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Platform competition with partial multi-homing: When both same-side and cross-side network effects exist

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ABSTRACT

In platform competition, users get on board because of network effects, and they shape a distinct platform service supply chain (PSSC) structure contingent upon the participation decision of both sides, which can be: both sides single-homing (SH–SH), buyers single-homing and sellers partially multi-homing (SH–MH), buyers partially multi-homing and sellers single-homing (MH–SH), and both sides partially multi-homing (MH–MH). One thing in common is that in either PSSC, there exist both same-side and cross-side network effects among users. Although platform competition in practice can be easily captured, the impact of network effects on platform's pricing decisions in different scenarios may vary. Based on a stylized Hotelling model, this paper incorporates buyers' same-side network effects and both buyers' and sellers' cross-side network effects while considering heterogeneous taste preferences of users on each side. We analyze the two-sided pricing, market share, and platform profit in equilibrium and conduct sensitivity analyses under each scenario supplemented by numerical verification. For each case, the findings are as follows. (1) SH–SH: the equilibrium market shares of both platforms are equal yet unaffected by two-sided pricing. (2) SH–MH: the stronger the sellers' taste preferences and the users' cross-side network effects, the more the sellers prefer single-homing. When sellers' cross-side network effects are stronger than that of buyers, the platform posts a charge to sellers; otherwise, it offers a subsidy. (3) MH–SH: the stronger the buyer's taste preferences and the total network effects, the more the buyers prefer single-homing. Moreover, the buyers' same-side network effects have a non-monotonic impact on their price and a monotonically decreasing impact on the sellers' price. (4) MH–MH: whether equilibrium solutions exist is ambiguous.

1. Introduction

1.1. Background

With the rapid development of internet technology, business models are transforming from the traditional "pipeline type" to a more prevalent "platform pattern." According to the "2019 Internet Trend Report" released by Mary Meeker, seven out of the top ten global companies in terms of market value are internet platform companies.[1] The rise of the platform economy has incentivized more and more companies to uproot their traditional thinking, becoming facilitators of interactions across different groups of users in the market. The impact of platforms is felt in people's daily lives, with game console platforms connecting developers and players, food delivery platforms connecting restaurants and consumers, and so on. A second glance at these established platforms reveals that they are essentially "service providers", offering value-added services associated with specific phases of transactions and transfers of goods: this facilitates the emergence of the platform service supply chain (PSSC).

Network effects are inherent in PSSCs, acting as a catalyst for platforms to get both sides on board. A typical network effect relates to the inter-attraction across different groups. For example, a higher number of games provided by Nintendo compared with Sony would attract a greater number of game players to purchase a Switch rather than a PlayStation. Noticeably, network effects can also exist among users in the same group. In the given example, a Switch player may purchase the device simply to play multi-player games with friends who own the same devices and not primarily because of the game's attraction. The

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[1] Source: https://tech.sina.com.cn/i/2019-06-12/doc-ihvhiqay5023579.shtml?source=cj&dv=1. The seven companies mentioned above are Microsoft, Amazon, Apple, Alphabet, Facebook, Alibaba, and Tencent in sequence.

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existence of both network effects accelerates the growth of PSSCs. More platform companies are starting to enter the market, triggering competition between platforms. For example, in China, Meituan launched its catering take-out service in 2013, five years after Ele. me started its operations. Since then, the catering delivery market has been subject to a duopoly competition between two platform companies, which applies to a variety of other industries.

In platform competition, users on both sides of the market can either join one platform, termed single-homing, or simultaneously join both platforms, termed multi-homing. To distinguish between the two groups, we classify them as “buyers” and “sellers”, and they are both considered platform “users”. Since users on both sides have two options when making participation decisions on a platform, these options together lead to four different PSSC structures: both sides single-homing (SH–SH), buyers single-homing and sellers partially multi-homing (SH–MH), buyers partially multi-homing and sellers single-homing (MH–SH), and both sides partially multi-homing (MH–MH). The distinction in market structure comes from diverse aspects, including product or service prices (the higher the price, the less likely for buyers to multi-home), intellectual property (IP) concerns (the more stringent the IP protection, the less likely for sellers to multi-home), firm’s marketing strategies (“marquee” strategy by securing big seller’s exclusive participation) and so on. In Table 1, we summarized some typical real-world cases of platform competition involving user participation decisions, and analyzed both the market composition and the common behavior of two-sided users.

In the software industry, consumers on one side averagely possess one laptop, one mobile phone, or one game console and thus single-home, while developers on the other side either single-home or multi-home depending on whether the technology is proprietary. The case of video-conferencing software, however, shows some discrepancies in that software users usually multi-home while software developers single-home.[2] In the daily consumption industry regarding catering services, both consumers and restaurants are inclined to multi-home on different platforms, so that the formers get more choices while the latters gain more exposure, which is also the case of supermarket. In addition, it is worth noticing that all of the four cases can possibly reside in the same industry. A typical example is the shopping mall, which connects consumers with high-end brands. On one side of this market, consumers will prefer single-homing to multi-homing if the shopping mall adopts a membership-based system, so that a more concentrated consumption can then redeem for cash or gifts; on the other side, brands will choose to single-home rather than multi-home if the shopping mall pursues a “marquee” strategy, that is, signing an exclusive contract with one or several leading brands so as to get more traffic locked in its own place. Thus, it can be seen that differences in market structure exist both within and across industries, which is a result of the participation decision of two-sided users.

1.2. Motivation and contribution

Multi-platform competition is an inevitable challenge faced by PSSC management. In most markets with two major platforms competing against each other, the existence of both same-side and cross-side network effects can be captured. Users on both sides make their participation decisions based on the pricing strategies of competing platforms and the taste preferences of their own, which lead to a corresponding PSSC structure. Trade-offs exist in both the pricing decision of platforms and the participation decision of two-sided users: for platforms, a higher price charged on either side increases marginal revenue but disperses affiliated users; while for users, multi-homing on both platforms enables more transaction with larger network benefits, but also causes higher costs since they will be charged by both platforms.

Motivated by the real-world cases of platform competition involving user multi-homing behaviors, we raise the following research questions in our study: 1) What are the equilibrium two-sided pricing strategies for platforms in different PSSCs considering users’ multi-homing behaviors? 2) What is the impact of network effects on platform pricing in different participation scenarios? 3) How will the market share change with respect to network effects? 4) How will the equilibrium results change with user heterogeneity on both sides? To answer the above questions, in this paper, we build a duopoly competition model based on the stylized Hotelling framework. Apart from the embedded heterogeneous taste preferences of two-sided users, we also incorporate buyers’ same-side network effects and both buyers’ and sellers’ cross-side network effects, and analyze the competitive equilibrium for each of the four PSSC structures.

Our research contribution manifests in the following two aspects. Theoretically, we contribute to the existing literature on platform competition, two-sided pricing, and partial multi-homing. Moreover, we considered both same-side and cross-side network effects in two-sided markets and examined their impact on the optimal pricing schemes of platforms in different PSSC structures. Practically, the differences in equilibrium results indicate the necessity for platform companies to clarify PSSC structures before determining the pricing strategies for both sides. Our conclusions provide guidance for platform companies to set two-sided prices, adjust the proportion of users with different participation choices, achieve profit optimization and thereby maintain sustainable progress in the market.

For each scenario, our main conclusions are as follows. SH–SH: the equilibrium market shares of both platforms are equal yet unaffected by two-sided pricing. SH–MH: the stronger the sellers’ taste preferences and users’ cross-side network effects, the more the sellers tend to choose single-homing instead of multi-homing. In addition, when sellers’ cross-side network effects are stronger than that of buyers, the platform posts a charge to sellers; otherwise, it offers a subsidy. MH–SH: the stronger the buyers’ taste preferences and the total network effects, the more the buyers prefer single-homing to multi-homing. In addition, the same-side network effects of buyers have a non-monotonic impact on their own price and a monotonically decreasing impact on the sellers’ price. MH–MH: whether the equilibrium solutions exist is ambiguous.

The rest of this paper is organized as follows. We first review the literature relevant to our research in Section 2. In Section 3, we introduce our SH–SH base model and solve for equilibrium solutions. In Section 4, we extend our research framework to cases involving partial multi-homing, namely, SH–MH, MH–SH, and MH–MH, and derive the equilibrium outcomes supplemented with sensitivity analysis for each of the scenarios. Section 5 presents the numerical analysis. Section 6 provides a summary and the conclusions.

2. Literature review

Our work is primarily connected with two domains in the existing literature: one is the pricing strategy under platform competition, and the other is the impact of user participation decisions on platform competition.

2.1. Two-sided pricing strategy under platform competition

2.1.1. Network effects

The emergence of a two-sided market requires three conditions: the existence of distinct groups of users, benefits generated from interactions across groups, and efficiency in the coordination achieved by intermediaries (Evans, 2003), and the second condition implies network effects. The network effect, also known as network externality, refers to

[2] The reason here is that, compared with open-source platforms such as GitHub and InnoCentive, video conferencing companies like Zoom and Tencent form a clear employment relationship with their individual developers, which made it less possible for their employees to work simultaneously for the competing company considering business confidential issues.

Table 1
Typical examples of platform competition involving user multi-homing decisions.

Industry	Platform	Example	Side one (buyer)	Common choice	Side two (seller)	Common choice
Software	Video game console	Nintendo, Sony	Game player	SH	Game developer	SH/MH
	Operating system	Windows, MacOS; Android, iOS	Application user	SH	Application developer	SH/MH
	Video conferencing	Zoom, Tencent Meeting	Software user	MH	Software developer	SH
Daily consumption	Shopping mall	Nordstrom, Bloomingdale's	Consumer	SH/MH	Premium brand	SH/MH
	Supermarket	Walmart, Carrefour	Consumer	MH	Grocery brand	MH
	Food delivery	Ele.me, Meituan	Consumer	MH	Restaurant	MH

the phenomenon in which the utility a user obtains from consuming a product or service increases as the number of users who consume the same product or service rises (Katz and Shapiro, 1985). Later on, the existence of network effects was first confirmed through empirical research in the telephone yellow pages market (Rysman, 2009). Based on the path of generation, network effects can be divided into same-side and cross-side effects (Eisenmann et al., 2006). The former refers to the situation where a user's utility increases with the expansion of the group he/she belongs to, while the latter refers to the increase in the user's utility with the expansion of the group on the other side of the market. According to the "vanilla" network theory, in the competitive markets where network effects play an important role, the scale of network effects determines the competition in a direct manner (Chang et al., 2010). Abstracting from the video game industry, Zhu and Iansiti (2012) studied empirically the factors affecting entry into platform-based market, and found that an entrant's success depends on the strength of cross-side network effects. Later on, Anderson et al. (2014) studied the impact of investment on platform performance in the presence of strong cross-network externalities, and questioned the conventional wisdom of "winner-take-all" by observing that heavy investment does not always yield a competitive edge for the platform. In general, network effects are essential in two-sided markets to get both sides on board, but much of the attention in existing literature has been focused on the cross-side effect while little on the same-side effect, the latter of which is critical in platform development at the early stages (Chi et al., 2019).

