \theta \le 50\%$.

Since the value of ρ will affect both the profits of the CSaaS platform and the PT operator, we will present the sensitivity analysis of ρ regarding these two profits in Figure 6. It can be found that the profit of the CSaaS platform will linearly increase with the increase of ρ, while the profit of the PT operator will linearly decrease with the increase of ρ. Specifically, the CSaaS platform will benefit from this strategy when and only when $\rho > 31.2\%$ considering its operating cost regarding transferring parcels needs to be offset, small ρ is not accepted by the CSaaS platform. On the contrary, a large ρ is not favored by the PT operator. Therefore, the preferred ρ should be set in a proper range, no more and no less, to satisfy both the CSaaS platform and the PT operator.

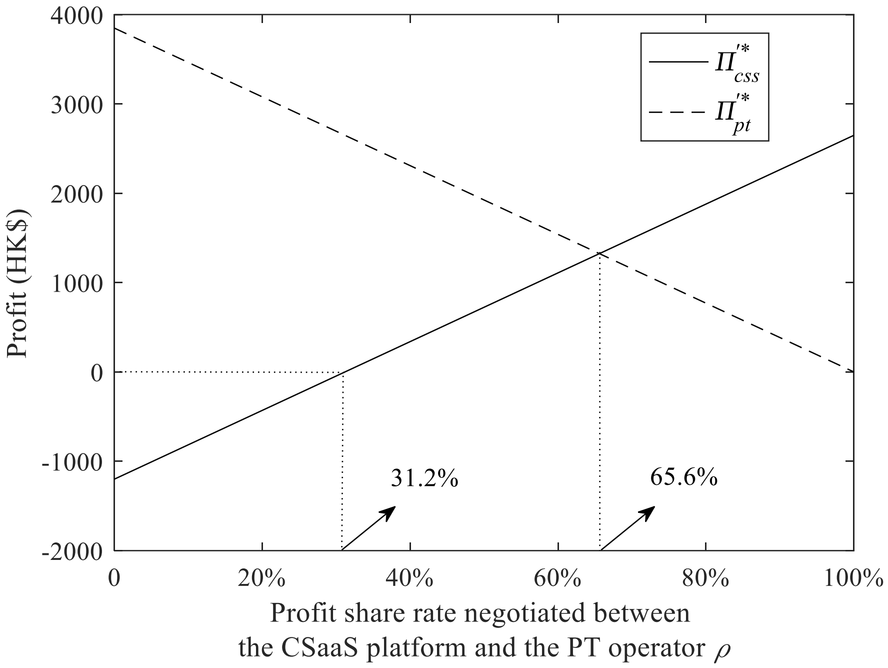


Figure 6. Sensitivity analysis of the profit share rate negotiated between the CSaaS platform and the PT operator

5.3. Extension regarding consignees' budget for new shipping modes

This subsection considers that consignees will have certain budgets for the two new shipping modes, i.e., the I-CS and CSaaS modes, while the conventional CL mode can be regarded as a substitute without the budget to satisfy the basic shipping demands. For simplicity, we consider that the consignees will have the same budget b for both the I-CS and CSaaS modes. Similar to the sensitivity analysis, we also focus on the profit of the shipping platforms under the most profitable operating strategy, i.e., the commission-based operating strategy. The parameters are set the same as the basic simulation, i.e., $L = 10\text{km}$, $N = 80{,}000$, $C_t = 1{,}200\text{HK\$}$, $C_{cl} = 10{,}000\text{HK\$}$, $\tau = 20\%$, and $\theta = 50\%$, while the value of ρ is set to be 65.6% according to the sensitivity analysis. According to Eq. (24), the shipping fees of the two novel modes, i.e., the I-CS and CSaaS modes, are calculated as $F'^*_{ics} = 0.15\text{HK\$}$ and $F'^*_{pt} = 0.05\text{HK\$}$, respectively. This indicates that three modes will co-exist in the market when the budget b is larger than $0.15\text{HK\$}$, while only the I-CS and CL modes are involved in the market when $0.05\text{HK\$} \le b \le 0.15\text{HK\$}$ and only the CL mode can be chosen when $b < 0.05\text{HK\$}$. If $b > 0.15\text{HK\$}$, the profits of the four platforms/operators can be directly referred to Eq. (26); If $0.05\text{HK\$} \le b \le 0.15\text{HK\$}$, the business model with CSaaS will reduce to the business mode without CSaaS, the profit of the involved platforms can be referred to Eq. (13); If $b < 0.05\text{HK\$}$, the model will further reduce to the conventional model with only the CL supplies, the profit of the CL platform can be obtained by adopting the proposed game-theoretic model, which is given by

$$\Pi_{cl}^{\prime *} = \frac{N + 2F_a LN + F_a^2 L^2 N - 8C_{cl}}{8} \tag{37}$$

where F_a denotes the alternative gains for consignees when they choose not to use shipping services. In particular, F_a is set to be $0.125\text{HK\$}$ measured by kilometer. Based on the preset parameters and Eqs. (13), (26), and (37), the profits of the involved platforms/operators affected by consignees' budgets are illustrated in Figure 7.