2.1.2. Platform competition with two-sided pricing

Research on platform competition originates from Rochet and Tirole (2003). Their work serves as the "shoulder of giants" in two ways: they were the first to build a two-sided platform competition model and led the way for follow-up studies, and they unveiled the phenomenon of multi-homing in the market. Owing to the existence of network effects, a platform needs to grow a sufficient seller base to attract buyers; however, sellers are willing to join only if they observe a large number of buyers ex ante. This seemingly contradictory yet common phenomenon has been called the "chicken and egg" problem by Caillaud and Jullien (2003). In this regard, Eisenmann et al. (2006) proposed that a platform should adopt a "divide-and-conquer" strategy by first setting the price low and even offering subsidy to one party to ensure their participation, and then charging the other an exorbitantly high price to make up for the loss and collect profits. This rationally explained the existence of some free-goods market as observed by Parker and Van Alstyne (2005). For example, streaming media platforms provide consumers with free software but charge developers to create contents. Besides the indirect benefit toward producers because of more consumers, Hagiu (2009) observed an additional motivation for a platform to lower its price on the consumer side, which is to undercut the rival platform and thereby stealing some of its consumers. However, this "stealing behavior" will be less effective when consumers' preferences are strong.

Apart from these early studies concentrating on fundamental platforms, scholars have extended research by adopting an industry-specific manner. For example, Economides and Katsamakas (2006) compared the pricing strategies in the software industry between a proprietary platform and an open-source platform, and found that when users have a strong preference for application variety, the total profit of the former is larger than that of the latter. Rochet and Tirole (2008) analyzed the effects of tying on competition in the credit card industry with multi-homing of cardholders, and found that product tying increased social welfare, which is also studied by Choi (2010) in view of the digital media market. Besides these studies focusing on typical industries with two-sided characteristics, many scholars have also examined platform competition in more concrete settings, such as vertically differentiated platforms (Wan and Gao, 2013; Jung et al., 2019), first-party content platforms (Hagiu and Spulber, 2013; Lin et al., 2020), media advertising platforms (Ambrus et al., 2016; Athey et al., 2018) and so on. Platform competition creates more choices for users in their way of participating in the market, however, not many of the above studies have considered the multi-homing decision of two-sided users as well as its impact on the resulting PSSC structure.

2.2. Impact of user participation decisions on platform competition

Users' participation behaviors can be generally classified into two types: single-homing and multi-homing, and the latter is further divided into complete multi-homing and partial multi-homing. The former refers to the case when each participant on one side joins both platforms, while the latter indicates that only some of them join both, and users are thus divided into three types: single-homing on platform 1, multi-homing on both platforms, and single-homing on platform 2. Multi-homing stems from the users' desire to reap the benefits of network externalities in an environment of non-interconnected platforms (Rochet and Tirole, 2006). The literature on this topic can be sorted specifically into three streams.

First, research on single-homing is uniformly tied with multi-homing based on market categorization. The most foundational work under the topic comes from Armstrong (2006), which considered two market scenarios, namely, both groups single-homing, and one group single-homing while the other multi-homing, with the latter termed as a "competitive bottleneck". The author believed that a third case of multi-homing on both sides is not common, because if each member of group 1 joins both platforms, then for group 2, a single-homing choice of either platform can enable them to achieve interaction with all group 1 members and therefore no need to join both again. However, this opinion was derived from the premise of a "complete" multi-homing, which, in practice, is not that common compared with "partial" multi-homing. Specifically, Doganoglu and Wright (2006) built their model by considering multi-homing in a one-sided market setting, and found that multi-homing increases social welfare but reduces firms' incentive to invest in compatibility. Many if not most markets with network externalities are two-sided (Rochet and Tirole, 2003), therefore, most studies in this field still focus on platform competition in a two-sided setting, which is also the basis and rationale of our research.

Second, most of the research involving complete multi-homing has adopted the model of a competitive bottleneck. Armstrong and Wright (2007) stated that competitive bottleneck arises when platforms are viewed homogenous by sellers but heterogenous by buyers, leading to multi-homing of the former while single-homing of the latter. Therefore, in equilibrium, platforms will compete on the buyer side by offering subsidies to attract them to join. The competitive bottleneck model was also introduced into asymmetric information environment (Hagiu and Hałaburda, 2014). In some recent studies, Belleflamme and Peitz (2019) analyzed the optimal prices in pure single-homing and competitive bottleneck models, respectively. Although multi-homing on both sides is not addressed in their work, they recognized the importance of studying platform competition when both sides choose to multi-home. Zhou et al. (2019) found that when the marginal cost of the platform and the scale of cross-side network effects are strong, the signing of exclusive contracts can enhance social welfare. Apart from these, some scholars begin to study multi-homing on both sides. For example, Bryan and Gans (2018) modeled competition between two ridesharing platforms where both riders and drivers multi-home. However, they still assume a complete multi-homing in their model, which lacks differentiation in the multi-homing side.

Third, a growing trend of literature has been focusing on the behavior of partial multi-homing. Poolsombat and Vernasca (2006) first proposed the concept of partial multi-homing and analyzed the equilibrium pricing of competing platforms in three different scenarios, namely, single-homing on both sides, partial multi-homing on one side only, and partial multi-homing on both sides. However, the utility functions of the two-sided users in their study are essentially symmetrical, making it less likely to distinguish between the groups, which is also the limitation of Doganoglu and Wright (2006). Later on, scholars have conducted in-depth studies on partial multi-homing. Rasch (2007) studied platform competition with partial multi-homing by incorporating heterogenous transportation costs of both sides, which extended the study of Poolsombat and Vernasca (2006) since they assumed equal transportation costs. Many scholars have then studied asymmetric platforms in the scale of network externalities (Ji and Wang, 2014), the sequence of entry into the market (Gao, 2017), and the technology gap in production cost (Jung et al., 2019). In some recent work, Bakos and Hałaburda (2020) studied multi-homing on both sides with platforms' subsidization policies. However, these studies only paid attention to the cross-side network effects in the market but ignored its same-side companion. Chellappa and Mukherjee (2020) incorporated both same-side and cross-side network effects while studying platform competition in the video game console market. However, subject to the preset industry background, they assumed single-homing on the gamer side, and compared the equilibrium results when developers choose to single-home and multi-home, respectively.

2.3. Contributions to the literature

On the whole, current studies either focused on a specific PSSC structure, such as single-homing on one side and partial multi-homing on the other (Rasch, 2007; Cheng, 2010) and partial multi-homing on both sides (Ji and Wang, 2014; Jung et al., 2019), or took single-homing on one side as a prerequisite and studied the impact of participation decisions on the other side on the competitive equilibrium outcomes (Zhang and Li, 2010; Chellappa and Mukherjee, 2020). Most of the above literature have, to some extent, ignored the rest of the PSSC structures. In Table 2, we summarized and compared some of the existing studies relevant to, but different from our paper in certain aspects.

Moreover, although the existence of network effects in two-sided markets is self-evident, most studies only considered network effects among users across distinct groups (Poolsombat and Vernasca, 2006; Rasch, 2007; Zhang and Li, 2010; Ji and Wang, 2014; Gao, 2017; Jung et al., 2019; Wang and Fu, 2019; Bakos and Hałaburda, 2020) while ignoring network effects within the same group. For some two-sided platforms, user participation on one side is more likely to be determined by the scale of same-side network effect. For example, an individual user installs Zoom or Tencent Meeting mainly for communication with users on the same side, so the current user base of a platform largely determines a potential user's choice. In this regard, taking into consideration the existence and impact of same-side network effects is important both theoretically and practically.

Table 2
Research comparison of previous literature involving multi-homing decisions.

	Network effects		Platform service supply chain structures			
	Same-side	Cross-side	SH-SH	SH-MH	MH-SH	MH-MH
Competitive bottleneck						
Armstrong (2006); Zhou et al. (2019)		✓	✓	✓		
Armstrong and Wright (2007); Belleflamme and Peitz (2019)		✓	✓	✓		
Partial multi-homing						
Poolsombat and Vernasca (2006)		✓	✓	✓		✓
Rasch (2007)		✓		✓		
Cheng (2010)		✓	✓	✓		
Ji and Wang (2014); Jung et al. (2019)		✓				✓
Zhang and Li (2010)		✓		✓		✓
Gao (2017); Bakos and Hałaburda (2020)		✓	✓	✓		✓
Bryan and Gans (2018)			✓	✓	✓	✓
Wang and Fu (2019)		✓	✓	✓	✓	✓
Chellappa and Mukherjee (2020)	✓	✓	✓	✓		
Our paper	✓	✓	✓	✓	✓	✓

Notes.
1. The definition of multi-homing in the competitive bottleneck model refers to a complete multi-homing where all users at that side multi-home.
2. The merge of SH-MH and MH-SH means that users at two sides are not clearly distinguished by buyers and sellers but generally represented by group 1 and group 2.
3. The cross-side network effects in Cheng (2010) is negative because its research context is the media market which connects consumers and advertisers, and hence more ads distributed would result in less utility enjoyed by consumers.

Our study in the context of PSSC management contributes to the existing literature in two ways. **First**, previous research on platform competition has scarcely considered different types of PSSC structures in a comprehensive framework. In this regard, we constructed our platform competition model by considering four PSSC structures contingent upon the participation decision of users on both sides, and analyzed two-sided pricing, market share, and platform profit for each of the scenarios. **Second**, existing two-sided platform researches mainly focused on the cross-side network effects while failing to notice the potential impact of same-side effects. We thus focused on both same-side and cross-side network effects, to be specific, same-side network effects in the buyers' group and the cross-side network effects in both the buyers' and sellers' groups.[3] Our paper could, to some extent, provide a more generic and compatible framework in studying platform competition involving user partial multi-homing behaviors, and shed light on the formation of different PSSC structures in real markets as well as guide the two-sided pricing decisions of platform enterprises.

[3] Theoretically, the existence of same-side network effects in the sellers' group is also possible; for example, the higher salary of software developers will attract more people to choose it as career. However, according to Chellappa and Mukherjee (2020), this positive effect will be eroded in a competitive environment. As such, we do not consider same-side network effects among sellers in this study.

3. Base model

3.1. Problem description

We construct our platform competition model involving user participation decisions based on the stylized Hotelling model. There are two groups of users in the market: the buyers (denoted by b) and the sellers (denoted by s). Each of the groups forms a Hotelling line with a length of 1, and users are uniformly distributed along the line. There are two horizontally differentiated platforms (denoted by i and $-i$, respectively) on the market, with each located at the terminal of the Hotelling lines. The location of an individual user represents his/her ideal platform choice. Since there are two options available in the market, each user, apart from those located perfectly at the terminal, will incur some transportation costs, which are denoted by t_b and t_s for buyers and sellers, respectively. The transportation cost also reflects a user's strength of taste preferences to the platform, in that the greater this value is, the stronger the user's willingness to choose the ideal platform and thus, the higher the disutility he/she will suffer when settling for a choice away from the optimum. Users who join the platform will obtain a reserved utility denoted by θ. We assume this value to be large enough so that the duopolies together could cover all users in the market. An individual buyer or seller needs to pay a certain amount of p or w to join the platform. The participation of the former can generate both same-side network effects, α_b, and cross-side network effects, β_b, while the participation of the latter can generate cross-side network effects, β_s. It is optional for users at both sides to join either one platform (SH) or both platforms (MH), which, after making the decision, shapes a specific PSSC structure. The number of single-homing buyers and sellers on platform i and $-i$ is denoted by n_b^i, n_s^i and n_b^{-i}, n_s^{-i}, respectively, while the number of multi-homing buyers and sellers is denoted by $n_b^{i,-i}$ and $n_s^{i,-i}$, respectively. A summary of the notations is provided in Table 3.