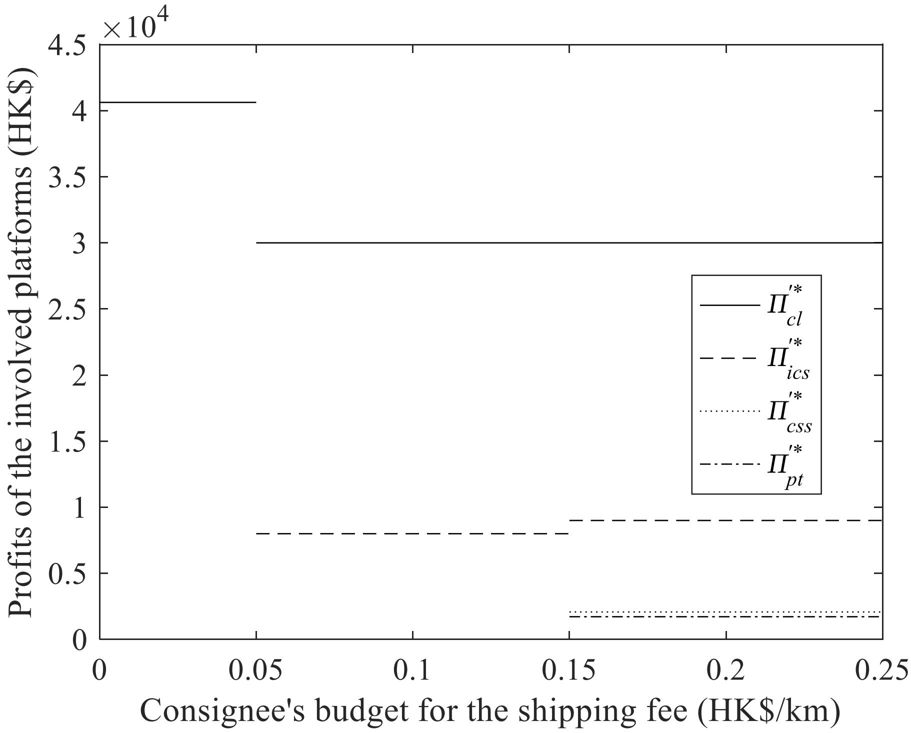


Figure 7. The impact of the consignee's budget on the profits of the shipping platforms

Figure 7 illustrates that the consignee's budget plays a role in reshaping the market. All three shipping modes will be included in the market when the budget is at a high level, i.e., $b > 0.15\text{HK\$}$ in this case. Only the I-CS and CL modes are involved in the market when the budget is at a middle level, i.e., $0.05\text{HK\$} \le b \le 0.15\text{HK\$}$, because the shipping fee of the CSaaS mode exceeds the budget of the consignee's budget. The consignees in this case will not choose the CSaaS mode, leading to the non-profit of the CSaaS platform and the PT operator. Only the CL mode is involved in the market when the budget is at a low level, i.e., $b < 0.05\text{HK\$}$ in this case, because the small budget of consignees cannot support their diversified shipping choices including the CSaaS and I-CS modes. In particular, the CL platform will generate more profits when the budget ranges from high to low, e.g., increases from 30,000HK$ to 40,625HK$ in this case, considering that the CL market share will increase in the absence of the CSaaS and I-CS modes.

5.4. Policy implications

Targeting the launch of the CSaaS service, this subsection summarizes three managerial implications according to the theoretical and numerical findings.

(i) Adopt the commission-based operating strategy for the CSaaS platform

Facing the proposed two operating strategies, the CSaaS platform is encouraged to choose the profitable commission-based strategy. This choice largely simplifies the CSaaS operating process, considering the platform will no longer need to make price decisions (conducted in the integrator-based strategy) but set a negotiable profit share rate with the PT operator in advance. The CSaaS platform can thus have spare efforts to enhance the CSaaS service, such as recruiting experienced staff to handle the parcel transshipment and installing lockers at stations for quick and safe delivery. This, in turn, helps to prompt the mode shift from I-CS and CL services to the CSaaS service for consignees and further benefits both the PT operator and the CSaaS platform.