We follow the assumption of $t_j > \beta_j$, where $j \in \{b,s\}$, indicating that a user's taste preference will not be dominated by network effects (Armstrong 2006; Armstrong and Wright, 2007; Jung et al., 2019). Since we have decomposed network effects into same-side and cross-side effects, an additional condition of $t_b > \alpha_b$ is added to keep it consistent with the above assumptions. The game between duopoly platforms and two-sided users consists of two stages. In the first stage, platforms i and $-i$ set their pricing strategies (p^i,w^i) and (p^{-i},w^{-i}) simultaneously; and in the second stage, users on both sides observe the pricing and make participation decisions of their own. We adopt backward induction to solve this dynamic game.

Table 3
Notations of parameters and variables.

Parameters			
θ	Reservation utility of both sides	α_b	Same-side network effects of buyers
β_b	Cross-side network effects of buyers	β_s	Cross-side network effects of sellers
t_b	Transportation cost of buyers	t_s	Transportation cost of sellers
n_b^i	Number of buyers single-homing on platform i	n_s^i	Number of sellers single-homing on platform i
$n_b^{i,-i}$	Number of buyers multi-homing on both platforms i and $-i$	$n_s^{i,-i}$	Number of sellers multi-homing on both platforms i and $-i$
U_b^i	Utility function of buyers single-homing on platform i	U_s^i	Utility function of sellers single-homing on platform i
$U_b^{i,-i}$	Utility function of buyers multi-homing on both platforms i and $-i$	$U_s^{i,-i}$	Utility function of sellers multi-homing on both platforms i and $-i$
Π^i	Profit function of platform i		
Decision variables			
p^i	Platform i's pricing to buyers	w^i	Platform i's pricing to sellers

3.2. Single-homing on both sides (SH-SH)

First, we consider the base case. The PSSC structure in this scenario is shown in Fig. 1. Because both buyers and sellers single-home, we have $n_b^i + n_b^{-i} = 1$, and $n_s^i + n_s^{-i} = 1$. There exists a unique indifference point on either the Hotelling line of buyers and sellers, meaning that the particular user located at that point is indifferent about joining either platform i or platform $-i$. The utility of the indifferent buyer single-homing on platform i is

$$U_b^i = \theta + \alpha_b n_b^i + \beta_b n_s^i - p^i - t_b n_b^i. \tag{1}$$

Among them, the first term is a reservation utility of accessing the platform, which is a standalone value independent of network effects. The second and third terms indicate the same-side and cross-side network utilities, respectively; both of them are increasing with the number of platform-connected buyers and sellers. The fourth term refers to the price charge by the platform. And the last term is the transportation cost, or the disutility, caused by relegating to platform i.

Similarly, the utility of that buyer single-homing on platform $-i$ is

$$U_b^{-i} = \theta + \alpha_b n_b^{-i} + \beta_b n_s^{-i} - p^{-i} - t_b\left(1 - n_b^i\right) \tag{2}$$

In this function, the last term is the disutility of settling for platform $-i$, which increases with the buyer's psychological distance to that platform.

In addition, the utility of the indifferent seller single-homing on platform i is

$$U_s^i = \theta + \beta_s n_b^i - w^i - t_s n_s^i. \tag{3}$$

The utility of that seller single-homing on platform $-i$ is

$$U_s^{-i} = \theta + \beta_s n_b^{-i} - w^{-i} - t_s\left(1 - n_s^i\right) \tag{4}$$

From the rationale of the Hotelling model, we can find the location of the indifferent buyer and seller from the conditions of $U_b^i = U_b^{-i}$ and $U_s^i = U_s^{-i}$, respectively. Thus, by equating (1)(2) and (3)(4), the number of single-homing buyers and sellers on platform i can be obtained as follows:

$$\begin{aligned} n_b^i &= \frac{1}{2} - \frac{t_s\left(p^i - p^{-i}\right) + \beta_b\left(w^i - w^{-i}\right)}{2[t_s(t_b - \alpha_b) - \beta_b\beta_s]}, \\ n_s^i &= \frac{1}{2} - \frac{\beta_s\left(p^i - p^{-i}\right) + (t_b - \alpha_b)\left(w^i - w^{-i}\right)}{2[t_s(t_b - \alpha_b) - \beta_b\beta_s]}. \end{aligned} \tag{5}$$

In this case, the profit of platform i is

$$\Pi_{SS}^i = p^i n_b^i + w^i n_s^i. \tag{6}$$

Substituting (5) into (6), we can calculate the first- and second-order partial derivatives of Π_{SS}^i with respect to p^i and w^i, respectively. Here, the following technical assumptions are required to ensure the existence of equilibrium solutions: (1) $t_s(t_b - \alpha_b) > \beta_b\beta_s$; and (2) $4t_s(t_b - \alpha_b) > (\beta_b + \beta_s)^2$. These conditions guarantee that the first-order and second-order principal minor determinants of the corresponding Hessian Matrix are non-positive and non-negative, respectively. Therefore, according to the first-order conditions of both platforms i and $-i$, we have

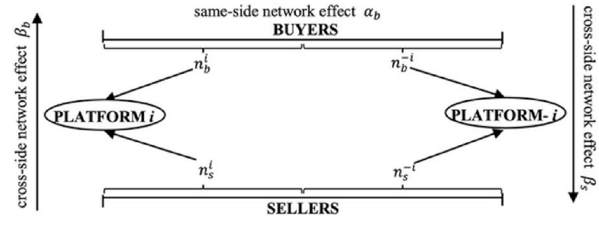


Fig. 1. The platform service supply chain structure in the single-homing–single-homing case.

$$p^i_{SS}=p^{-i}_{SS}=t_b-\alpha_b-\beta_s,\\ w^i_{SS}=w^{-i}_{SS}=t_s-\beta_b. \tag{7}$$

Substituting (7) into (5) and (6), the equilibrium market share and platform profit, respectively, can be obtained, which leads to Proposition 1.

Proposition 1. *For the SH–SH case, the equilibrium pricing is $p_{SS}=t_b-\alpha_b-\beta_s$ and $w_{SS}=t_s-\beta_b$. The number of single-homing buyers is $n^i_{bSS}=\frac{1}{2}$; and the number of single-homing sellers is $n^i_{sSS}=\frac{1}{2}$. The optimal profit of the platform is $\Pi^i_{SS}=\frac{t_b+t_s-\alpha_b-(\beta_b+\beta_s)}{2}$.*

All the proofs are shown in the appendix.

Proposition 1 indicates that in equilibrium, duopoly platforms divide the market in an equal manner, and this market segmentation scheme is neither affected by the scale of cross-side network effects nor by the strength of taste preferences. Because multi-homing is not allowed in this situation, users will join the nearest platform based on their positions. As for the individual located in the middle, the utility he/she will obtain from joining either platform is identical; thus, he/she will make a random choice. Besides, it is shown that the platform's equilibrium profit is positively correlated with the strength of taste preferences of both sides while negatively correlated with the scale of total network effects, which is consistent with the result of constant market share. Since equal occupation is always the case, stronger network effects induce milder pricing strategies and therefore, lower platform profits. In addition, by taking the derivative of equilibrium pricing with respect to the parameters, we have the following Corollary 1:

Corollary 1. For the SH–SH case, the results of the sensitivity analysis reveal the following:

$$\frac{\partial p_{SS}}{\alpha_b}<0,\frac{\partial p_{SS}}{\beta_s}<0,\frac{\partial p_{SS}}{t_b}>0;\frac{\partial w_{SS}}{\beta_b}<0,\frac{\partial w_{SS}}{t_s}>0.$$

Corollary 1 indicates that, the equilibrium pricing for each side is affected by the strength of taste preferences of its own side and the scale of cross-side network effects of the other side, while being independent of its own cross-side network effects. On the one hand, the stronger the cross-side network effects of one side, the lower the platform pricing for the other. This implies that a platform, when designing its pricing strategies, will make some profit compromise to users who are less motivated by setting prices sufficiently low to make itself more appealing to these users. To be specific, the enhancing of cross-side network effects among buyers will trigger an influx of them into the market, and rational platforms will then cut their pricing to sellers in order to balance supply and demand. On the other hand, the stronger the taste preferences of both sides, the higher the pricing of platforms, meaning that users who are more inclined to their ideal platforms will incur higher costs when settling for alternative choices. Moreover, the same-side network effects among buyers only affect platform pricing for their own with a decreasing trend. The reason here rests with the unilateral distribution of same-side network effects. Compared with sellers, buyers with both same-side and cross-side network effects are more efficient in attracting users. And specific to the fact of duopoly competition, competing platforms will drop their prices to secure the participation of buyers, using them as a signboard to further draw more sellers. Therefore, compared with setting an ambitious price, platform with a lower price is more likely to strike a point of mutual attraction among users.

4. Partial multi-homing in platform competition

In this section, we analyze three cases involving the behavior of partial multi-homing based on whether it appears on either side or both sides of the market.

4.1. Buyers single-homing and sellers partial multi-homing (SH–MH)

When partial multi-homing appears only on the seller side, the PSSC structure is shown in Fig. 2. Here we have $n^i_b+n^{-i}_b=1$ and $n^i_s+n^{i,-i}_s+n^{-i}_s=1$. In this case, there exists one indifference point on the buyer side and two on the seller side. The left one on the seller side represents the particular seller who is indifferent between single-homing on platform *i* and multi-homing on both platforms, and the right one represents the particular seller indifferent between multi-homing and single-homing on platform *-i*, which together, partition all the sellers into three segments. The utility of the indifferent buyer single-homing on platform *i* is

$$U^i_b=\theta+\alpha_b n^i_b+\beta_b\left(n^i_s+n^{i,-i}_s\right)-p^i-t_b n^i_b. \tag{8}$$

Similarly, the utility of that buyer single-homing on platform *-i* is

$$U^{-i}_b=\theta+\alpha_b n^{-i}_b+\beta_b\left(n^{-i}_s+n^{i,-i}_s\right)-p^{-i}-t_b\left(1-n^i_b\right) \tag{9}$$

The utility of the indifferent seller on the left single-homing on platform *i* is

$$U^i_s=\theta+\beta_s n^i_b-w^i-t_s n^i_s. \tag{10}$$

The utility of a seller multi-homing on both platforms *i* and *-i* is

$$U^{i,-i}_s=\theta+\beta_s\left(n^i_b+n^{-i}_b\right)-w^i-w^{-i}-t_s. \tag{11}$$

The utility of the indifferent seller on the right single-homing on platform *-i* is

$$U^{-i}_s=\theta+\beta_s n^{-i}_b-w^{-i}-t_s\left(1-n^i_s-n^{i,-i}_s\right) \tag{12}$$