(ii) Choose the target market/region with proper PT accessibility to launch CSaaS

The PT accessibility rate θ, denoting the ratio of the backbone distance to the total shipping distance of one OD pair, affects the equilibrium profits of all O2O players. A well-designed CSaaS operating strategy should not only benefit new players (i.e., the CSaaS platform and the PT operator) but also help to maintain competitiveness for original players (i.e., the I-CS and CL platforms) without profit loss. Based on this principle, the preferred PT accessibility rate should be in a proper range, no more and no less, to benefit all players. Generally speaking, the downtown areas have the largest PT distance ratio (i.e., the highest PT accessibility) among all urban structures, followed by the suburban and rural areas in descending order. The adopted commission-based strategy is thus encouraged to target specific markets/regions, e.g., suburban areas of Tsuen Wan and Sha Tin Districts in Hong Kong, with the proper PT accessibility.

(iii) Set the proper profit share rate between the CSaaS platform and the PT operator

As the key player to launch the CSaaS service, the CSaaS platform should take measures to further increase its profit. Since the commission-based operating strategy is adopted, the CSaaS platform will benefit from a specific proportion of the PT operator's profit, where the profit share rate ρ can be negotiated between the two players. The CSaaS platform pursues a higher profit share rate to offset its operating cost and further boost its profit, while the PT operator prefers a lower profit share rate for self-benefiting. The two players have the opposite pursuing targets to share the total profit. It is thus a necessity to set an appropriate profit share rate, no more and no less, to satisfy both the CSaaS platform and the PT operator. The two players can sign a contract or be guided by the government to determine an acceptable profit share rate to avoid disorderly competition.

6. Conclusions

In this study, we propose a novel concept of CSaaS to integrate I-CS and PT-CS services for the O2O shipping market. Compared with existing pure I-CS and CL services, CSaaS provides an alternative shipping mode and largely increases the shipping capacities since PT vehicles with large shipping potential can be included. Considering that PT vehicles cannot access the warehouse/retailing areas and residential areas, the pick-up and last-leg delivery chains should rely on the I-CS service. We thus design two operating strategies based on the role of the CSaaS platform in operating the CSaaS mode, namely, the commission-based and integrator-based strategies. The CSaaS platform in the commission-based strategy acts as an intermediary to provide a convenient channel for consignees to access both I-CS (in the pick-up and last-leg delivery chains) and PT-CS (in the backbone chain) services, which can benefit from a specific proportion of the PT operator's profit. The CSaaS platform in the integrator-based strategy acts as a reseller to purchase the two CS services from the I-CS platform and the PT operator on the one hand and resell these services through a uniform fee to consignees on the other hand, which can benefit from the difference between fees charged and costs suffered. For comparison, we propose a game-theoretic approach to formulate two business models with and without CSaaS. The business models explicitly depict the interactive relations among players, i.e., the I-CS platform, the CL platform, and consignees when CSaaS is unavailable, while the I-CS platform, the CSaaS platform, the PT operator, the CL platform, and consignees when CSaaS is available. Equilibrium results with respect to each player's optimal behaviors, i.e., the price decisions and profits of the platforms/operators and the choice decisions of consignees, in each model are systematically derived. We then reveal the choice of operating strategy and the impact of CSaaS on original players in the market. Results show that the commission-based strategy should be selected and a target market with the proper PT accessibility should be carefully chosen to benefit all players.

To further explore CSaaS operations management at a strategic level, several aspects are worthy of investigation in the future. First, more complex and realistic scenarios can be explored and designed. For instance, the parcels in pick-up and last-leg delivery chains of CSaaS mode can be shipped by both I-CS shippers and the CL fleet. Second, the role of the government or the transport sector can be incorporated into the O2O market. Considering that the introduction of CSaaS results in the shift of private car/truck use to PT vehicle use and the equilibrium results of the market are related to urban PT structure, the government or the transport sector can act as a regulator to motivate all players in the market to behave for a certain carbon-reduction target. Third, the shipping operations can be further investigated by considering multiple lines. The impact of this setting on the macro-level results may be identified as the incentive for shippers to participate in the I-CS market, which can further enhance the I-CS market share and the I-CS platform's profits.