By equating (8)(9), (9)(10), and (10)(11), the number of single-homing buyers, single-homing sellers, and multi-homing sellers, respectively, on platform *i* can be obtained as follows:

$$\begin{aligned} n^i_b&=\frac{1}{2}-\frac{t_s\left(p^i-p^{-i}\right)+\beta_b\left(w^i-w^{-i}\right)}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]},\\ n^i_s&=\frac{2t_s-\beta_s+2w^{-i}}{2t_s}-\frac{\beta_s t_s\left(p^i-p^{-i}\right)+\beta_b\beta_s\left(w^i-w^{-i}\right)}{2t_s[t_s(t_b-\alpha_b)-\beta_b\beta_s]},\\ n^{i,-i}_s&=\frac{\beta_s-t_s-\left(w^i+w^{-i}\right)}{t_s}. \end{aligned} \tag{13}$$

In this case, the profit of platform *i* is

$$\Pi^i_{SM}=p^i n^i_b+w^i\left(n^i_s+n^{i,-i}_s\right) \tag{14}$$

Substituting (13) into (14), we can calculate the first- and second-order partial derivatives of Π^i_{SM} with respect to p^i and w^i, respectively. To ensure the existence of equilibrium solutions and the establishment of PSSC structure, the following conditions are required: (1) $t_s(t_b-\alpha_b)>\beta_b\beta_s$; (2) $8t_s(t_b-\alpha_b)>(\beta_b+\beta_s)^2+4\beta_b\beta_s$; and (3) $(\beta_b+\beta_s)/4<t_s<(\beta_b+\beta_s)/2$. Among them, the first two conditions guarantee that the optimal pricing of platforms exists, and the third ensures that the number of single-homing and multi-homing sellers in equilibrium is between 0 and 1. Hence, from the first-order conditions of both platforms, we have the following equilibrium pricing:

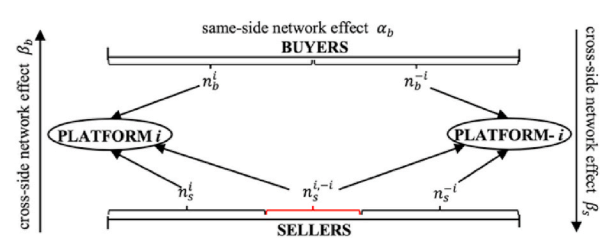


Fig. 2. The platform service supply chain structure in the single-homing–partial multi-homing case.

$$p^i_{SM} = p^{-i}_{SM} = t_b - \alpha_b - \beta_s \frac{3\beta_b + \beta_s}{4t_s},$$
$$w^i_{SM} = w^{-i}_{SM} = \frac{\beta_s - \beta_b}{4}. \tag{15}$$

Substituting (15) into (13) and (14), the equilibrium market share and platform profit, respectively, can be obtained, which leads to Proposition 2.

Proposition 2. For the SH–MH case, the equilibrium pricing is $p_{SM} = t_b - \alpha_b - \beta_s \frac{3\beta_b+\beta_s}{4t_s}$ and $w_{SM} = \frac{\beta_s-\beta_b}{4}$. The number of single-homing buyers is $n^i_{bSM} = \frac{1}{2}$; the number of single-homing sellers is $n^i_{sSM} = \frac{4t_s-\beta_b-\beta_s}{4t_s}$; and the number of multi-homing sellers is $n^{i,-i}_{sSM} = \frac{\beta_b+\beta_s-2t_s}{2t_s}$. The optimal profit of the platform is $\Pi^i_{SM} = \frac{8t_s(t_b-\alpha_b)-(\beta_b+\beta_s)^2-4\beta_b\beta_s}{16t_s}$.

Proposition 2 demonstrates that in equilibrium, duopoly platforms equally split buyers in the market, and occupy a portion of single-homing sellers while sharing the remaining multi-homing ones. Unlike in the SH–SH case, platform pricing to buyers is simultaneously affected by the strength of taste preferences of both sides and the scale of total network effects, whereas the pricing to sellers is only affected by the scale of cross-side network effects. To be precise, when $\beta_s > \beta_b$, the platform imposes a charge on the sellers; when $\beta_s < \beta_b$, it offers a subsidy. This result echoes with some established empirical research (Evans, 2003) and qualitative research (Eisenmann et al., 2006), further proving that in PSSCs where same-side network effects exist among buyers, one side is often "subsidized" while the other side "expropriated". In addition, by taking the derivative of the equilibrium market share and two-sided pricing with respect to the parameters, we have the following Corollary 2:

Corollary 2. *For the SH–MH case, the results of the sensitivity analysis show the following*:

(1) $\frac{\partial n^i_{sSM}}{\partial t_s} > 0, \frac{\partial n^{i,-i}_{sSM}}{\partial t_s} < 0; \frac{\partial n^i_{sSM}}{\partial \beta_j} < 0, \frac{\partial n^{i,-i}_{sSM}}{\partial \beta_j} > 0; j \in \{b, s\}$

(2) $\frac{\partial p_{SM}}{\partial \alpha_b} < 0, \frac{\partial p_{SM}}{\partial \beta_j} < 0, \frac{\partial p_{SM}}{\partial t_j} > 0; \frac{\partial w_{SM}}{\partial \beta_s} > 0, \frac{\partial w_{SM}}{\partial \beta_b} < 0; j \in \{b, s\}$

The first half of Corollary 2 reflects the trend of the market share with respect to certain parameters. The results show that with an increase in the strength of taste preferences of sellers and a decrease in the scale of cross-side network effects on both sides, more sellers tend to single-home rather than multi-home. Note that the total amount of users at one side is 1, so an increase in the number of single-homing users implies a decrease in the number of their multi-homing counterparts, and vice versa. This reveals that compared with the constant market share in the SH–SH case, platforms gain more flexibility in adjusting the proportion of different types of sellers by tuning their operational environment. For example, a platform can enhance cross-side network effects in the market by launching product preannouncement campaigns to enhance visibility, or creating a feedback system to facilitate two-way interaction, which can further encourage participation of more content providers and therefore, stronger serviceability of the platform. The second half of Corollary 2 reflects changes with parameters from the perspective of two-sided pricing. It is easily observed that on the one hand, platform pricing to buyers increases with the strength of taste preferences of both sides, and decreases with the scale of total network effects, which is similar yet involves wider contents compared with the results under SH–SH case. On the other hand, the cross-side network effects of buyers and sellers show opposite signs with regard to the impact of platform pricing for sellers, apart from which the pricing remains unaffected by the rest of the parameters.

4.2. Buyers partial multi-homing and sellers single-homing (MH–SH)

When partial multi-homing occurs only on the buyer side, the PSSC structure is shown in Fig. 3. In this case, we have $n^i_b + n^{i,-i}_b + n^{-i}_b = 1$ and $n^i_s + n^{-i}_s = 1$. In contrast to the previous section, two indifference points are observed on the buyer side and one on the seller side, which partition buyers into three segments and sellers into two segments, respectively. The utility of the indifferent buyer on the left single-homing on platform *i* is

$$U^i_b = \theta + \alpha_b\left(n^i_b + n^{i,-i}_b\right) + \beta_b n^i_s - p^i - t_b n^i_b. \tag{16}$$

The utility of a buyer multi-homing on both platforms *i* and *-i* is

$$U^{i,-i}_b = \theta + \alpha_b\left(n^i_b + n^{i,-i}_b + n^{-i}_b\right) + \beta_b\left(n^i_s + n^{-i}_s\right) - p^i - p^{-i} - t_b. \tag{17}$$

And the utility of the indifferent buyer on the right single-homing on platform *-i* is

$$U^{-i}_b = \theta + \alpha_b\left(n^{-i}_b + n^{i,-i}_b\right) + \beta_b n^{-i}_s - p^{-i} - t_b\left(1 - n^i_b - n^{i,-i}_b\right) \tag{18}$$

The utility of the indifferent seller single-homing on platform *i* is

$$U^i_s = \theta + \beta_s\left(n^i_b + n^{i,-i}_b\right) - w^i - t_s n^i_s. \tag{19}$$

Accordingly, the utility of that seller single-homing on platform *-i* is

$$U^{-i}_s = \theta + \beta_s\left(n^{-i}_b + n^{i,-i}_b\right) - w^{-i} - t_s\left(1 - n^i_s\right) \tag{20}$$

By equating (16)(17), (17)(18), and (19)(20), the number of single-homing buyers, multi-homing buyers, and single-homing sellers, respectively, on platform *i* can be obtained as follows:

$$n^i_b = \frac{2t_b - \beta_b + 2p^{-i}}{2(t_b + \alpha_b)} - \frac{(2\alpha_b t_s + \beta_b\beta_s)\left(p^i - p^{-i}\right) + \beta_b(t_b + \alpha_b)\left(w^i - w^{-i}\right)}{2(t_b + \alpha_b)[t_s(t_b - \alpha_b) - \beta_b\beta_s]},$$
$$n^{i,-i}_b = \frac{\alpha_b + \beta_b - t_b - \left(p^i + p^{-i}\right)}{t_b + \alpha_b},$$
$$n^i_s = \frac{1}{2} - \frac{\beta_s\left(p^i - p^{-i}\right) + (t_b - \alpha_b)\left(w^i - w^{-i}\right)}{2[t_s(t_b - \alpha_b) - \beta_b\beta_s]}. \tag{21}$$

In this case, the profit of platform *i* is

$$\Pi^i_{MS} = p^i\left(n^i_b + n^{i,-i}_b\right) + w^i n^i_s. \tag{22}$$

Substituting (21) into (22), the first- and second-order partial derivatives of Π^i_{MS} with respect to p^i and w^i, respectively, can be calculated. To ensure the existence of equilibrium solutions and the establishment of PSSC structure, the following conditions are required: (1) $t_s(t_b - \alpha_b) > \beta_b\beta_s$; (2) $4(t_b - \alpha_b)(2t_b t_s - \beta_b\beta_s) > (t_b + \alpha_b)(\beta_b + \beta_s)^2$; and (3) $2{t_b}^2 - \alpha_b t_b < (\beta_b + \beta_s)t_b + \alpha_b(\alpha_b + \beta_s) < 4{t_b}^2 - {\alpha_b}^2$. The effects of these conditions are in line with those in the previous SH–MH case. Hence, from the first-order conditions, we have the equilibrium pricing as follows:

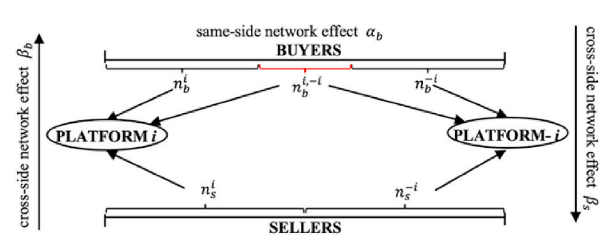


Fig. 3. The platform service supply chain structure in the partial multi-homing–single-homing case

$$p^i_{MS} = p^{-i}_{MS} = \frac{(2\alpha_b + \beta_b)(t_b - \alpha_b) - \beta_s(t_b + \alpha_b)}{2(2t_b - \alpha_b)}, \quad w^i_{MS} = w^{-i}_{MS} = t_s - \beta_b\frac{2\alpha_b + \beta_b + 3\beta_s}{2(2t_b - \alpha_b)}. \tag{23}$$

Substituting (23) into (21) and (22), the equilibrium market share and platform profit, respectively, can be obtained, which leads to Proposition 3.

Proposition 3. For the MH–SH case, the equilibrium pricing of the platform is $p_{MS} = \frac{(2\alpha_b+\beta_b)(t_b-\alpha_b)-\beta_s(t_b+\alpha_b)}{2(2t_b-\alpha_b)}$ *and* $w_{MS} = t_s - \beta_b\frac{2\alpha_b+\beta_b+3\beta_s}{2(2t_b-\alpha_b)}$. The number of single-homing buyers is $n^i_{bMS} = \frac{4t_b{}^2-(\beta_b+\beta_s)t_b-\alpha_b(2\alpha_b+\beta_s)}{2(t_b+\alpha_b)(2t_b-\alpha_b)}$; *the* number of multi-homing buyers is $n^{i,-i}_{bMS} = \frac{(\alpha_b+\beta_b+\beta_s)t_b-2t_b{}^2+\alpha_b(\alpha_b+\beta_s)}{(t_b+\alpha_b)(2t_b-\alpha_b)}$; and the number of single-homing sellers is $n^i_{sMS} = \frac{1}{2}$. The optimal profit of the platform is $\Pi^i_{MS} = \frac{(2\alpha_b+\beta_b)(t_b-\alpha_b)-\beta_s(t_b+\alpha_b)}{2(2t_b-\alpha_b)} \frac{t_b(2\alpha_b+\beta_b)+\beta_s(t_b+\alpha_b)}{2(t_b+\alpha_b)(2t_b-\alpha_b)} + \frac{2t_s(2t_b-\alpha_b)-\beta_b(2\alpha_b+\beta_b+3\beta_s)}{4(2t_b-\alpha_b)}$.

Proposition 3 indicates that in competitive equilibrium, platforms share equally the group of sellers while striving for the exclusive buyers. Unlike in the SH–MH case, pricing here is simultaneously affected by the strength of taste preferences of both sides and the scale of total network effects. Platforms charge buyers when the strength of taste preferences is higher than a threshold, that is, $t_b > \frac{\alpha_b(2\alpha_b+\beta_b+\beta_s)}{2\alpha_b+\beta_b-\beta_s}$, and offer subsidies vice versa. Similarly, for sellers, platforms' pricing strategies shift from subsidies to charges when the strength of their taste preferences is higher than a threshold, that is, $t_s > \frac{\beta_b(2\alpha_b+\beta_b+3\beta_s)}{2(2t_b-\alpha_b)}$, implying a heavier cost burden undertaken by users with stronger taste preferences. In addition, by taking the derivative of the equilibrium market share and pricing with respect to the parameters, we have the following Corollary 3:

Corollary 3. For the MH–SH case, the results of the sensitivity analysis reveal the following:

(1) $\frac{\partial n^i_{bMS}}{\partial t_b} > 0$, $\frac{\partial n^i_{bMS}}{\partial \alpha_b} < 0$, $\frac{\partial n^i_{bMS}}{\partial \beta_b} < 0$, and $\frac{\partial n^i_{bMS}}{\partial \beta_s} < 0$;

(2) $\frac{\partial p_{MS}}{\partial \alpha_b} < (>)\ 0$ *when* $\alpha_b < t_b < t^{MS}_{b2}$ $(t_b > t^{MS}_{b2})$, $\frac{\partial p_{MS}}{\partial \beta_b} > 0$, $\frac{\partial p_{MS}}{\partial \beta_s} < 0$, $\frac{\partial p_{MS}}{\partial t_b} > 0$;

$$\frac{\partial w_{MS}}{\partial \alpha_b} < 0, \ \frac{\partial w_{MS}}{\partial \beta_j} < 0, \ \frac{\partial w_{MS}}{\partial t_j} > 0; \ \text{and} \ j \in \{b, s\}$$

Note: $t^{MS}_{b2} = \frac{(8\alpha_b+\beta_b+3\beta_s)+\sqrt{(8\alpha_b+\beta_b+3\beta_s)^2-32\alpha_b{}^2}}{8}$.

The cases of SH–MH and MH–SH will be symmetrical to each other if the same-side network effects among buyers do not exist. When comparing the first half of Corollary 2 and Corollary 3, a difference in the impact of the same-side network effects on multi-homing user distribution is discovered. Specifically, in the MH–SH case, stronger same-side effects result in a higher number of multi-homing buyers, while in the SH–MH case, the number of multi-homing sellers remains constant with the effect. When comparing the second half of Corollary 2 and Corollary 3, it is observed that the difference in results still comes from the impact of same-side network effects on price charged to the multi-homing side. Specifically, in the MH–SH case, an increase in the effect has a non-monotonic impact on the platform price charged to buyers, which depends on the strength of buyers' taste preferences. To be precise, when t_b is small, the larger the effect, the lower the pricing, and vice versa. Besides, an increase in the effect has a monotonically decreasing impact on the platform price charged to sellers, which, on the contrary, has no effect in the SH-MH case.

4.3. Partial multi-homing on both sides (MH–MH)

When both sides take partial multi-homing behaviors, the PSSC structure is depicted in Fig. 4. Now in this scenario, we have $n^i_b + n^{i,-i}_b + n^{-i}_b = 1$, and $n^i_s + n^{i,-i}_s + n^{-i}_s = 1$. Two indifference points exist on either of the Hotelling lines, dividing users at both sides into three segments. The utility of the indifferent buyer on the left single-homing on platform *i* is

$$U^i_b = \theta + \alpha_b\left(n^i_b + n^{i,-i}_b\right) + \beta_b\left(n^i_s + n^{i,-i}_s\right) - p^i - t_b n^i_b. \tag{24}$$

The utility of a buyer multi-homing on both platforms *i* and *-i* is

$$U^{i,-i}_b = \theta + \alpha_b\left(n^i_b + n^{i,-i}_b + n^{-i}_b\right) + \beta_b\left(n^i_s + n^{i,-i}_s + n^{-i}_s\right) - p^i - p^{-i} - t_b. \tag{25}$$

And the utility of the indifferent buyer on the right single-homing on platform *-i* is

$$U^{-i}_b = \theta + \alpha_b\left(n^{-i}_b + n^{i,-i}_b\right) + \beta_b\left(n^{-i}_s + n^{i,-i}_s\right) - p^{-i} - t_b\left(1 - n^i_b - n^{i,-i}_b\right) \tag{26}$$

As for the seller side, the utility of the indifferent seller on the left single-homing on platform *i* is

$$U^i_s = \theta + \beta_s\left(n^i_b + n^{i,-i}_b\right) - w^i - t_s n^i_s. \tag{27}$$

The utility of a seller multi-homing on both platforms *i* and *-i* is

$$U^{i,-i}_s = \theta + \beta_s\left(n^i_b + n^{i,-i}_b + n^{-i}_b\right) - w^i - w^{-i} - t_s. \tag{28}$$

Similarly, the utility of the indifferent seller on the right single-homing on platform *-i* is

$$U^{-i}_s = \theta + \beta_s\left(n^{-i}_b + n^{i,-i}_b\right) - w^{-i} - t_s\left(1 - n^i_s - n^{i,-i}_s\right) \tag{29}$$

By equating (24)(25), (25)(26), (27)(28) and (28)(29), the number of both single-homing and multi-homing users, respectively, on platform *i* can be obtained as follows:

$$\begin{aligned}
n^i_b &= \frac{t_s(t_b - \beta_b)(t_b t_s - \beta_b\beta_s - \alpha_b t_s) - \alpha_b t_s t_s p^i + t_s(t_b t_s - \beta_b\beta_s)p^{-i} - \beta_b(t_b t_s - \beta_b\beta_s)w^i + \alpha_b\beta_b t_s w^{-i}}{(t_b t_s - \beta_b\beta_s + \alpha_b t_s)(t_b t_s - \beta_b\beta_s - \alpha_b t_s)},\\
n^{i,-i}_b &= \frac{(2\beta_b t_s + \alpha_b t_s - \beta_b\beta_s - t_b t_s) - t_s\left(p^i + p^{-i}\right) + \beta_b\left(w^i + w^{-i}\right)}{t_b t_s - \beta_b\beta_s + \alpha_b t_s},\\
n^i_s &= \frac{(t_b t_s - \beta_s t_b + \alpha_b t_s)(t_b t_s - \beta_b\beta_s - \alpha_b t_s) - \beta_s(t_b t_s - \beta_b\beta_s)p^i + \alpha_b\beta_s t_s p^{-i} - \alpha_b\beta_b\beta_s w^i + [t_b(t_b t_s - \beta_b\beta_s) - \alpha_b\alpha_b t_s]w^{-i}}{(t_b t_s - \beta_b\beta_s + \alpha_b t_s)(t_b t_s - \beta_b\beta_s - \alpha_b t_s)},\\
n^{i,-i}_s &= \frac{(2\beta_s t_b - \alpha_b t_s - \beta_b\beta_s - t_b t_s) + \beta_s\left(p^i + p^{-i}\right) - (t_b + \alpha_b)\left(w^i + w^{-i}\right)}{t_b t_s - \beta_b\beta_s + \alpha_b t_s}.
\end{aligned} \tag{30}$$

In this case, the profit of platform *i* is

$$\Pi^i_{MM} = p^i\left(n^i_b + n^{i,-i}_b\right) + w^i\left(n^i_s + n^{i,-i}_s\right) \tag{31}$$

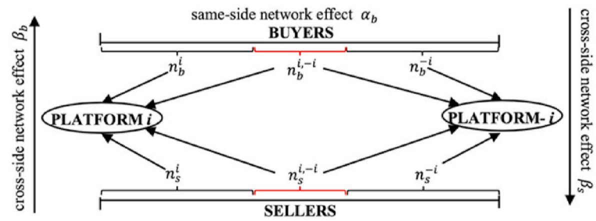


Fig. 4. The platform service supply chain structure in the partial multi-homing–partial multi-homing case

Substituting (30) into (31), we can calculate the first- and second-order partial derivatives of Π^i_{MM} with respect to p^i and, w^i respectively. Still, the following conditions are required: (1) $t_s(t_b - \alpha_b) > \beta_b\beta_s$; and (2) $4t_b(t_bt_s - \beta_b\beta_s)^2 > {\alpha_b}^2t_s[4t_bt_s + (\beta_b - \beta_s)^2]$. It should be noted that, these are only necessary but not sufficient conditions, to ensure the existence of equilibrium solutions. To achieve sufficiency, an additional condition guaranteeing that the number of single-homing and multi-homing users between 0 and 1 is needed. Since a direct examination of this condition is quite difficult, we first assume that the condition holds and then verify backwards. From the first-order conditions of both platforms *i* and *-i*, we have

$$
\begin{aligned}
p^i_{MM} = p^{-i}_{MM} &= \frac{(M-\alpha_bt_s)[\beta_bM(t_bt_s - \beta_st_b + M) - \alpha_bN(\alpha_bt_s + \beta_bt_s - \beta_b\beta_s) - \alpha_bt_s[\beta_s(\beta_b+\beta_s)(t_b-\beta_b) - 2t_bM]]}{(4t_bt_s - \beta_b\beta_s)M^2 - \alpha_bt_s\left[2M(t_bt_s+N) - \alpha_bt_sN - (M-\alpha_bt_s)(\beta_b+\beta_s)^2\right]},\\
w^i_{MM} = w^{-i}_{MM} &= \frac{(M-\alpha_bt_s)[\beta_sM(t_bt_s - \beta_bt_s + M) - \alpha_bt_s[\beta_st_s(t_b-\beta_b) - \beta_sM + (\beta_b+\beta_s)(\alpha_bt_s + \beta_bt_s - \beta_b\beta_s)]]}{(4t_bt_s - \beta_b\beta_s)M^2 - \alpha_bt_s\left[2M(t_bt_s+N) - \alpha_bt_sN - (M-\alpha_bt_s)(\beta_b+\beta_s)^2\right]}.
\end{aligned}
\tag{32}
$$

Among them, $M = t_bt_s - \beta_b\beta_s$, $N = 2\alpha_bt_s + \beta_b\beta_s$.