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Appendix A. Market Equilibrium Analysis for the Integrator-based Operating Strategy

This section presents the derivative process of the equilibrium results concerning the shipping fees, market shares, and profits under the integrator-based operating strategy. Applying the same method for the business model without CSaaS, the three market shares with respect to price decisions are obtained from Eqs. (32)-(34), which is given by

$$\begin{cases} \lambda''\left(F''_{css},F''_{ics}\right)=\dfrac{1+F''_{css}L-F''_{ics}L}{2} \\ \upsilon''\left(F''_{css},F''_{ics},F''_{cl}\right)=\dfrac{F''_{cl}L-2F''_{css}L+F''_{ics}L}{2} \\ \omega''\left(F''_{ics},F''_{cl}\right)=\dfrac{1-F''_{cl}L+F''_{css}L}{2} \end{cases} \tag{C1}$$

By substituting Eq (C1). into Eqs. (28)-(31), the four players' profits with respect to their price decisions are given by

$$\begin{cases} \Pi''_{css}\left(F''_{css},F''_{ics},F''_{pt},F''_{cl}\right)=\dfrac{N\left(F''_{cl}L-2F''_{css}L+F''_{ics}L\right)\left[F''_{css}L-F''_{ics}\left(L-L_b\right)-F''_{pt}L_b\right]}{2}-C_t \\ \Pi''_{ics}\left(F''_{css},F''_{ics},F''_{cl}\right)=\dfrac{F''_{ics}LN\tau\left[1+F''_{cl}L-F''_{css}L-\left(F''_{cl}-2F''_{css}+F''_{ics}\right)L_b\right]}{2} \\ \Pi''_{pt}\left(F''_{css},F''_{ics},F''_{pt},F''_{cl}\right)=\dfrac{F''_{pt}L_bN\left(F''_{cl}L-2F''_{css}L+F''_{ics}L\right)}{2} \\ \Pi''_{cl}\left(F''_{css},F''_{cl}\right)=\dfrac{F''_{cl}NL-2C_{cl}-F''^{2}_{cl}L^2N+F''_{cl}F''_{css}L^2N}{2} \end{cases}$$

(C2)

It can be deduced that the second derivatives of these profit functions with respect to their own price decisions are negative, indicating these platforms/operators have the maximum value under the price decisions derived from the setting that the first derivatives of these profit functions with respect to their own price decisions equal zero, which is given by

$$
\begin{cases}
F''_{css}\left(F''_{ics}, F''_{pt}, F''_{cl}\right) = \dfrac{F''_{cl}L + 3F''_{ics}L - 2F''_{ics}L_b + 2F''_{pt}L_b}{4L} \\
F''_{ics}\left(F''_{css}, F''_{cl}\right) = \dfrac{1 + F''_{cl}L - F''_{css}L - F''_{cl}L_b + 2F''_{css}L_b}{2L_b} \\
F''_{pt}\left(F''_{css}, F''_{ics}, F''_{cl}\right) = \dfrac{F''_{css}L + F''_{ics}\left(L_b - L\right)}{L_b} - \dfrac{2C_t}{L_b LN\left(F''_{cl} - 2F''_{css} + F''_{ics}\right)} \\
F''_{cl}\left(F''_{css}\right) = \dfrac{1 + F''_{css}L}{2L}
\end{cases}
\tag{C3}
$$

Considering that these platforms/operators will independently make their price decisions regarding other players' decisions as constant. We can further derive the equilibrium shipping fees from Eq. (C3). In particular, we derive two different results because there has a quadratic term here. Given the equilibrium shipping fees, other equilibrium results including market shares and profits can be obtained, which are listed in Table 1.

Appendix B. The Proof of Proposition 2

Proof. We first focus on the effect of the CSaaS on the shipping fee of the I-CS platform. The difference between the business model with CSaaS (under the commission-based strategy) and the business model without CSaaS regarding this fee is given by

$$
\Delta F_{ics} = F'^{*}_{ics} - F^{*}_{ics} = \frac{2\left(4LL_b - 5L_b^2\right)}{L\left(5L^2 - 9LL_b + 10L_b^2\right)} \tag{B1}
$$

Let $F\left(L_b\right)$ equal $5L^2 - 9LL_b + 10L_b^2$; we can derive that $F'\left(L_b\right) = 20L_b - 9L$ and $F''\left(L_b\right) = 20$, which indicates that $F\left(L_b\right)$ has the minimum value under a certain value of $L_b = \frac{9}{20}L$ derived from $F'\left(L_b\right) = 0$. The minimum value of $F\left(L_b\right)$ is $F^*\left(L_b\right) = \frac{119}{40}L^2 > 0$, which indicates that $F\left(L_b\right)$ is positive. Similarly, let $G\left(L_b\right)$ equal $4LL_b - 5L_b^2$; we can derive that $G'\left(L_b\right) = 4L - 10L_b$ and $G''\left(L_b\right) = -10$, which indicates that $G\left(L_b\right)$ has the maximum value $G^*\left(L_b\right) = \frac{4}{5}L^2 > 0$ under a certain value of $L_b = \frac{2}{5}L$. This demonstrates that $G(L_b)$ may or may not be positive. We further let $G(L_b)$ equal zero and find that $L_{b1}=0$ and $L_{b2}=\frac{4}{5}L$. It can be obtained that $G(L_b)\geq 0$ when $0\leq L_b\leq\frac{4}{5}L$ and $G(L_b)<0$ when $\frac{4}{5}L<L_b\leq L$. Combining the values of $F(L_b)$ and $G(L_b)$, we can obtain the following relationship:

$$\Delta F_{ics}\begin{cases}\geq 0,\ \text{if } 0\leq\theta\leq\frac{4}{5}\\ <0,\ \text{if } \frac{4}{5}<\theta\leq 1\end{cases} \tag{B2}$$

We then focus on the effect of the CSaaS on the I-CS market share. The difference between the business model with CSaaS (under the commission-based strategy) and the business model without CSaaS regarding this market share is given by

$$\Delta\lambda=\lambda'^{*}-\lambda^{*}=\frac{L_b^2-2LL_b}{5L^2-9LL_b+10L_b^2} \tag{B3}$$

Considering that $F(L_b)=5L^2-9LL_b+10L_b^2$ is positive, the value of $\Delta\lambda$ in Eq. (B3) depends on the value of $L_b^2-2LL_b$. With the constraint of $0\leq L_b\leq L$, we find that $L_b^2-2LL_b\leq 0$. Therefore, the value of $\Delta\lambda$ in Eq. (B3) is nonpositive ($\lambda'^{*}\leq\lambda^{*}$) all the time.

The proof of Proposition 2 is completed. □

Appendix C. The Proof of Proposition 3

Proof. We first focus on the effect of the CSaaS on the shipping fee of the CL platform. The difference between the business model with CSaaS (under the commission-based strategy) and the business model without CSaaS regarding this fee is given by

$$\Delta F_{cl}=F_{cl}'^{*}-F_{cl}^{*}=\frac{2\left(LL_b-2L_b^2\right)}{L\left(5L^2-9LL_b+10L_b^2\right)} \tag{C1}$$

Considering that $F(L_b)=5L^2-9LL_b+10L_b^2$ is positive, the value of ΔF_{cl} in Eq. (C1) depends on the value of $LL_b - 2L_b^2$. Let $H(L_b)$ equal $LL_b - 2L_b^2$; we can derive that $H'(L_b) = L - 4L_b$ and $H''(L_b) = -4$, which indicates that $H(L_b)$ has the maximum value $H^*(L_b) = \frac{L^2}{8} > 0$ under a certain value of $L_b = \frac{L}{4}$ derived from $H'(L_b) = 0$. This demonstrates that $H(L_b)$ may or may not be positive. We further let $H(L_b)$ equal zero and find that $L_{b3} = 0$ and $L_{b4} = \frac{1}{2}L$. It can be obtained that $H(L_b) \geq 0$ when $0 \leq L_b \leq \frac{1}{2}L$ and $H(L_b) < 0$ when $\frac{1}{2}L < L_b \leq L$. Combining the values of $F(L_b)$ and $H(L_b)$, we can obtain the following relationship:

$$\Delta F_{cl} \begin{cases} \geq 0, \text{ if } 0 \leq \theta \leq \frac{1}{2} \\ < 0, \text{ if } \frac{1}{2} < \theta \leq 1 \end{cases} \tag{C2}$$

We then focus on the effect of the CSaaS on the CL market share. The difference between the business model with CSaaS (under the commission-based strategy) and the business model without CSaaS regarding this market share is given by

$$\Delta\omega = \omega'^* - \omega^* = \frac{LL_b - 2L_b^2}{5L^2 - 9LL_b + 10L_b^2} \tag{C3}$$

Similar to the comparison regarding the CL shipping fees, we can obtain the following relationship concerning the value of $\Delta\omega$ in Eq. (C3):

$$\Delta\omega \begin{cases} \geq 0, \text{ if } 0 \leq \theta \leq \frac{1}{2} \\ < 0, \text{ if } \frac{1}{2} < \theta \leq 1 \end{cases} \tag{C4}$$

In other words, the introduction of CSaaS has the same effect on the CL shipping fee and the CL market share.

The proof of Proposition 3 is completed. □