Substituting (32) into (30) and (31), the equilibrium market share and platform profit can be derived. Predictably, the results obtained after substitution will be complicated; thus, we mainly demonstrate the equilibrium pricing strategies in Proposition 4.

Proposition 4. *For the MH–MH case, if the PSSC structure is established, the equilibrium pricing of the platform is* $p_{MM} = \frac{1}{(4t_bt_s-\beta_b\beta_s)M^2-\alpha_bt_s[2M(t_bt_s+N)-\alpha_bt_sN-(M-\alpha_bt_s)(\beta_b+\beta_s)^2]}(M-\alpha_bt_s)[\beta_bM(t_bt_s - \beta_st_b + M) - \alpha_bN(\alpha_bt_s + \beta_bt_s - \beta_b\beta_s) - \alpha_bt_s[\beta_s(\beta_b+\beta_s)(t_b-\beta_b) - 2t_bM]]$ *and* $w_{MM} = \frac{1}{(4t_bt_s-\beta_b\beta_s)M^2-\alpha_bt_s[2M(t_bt_s+N)-\alpha_bt_sN-(M-\alpha_bt_s)(\beta_b+\beta_s)^2]}(M - \alpha_bt_s)[\beta_sM(t_bt_s - \beta_bt_s + M) - \alpha_bt_s[\beta_st_s(t_b - \beta_b) - \beta_sM + (\beta_b + \beta_s)(\alpha_bt_s + \beta_bt_s - \beta_b\beta_s)]]$*, where* $M = t_bt_s - \beta_b\beta_s$, $N = 2\alpha_bt_s + \beta_b\beta_s$.

Proposition 4 concludes the optimal pricing of platforms when the equilibrium solutions exist and the PSSC structure of multi-homing on both sides is preserved. Compared with previous cases, the expressions here are difficult to be further examined due to complication. Nevertheless, if we temporarily ignore the existence of same-side network effects of buyers, the optimal pricing equations stated above can be simplified. As denoted by $\widetilde{p}_{MM}$ *and* $\widetilde{w}_{MM}$, the optimal pricing of platforms without considering the buyers' same-side network effects leads to Corollary 4.

Corollary 4. *For the MH–MH case, if the PSSC structure is established and the same-side network effects do not exist, that is,* $\alpha_b = 0$, the equilibrium pricing in such a case is $\widetilde{p}_{MM} = \frac{\beta_b(2t_bt_s - \beta_st_b - \beta_b\beta_s)}{4t_bt_s - \beta_b\beta_s}$ and $\widetilde{w}_{MM} = \frac{\beta_s(2t_bt_s - \beta_bt_s - \beta_b\beta_s)}{4t_bt_s - \beta_b\beta_s}$. The results of the sensitivity analysis reveal that:

(1) $\frac{\partial\widetilde{p}_{MM}}{\partial\beta_b} < (>)\ 0$ *when* $\beta_b < t_b < t^{MM}_{b2}$ $(t_b > t^{MM}_{b2})$, $\frac{\partial\widetilde{p}_{MM}}{\partial\beta_s} < 0$, $\frac{\partial\widetilde{p}_{MM}}{\partial t_b} > 0$, and $\frac{\partial\widetilde{p}_{MM}}{\partial t_s} > 0$;

(2) $\frac{\partial\widetilde{w}_{MM}}{\partial\beta_b} < 0$, $\frac{\partial\widetilde{w}_{MM}}{\partial\beta_s} < (>)\ 0$ *when* $\beta_s < t_s < t^{MM}_{s2}$ $(t_s > t^{MM}_{s2})$, $\frac{\partial\widetilde{w}_{MM}}{\partial t_b} > 0$, and $\frac{\partial\widetilde{w}_{MM}}{\partial t_s} > 0$.

Notes: $t^{MM}_{b2} = \frac{\beta_b\beta_s(2t_s + \sqrt{t_s(2t_s+\beta_s)})}{2t_s(2t_s-\beta_s)}$; $t^{MM}_{s2} = \frac{\beta_b\beta_s(2t_b + \sqrt{t_b(2t_b+\beta_b)})}{2t_b(2t_b-\beta_b)}$.

Corollary 4 indicates that when the same-side network effects are not considered, the platforms' pricing strategies are symmetrical and simultaneously affected by the scale of cross-side network effects and the strength of taste preferences of both sides. The buyers' cross-side network effects have a non-monotonic impact on the platform price charged to themselves and a monotonically decreasing impact on the price charged to sellers. The former has to do with the strength of taste preferences of buyers: when t_b is small, the impact tends to be decreasing; and when t_b is large, it increases vice versa. Symmetrically, the impact of the cross-side network effects of sellers on the platform price charged to sellers is non-monotonic and depends on the strength of their own taste preferences, while that on the price charged to buyers is decreasing. Therefore, the impact of taste preferences on the platform pricing has dual effects: a direct effect by affecting pricing straightforwardly, as well as an indirect effect by affecting pricing through the cross-side network effects among users in the respective side.

4.4. Simplified comparison among different platform service supply chain structures

Since our platform competition model contains a variety of parameters with constraints under each PSSC structure differing from each other, certain simplifications are needed for a horizontal comparison. In this section, we exclude the same-side network effects and unify the strength of taste preferences of both sides; that is, set $\alpha_b = 0$ and $t_b = t_s = t$. We now obtain the constraint, two-sided pricing, market share, and platform profit under each of the four PSSC structures as shown in Table 4.

From further analysis, the following conclusions can be drawn.

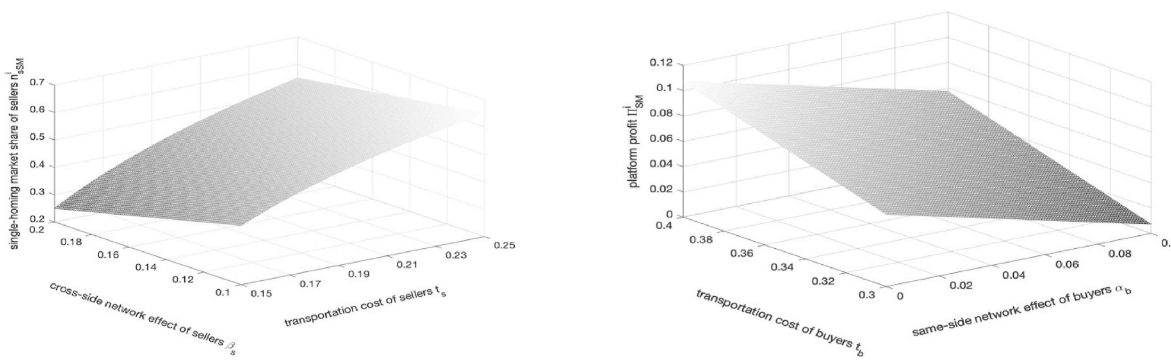
Conclusion 1. When the strength of taste preferences is high ($t > \frac{\beta_b+\beta_s}{2}$), the PSSC structure tends to be single-homing on both sides. When the strength of taste preferences is moderate ($\sqrt{\beta_b\beta_s + \frac{(\beta_b-\beta_s)^2}{8}} < t < \frac{\beta_b+\beta_s}{2}$), the PSSC structure moves toward single-homing on one side and partial multi-homing on the other. And when the strength of taste preferences is low ($\sqrt{\beta_b\beta_s} < t < \sqrt{\beta_b\beta_s + \frac{(\beta_b-\beta_s)^2}{8}}$), the PSSC structure favors partial multi-homing on both sides.

Conclusion 2. When buyers choose to single-home (SH–), it is more beneficial for sellers to partially multi-home than to purely single-home ($w^i_{SM} < w^i_{SS}$). In this case, the platform's market share on the seller side is higher than that on the buyer side. Similarly, when sellers choose to single-home (–SH), buyers are more inclined to partially multi-home than to purely single-home ($p^i_{MS} < p^i_{SS}$). In this case, the platform's market share is higher on the buyer side.

Conclusion 3. When buyers choose to partially multi-home (MH–), the platform price charged to sellers always increases with the strength

Table 4
Simplified comparison of equilibrium outcomes under the four platform service supply chain structures.

PSSC structure		SH–SH	SH–MH	MH–SH	MH–MH
Constraint		$t > \frac{\beta_b + \beta_s}{2}$	$\sqrt{\beta_b\beta_s + \frac{(\beta_b - \beta_s)^2}{8}} < t < \frac{\beta_b + \beta_s}{2}$	$\sqrt{\beta_b\beta_s + \frac{(\beta_b - \beta_s)^2}{8}} < t < \frac{\beta_b + \beta_s}{2}$	$\sqrt{\beta_b\beta_s} < t < \sqrt{\beta_b\beta_s + \frac{(\beta_b - \beta_s)^2}{8}}$
Two-sided pricing	p^i	$t - \beta_s$	$t - \beta_s\frac{3\beta_b + \beta_s}{4t}$	$\frac{\beta_b - \beta_s}{4}$	$\frac{\beta_b(2t^2 - \beta_s t - \beta_b\beta_s)}{4t^2 - \beta_b\beta_s}$
	w^i	$t - \beta_b$	$\frac{\beta_s - \beta_b}{4}$	$t - \beta_b\frac{\beta_b + 3\beta_s}{4t}$	$\frac{\beta_s(2t^2 - \beta_b t - \beta_b\beta_s)}{4t^2 - \beta_b\beta_s}$
Market share	n_b^i	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{4t - \beta_b - \beta_s}{4t}$	$\frac{4t^4 - 2\beta_b t^3 - 4\beta_b\beta_s t^2 + \beta_b{}^2\beta_s t + \beta_b{}^2\beta_s{}^2}{(t^2 - \beta_b\beta_s)(4t^2 - \beta_b\beta_s)}$
	$n_b^{i,-i}$	–	–	$\frac{\beta_b + \beta_s - 2t}{2t}$	$\frac{-4t^4 + 4\beta_b t^3 + 3\beta_b\beta_s t^2 - 2\beta_b{}^2\beta_s t - \beta_b{}^2\beta_s{}^2}{(t^2 - \beta_b\beta_s)(4t^2 - \beta_b\beta_s)}$
	$n_b^i + n_b^{i,-i}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{\beta_b + \beta_s}{4t}$	$\frac{\beta_b t(2t^2 - \beta_s t - \beta_b\beta_s)}{(t^2 - \beta_b\beta_s)(4t^2 - \beta_b\beta_s)}$
	n_s^i	$\frac{1}{2}$	$\frac{4t - \beta_b - \beta_s}{4t}$	$\frac{1}{2}$	$\frac{4t^4 - 2\beta_s t^3 - 4\beta_b\beta_s t^2 + \beta_b\beta_s{}^2 t + \beta_b{}^2\beta_s{}^2}{(t^2 - \beta_b\beta_s)(4t^2 - \beta_b\beta_s)}$
	$n_s^{i,-i}$	–	$\frac{\beta_b + \beta_s - 2t}{2t}$	–	$\frac{-4t^4 + 4\beta_s t^3 + 3\beta_b\beta_s t^2 - 2\beta_b\beta_s{}^2 t - \beta_b{}^2\beta_s{}^2}{(t^2 - \beta_b\beta_s)(4t^2 - \beta_b\beta_s)}$
	$n_s^i + n_s^{i,-i}$	$\frac{1}{2}$	$\frac{\beta_b + \beta_s}{4t}$	$\frac{1}{2}$	$\frac{\beta_s t(2t^2 - \beta_b t - \beta_b\beta_s)}{(t^2 - \beta_b\beta_s)(4t^2 - \beta_b\beta_s)}$
Platform profit	Π^i	$\frac{2t - (\beta_b + \beta_s)}{2}$	$\frac{8t^2 - 6\beta_b\beta_s - \beta_b{}^2 - \beta_s{}^2}{16t}$	$\frac{8t^2 - 6\beta_b\beta_s - \beta_b{}^2 - \beta_s{}^2}{16t}$	$\frac{\beta_b{}^2 t(2t^2 - \beta_s t - \beta_b\beta_s)^2 + \beta_s{}^2 t(2t^2 - \beta_b t - \beta_b\beta_s)^2}{(t^2 - \beta_b\beta_s)(4t^2 - \beta_b\beta_s)^2}$



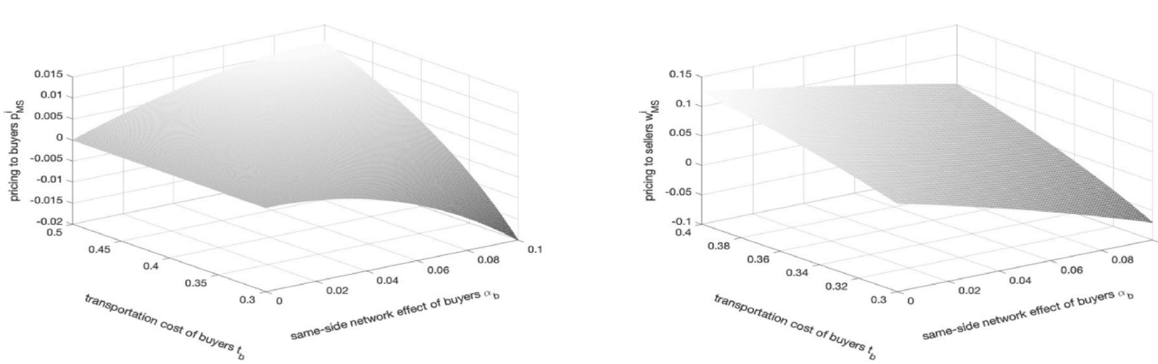
(a) Number of single-homing sellers **(b) Platform profit**

Fig. 5. The trend of market share and platform profit in the single-homing–partial multi-homing case.

of taste preferences. The condition for platforms to offer subsidies to sellers when they single-home is $\sqrt{\beta_b\beta_s + \frac{(\beta_b-\beta_s)^2}{8}} < t < \min\left(\frac{\beta_b+\beta_s}{2}, \frac{\sqrt{\beta_b(\beta_b+3\beta_s)}}{2}\right)$, while the condition to offer subsidies when they partially multi-home is $\sqrt{\beta_b\beta_s} < t < \min\left(\frac{\beta_b+\sqrt{\beta_b(\beta_b+8\beta_s)}}{4}, \sqrt{\beta_b\beta_s + \frac{(\beta_b-\beta_s)^2}{8}}\right)$. Similarly, when sellers choose to partially multi-home (–MH), the conditions for platforms to subsidize buyers when they single-home and partially multi-home are $\sqrt{\beta_b\beta_s + \frac{(\beta_b-\beta_s)^2}{8}} < t < \min\left(\frac{\beta_b+\beta_s}{2}, \frac{\sqrt{\beta_s(3\beta_b+\beta_s)}}{2}\right)$ and $\sqrt{\beta_b\beta_s} < t < \min\left(\frac{\beta_s+\sqrt{\beta_s(8\beta_b+\beta_s)}}{4}, \sqrt{\beta_b\beta_s + \frac{(\beta_b-\beta_s)^2}{8}}\right)$, respectively.

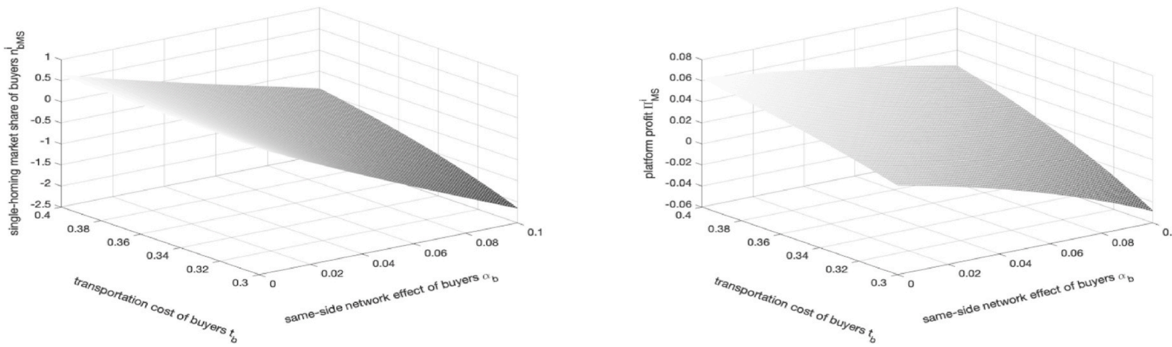
5. Numerical analysis

In this section, we use MATLAB to conduct numerical analysis. First, we verify the impact of the scale of total network effects and the strength



(a) Platform pricing to buyers **(b) Platform pricing to sellers**

Fig. 6. The trend of two-sided pricing with respect to α_b and t_b in the partial multi-homing–single-homing case.



(a) Number of single-homing buyers

(b) Platform profit

Fig. 7. The trend of market share and platform profit in the partial multi-homing–single homing case.

of taste preferences of both sides on the two-sided pricing, market share, and platform profit for the first three cases. Since the results under the SH–SH base case are relatively intuitive, we will not go into detail here. The simulation results of the SH–MH and MH–SH cases are shown below.

Fig. 5 depicts the number of single-homing sellers and platform profit with respect to certain parameters. To ensure the existence of equilibrium solutions and the establishment of PSSC structure in the SH–MH case, the values of remaining parameters in Figures 5(a) and (b) are set as $\alpha_b = 0.1$, $\beta_b = 0.25$, $t_b = 0.3$ and $\beta_s = 0.1$, $t_s = 0.15$. Specifically, Fig. 5(a) shows that the number of single-homing sellers increases with the strength of their taste preferences and decreases with the scale of their cross-side network effects. The number of multi-homing sellers changes at the exactly opposite direction. Fig. 5(b) shows that platform profit decreases with the scale of same-side network effects and increases with the strength of taste preferences of buyers. Thus, the results in Corollary 2 have been verified.

Fig. 6 describes the impact of same-side network effects and the strength of taste preferences of buyers on the pricing of platforms in the MH–SH case. Still, to ensure the existence of equilibrium solutions and the establishment of PSSC structure in this case, the values of remaining parameters in Figs. 6 and 7 are set as $\beta_b = 0.3$, $\beta_s = 0.3$, and $t_s = 0.15$. According to Fig. 6(a), when the taste preferences of buyers are weak, the platform price charged to buyers decreases with an increase in the same-side network effects; whereas when the taste preferences are strong, the price increases with the same-side network effects. Fig. 6(b) indicates that the platform price charged to sellers always decreases with the same-side network effects and increases with the strength of taste preferences of buyers. Thus, the results in Corollary 3 have been validated.

Fig. 7 further illustrates the number of single-homing buyers and platform profit with respect to the scale of same-side network effects and the strength of buyers' taste preferences. Fig. 7(a) shows that the number of single-homing buyers on each platform decreases with the same-side network effects and increases with the strength of their taste preferences, which leads to opposite results in the changes of their multi-homing counterparts. From Fig. 7(b), it can be inferred that the weaker the same-side effects and the stronger the buyers' taste preferences, the higher the platform profit. Thus, the results in Corollary 3 have been proven.

As for the case when both buyers and sellers are partially multi-homing, our theoretical analysis has been limited to the equilibrium pricing results as shown in Eq. (32), which, since it was derived by relaxing the establishment condition of the PSSC structure, has to be verified by substituting the results into the expression of user distribution in Eq. (30). In this section, we explore the optimal solutions using different sets of parameter values, and part of the results are shown in Table 5. Although we have tested for different groups of parameter values, the results in the table show that the number of multi-homing users tend to be negative. Even in the simplified model, when we ignored the same-side network effects of buyers and unified the strength of taste preferences of both sides as consistent with Table 4, that is, setting $\alpha_b = 0$ and $t_b = t_s = t$ (corresponding to group ⑤ in Table 5), partial multi-homing on both sides is not always guaranteed. Consequently, the existence of equilibrium solutions in this scenario is ambiguous.

6. Conclusion

In platform competition, users on both sides get on board because of network effects, and the way they participate in the two-sided market through intermediary platforms naturally leads to a specific PSSC structure. In this study, we incorporated buyers' same-side network effects and both buyers' and sellers' cross-side network effects based on a stylized Hotelling model. We constructed our platform competition model under four different PSSC structures contingent upon the

Table 5
The equilibrium outcomes under different parameter values in the partial multi-homing–partial multi-homing case.

Sets of parameter values		p^i_{MM}	w^i_{MM}	n^i_{bMM}	$n^{i,-i}_{bMM}$	n^i_{sMM}	$n^{i,-i}_{sMM}$	Π^i_{MM}
	$\alpha_b = 0$, $\beta_b = 0.20$, $\beta_s = 0.22$, $t_b = 0.35$, $t_s = 0.30$	0.0473	0.0620	0.7672	−0.5344	0.6441	−0.2883	0.0331
②	$\alpha_b = 0$, $\beta_b = 0.25$, $\beta_s = 0.22$, $t_b = 0.35$, $t_s = 0.30$	0.0534	0.0482	0.6795	−0.3589	0.6625	−0.3249	0.0334
③	$\alpha_b = 0$, $\beta_b = 0.20$, $\beta_s = 0.25$, $t_b = 0.35$, $t_s = 0.30$	0.0392	0.0676	0.7862	−0.5725	0.5700	−0.1400	0.0374
④	$\alpha_b = 0$, $\beta_b = 0.20$, $\beta_s = 0.22$, $t_b = 0.40$, $t_s = 0.30$	0.0571	0.0569	0.7367	−0.4733	0.6496	−0.2992	0.0350
⑤	$\alpha_b = 0$, $\beta_b = 0.20$, $\beta_s = 0.22$, $t_b = 0.35$, $t_s = 0.35$	0.0556	0.0646	0.7521	−0.5042	0.7119	−0.4238	0.0324
⑥	$\alpha_b = 0.10$, $\beta_b = 0.20$, $\beta_s = 0.22$, $t_b = 0.35$, $t_s = 0.30$	0.0324	0.0330	0.5908	−0.1816	0.6767	−0.3533	0.0316
⑦	$\alpha_b = 0.10$, $\beta_b = 0.25$, $\beta_s = 0.22$, $t_b = 0.35$, $t_s = 0.30$	0.0467	0.0126	0.5107	−0.0214	0.6674	−0.3348	0.0270
⑧	$\alpha_b = 0.10$, $\beta_b = 0.20$, $\beta_s = 0.25$, $t_b = 0.35$, $t_s = 0.30$	0.0381	0.0344	0.5828	−0.1656	0.6291	−0.2583	0.0287
⑨	$\alpha_b = 0.10$, $\beta_b = 0.20$, $\beta_s = 0.22$, $t_b = 0.40$, $t_s = 0.30$	0.0610	0.0451	0.6536	−0.3071	0.6712	−0.3424	0.0360
⑩	$\alpha_b = 0.10$, $\beta_b = 0.20$, $\beta_s = 0.22$, $t_b = 0.35$, $t_s = 0.35$	0.0630	0.0367	0.5922	−0.1844	0.7326	−0.4651	0.0355

participation decision of users on both sides, namely: both sides single-homing (SH–SH), buyers single-homing and sellers partially multi-homing (SH–MH), buyers partially multi-homing and sellers single-homing (MH–SH), and both sides partially multi-homing (MH–MH). Moreover, we examined the equilibrium results of two-sided pricing, market share, and platform profit with sensitivity analyses conducted under each of the scenarios.

In correspondence to our research questions, the main results of this study are as follows: 1) The equilibrium two-sided pricing strategies are asymmetrical in each PSSC due to the existence of same-side network effects among buyers, and the embedded network effects and taste preferences exert impact, but not always simultaneously, on platform pricing schemes toward both sides in each scenario. 2) The same-side network effects have no impact on platform pricing to sellers once all the buyers tend to single-home; especially when sellers multi-home, their encountered pricing is only affected by the cross-side network effect. To be specific, when the cross-side network effects of sellers is larger than that of buyers, the platform imposes a charge; otherwise, it offers a subsidy. Besides, when buyers tend to partially multi-home, the same-side or cross-side network effects have a non-monotonic impact on the buyers' price when sellers single-home or partially multi-home, respectively. 3) Both buyers and sellers, when they single-home, are equally split by the two competing platforms regardless of the scale of network effects. And the number of multi-homing buyers and sellers are increasing with the strength of cross-side network effects, which leads to opposite results in the changes of their single-homing counterparts. 4) The higher the transportation cost or the taste preference of two-sided users, the higher the platform pricing implemented, indicating that users with stronger taste preferences incur larger disutility when settling for choices away from their optimum. The impact of users' taste preferences on pricing has dual effects: a direct impact and an indirect impact which affects pricing through network effects on their own side. Moreover, the increase in the taste preferences also shifts the equilibrium PSSC structure from multi-homing to single-homing.

Multi-platform competition is an inevitable challenge faced by PSSC management. From the theoretical perspective, our study helped to unveil the platform competition equilibrium considering users' multi-homing decisions. First, based on the stylized Hotelling model, we studied the common duopoly competition in two-sided markets under different PSSC structures characterized by user multi-homing decisions, which provided a more clear and structural approach toward the classification of two-sided markets. Second, through the incorporation and categorization of network effects, we analyzed the impact of both same-side and cross-side network effects on platform pricing strategies in different PSSCs, which revealed the determinants of platform pricing from market-intrinsic conditions. Third, from equilibrium analysis and horizontal comparison, we examined two-sided pricing, market share and platform profit in each PSSC scenario, which facilitated the understanding of platform competition and its induced outcomes from multi-aspects, serving as a theoretical guidance for platform decisions in real business practices.

From the practical perspective, our findings have some implication on the development of platform companies. On the one hand, in markets where buyers generally singe-home and sellers partially multi-home, such as video game consoles and personal computers, to avoid product homogenization, platform could provide better support services to strengthen the taste preference of an individual developer to the current platform, thus guiding more users on this side to single-home and become the platform's loyal participants. Besides, platforms could also offer subsidies to consumers and/or developers based on the scale of cross-side network effects on each side so as to expand the market more efficiently. On the other hand, in markets where buyers often partially multi-home and sellers single-home, such as knowledge-sharing platforms and streaming media platforms, the platform could endeavor to build a more interactively friendly in-app community, or optimize the one-click sharing function to enhance the same-side network effects among consumers. These actions are helpful in motivating more consumers to switch from multi-homing to single-homing and hence, help the platform to lock in future profits.

There are some limitations to our study. For instance, we considered only competition between duopoly platforms while ignoring the possibility of cooperation. Besides, we assumed a horizontal differentiation between platforms. Further research may consider the co-existence of platform competition and cooperation, or co-opetition, and introduce vertical differentiation between platforms in terms of service cost and quality, so as to explore the decision-making issues in PSSC with more comprehensive considerations.

Declaration of competing interest

None.

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Appendix A

■ **Proof of Proposition 1:**

The profit function of platform i in SH-SH is

$$\Pi_{SS}^i = p^i n_b^i + w^i n_s^i = p^i \left[\frac{1}{2} - \frac{t_s(p^i - p^{-i}) + \beta_b(w^i - w^{-i})}{2[t_s(t_b - \alpha_b) - \beta_b\beta_s]}\right] + w^i \left[\frac{1}{2} - \frac{\beta_s(p^i - p^{-i}) + (t_b - \alpha_b)(w^i - w^{-i})}{2[t_s(t_b - \alpha_b) - \beta_b\beta_s]}\right] \tag{A1}$$

Taking the first- and second-order partial derivatives of Π_{SM}^i with respect to p^i and w^i, we have

$$\begin{cases}\dfrac{\partial\Pi_{SS}^i}{\partial p^i}=\dfrac{1}{2}-\dfrac{t_s\left(2p^i-p^{-i}\right)+\beta_b\left(w^i-w^{-i}\right)+\beta_s w^i}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]}\\ \dfrac{\partial^2\Pi_{SS}^i}{\partial p^{i2}}=-\dfrac{t_s}{t_s(t_b-\alpha_b)-\beta_b\beta_s}\\ \dfrac{\partial\Pi_{SS}^i}{\partial w^i}=\dfrac{1}{2}-\dfrac{\beta_s\left(p^i-p^{-i}\right)+(t_b-\alpha_b)\left(2w^i-w^{-i}\right)+\beta_b p^i}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]}\\ \dfrac{\partial^2\Pi_{SS}^i}{\partial w^{i2}}=-\dfrac{t_b-\alpha_b}{t_s(t_b-\alpha_b)-\beta_b\beta_s}\\ \dfrac{\partial^2\Pi_{SS}^i}{\partial p^i\partial w^i}=-\dfrac{\beta_b+\beta_s}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]}\end{cases} \tag{A2}$$

The constraints of the Hessian Matrix are

$$\begin{cases}H_1^{SS}=\dfrac{\partial^2\Pi_{SS}^i}{\partial p^{i2}}<0\Rightarrow t_s(t_b-\alpha_b)>\beta_b\beta_s\\ H_2^{SS}=\left(\dfrac{\partial^2\Pi_{SS}^i}{\partial p^{i2}}\right)\left(\dfrac{\partial^2\Pi_{SS}^i}{\partial w^{i2}}\right)-\left(\dfrac{\partial^2\Pi_{SS}^i}{\partial p^i\partial w^i}\right)^2>0\Rightarrow 4t_s(t_b-\alpha_b)>(\beta_b+\beta_s)^2\end{cases} \tag{A3}$$

Under these conditions, we can derive the equilibrium pricing from FOC as

$$\begin{cases}p_{SS}^i=p_{SS}^{-i}=t_b-\alpha_b-\beta_s\\ w_{SS}^i=w_{SS}^{-i}=t_s-\beta_b\end{cases} \tag{A4}$$

Therefore, the corresponding market share and profit of platform i are

$$n_{bSS}^i=\frac{1}{2},n_{sSS}^i=\frac{1}{2} \tag{A5}$$

$$\Pi_{SS}^i=\frac{t_b+t_s-\alpha_b-(\beta_b+\beta_s)}{2} \tag{A6}$$

■ **Proof of Proposition 2:**

The profit function of platform i in SH-MH is

$$\Pi_{SM}^i=p^in_b^i+w^i\left(n_s^i+n_s^{i,-i}\right)=p^i\left[\frac{1}{2}-\frac{t_s(p^i-p^{-i})+\beta_b(w^i-w^{-i})}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]}\right]$$
$$+w^i\left[\frac{2t_s-\beta_s+2w^{-i}}{2t_s}-\frac{\beta_st_s(p^i-p^{-i})+\beta_b\beta_s(w^i-w^{-i})}{2t_s[t_s(t_b-\alpha_b)-\beta_b\beta_s]}+\frac{\beta_s-t_s-(w^i+w^{-i})}{t_s}\right] \tag{A7}$$

Taking the first- and second-order partial derivatives of Π_{SM}^i with respect to p^i and w^i, we have

$$\begin{cases}\dfrac{\partial\Pi_{SM}^i}{\partial p^i}=\dfrac{1}{2}-\dfrac{t_s\left(2p^i-p^{-i}\right)+\beta_b\left(w^i-w^{-i}\right)+\beta_s w^i}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]}\\ \dfrac{\partial^2\Pi_{SM}^i}{\partial p^{i2}}=-\dfrac{t_s}{t_s(t_b-\alpha_b)-\beta_b\beta_s}\\ \dfrac{\partial\Pi_{SM}^i}{\partial w^i}=\dfrac{\beta_s-4w^i}{2t_s}-\dfrac{\beta_st_s\left(p^i-p^{-i}\right)+\beta_b\beta_s\left(2w^i-w^{-i}\right)+\beta_bt_sp^i}{2t_s[t_s(t_b-\alpha_b)-\beta_b\beta_s]}\\ \dfrac{\partial^2\Pi_{SM}^i}{\partial w^{i2}}=-\dfrac{2t_s(t_b-\alpha_b)-\beta_b\beta_s}{t_s[t_s(t_b-\alpha_b)-\beta_b\beta_s]}\\ \dfrac{\partial^2\Pi_{SM}^i}{\partial p^i\partial w^i}=-\dfrac{\beta_b+\beta_s}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]}\end{cases} \tag{A8}$$

The constraints of the Hessian Matrix are

$$\begin{cases}H_1^{SM}=\dfrac{\partial^2\Pi_{SM}^i}{\partial p^{i2}}<0\Rightarrow t_s(t_b-\alpha_b)>\beta_b\beta_s\\ H_2^{SM}=\left(\dfrac{\partial^2\Pi_{SM}^i}{\partial p^{i2}}\right)\left(\dfrac{\partial^2\Pi_{SM}^i}{\partial w^{i2}}\right)-\left(\dfrac{\partial^2\Pi_{SM}^i}{\partial p^i\partial w^i}\right)^2>0\Rightarrow 8t_s(t_b-\alpha_b)>(\beta_b+\beta_s)^2+4\beta_b\beta_s\end{cases} \tag{A9}$$

Besides, the number of multi-homing sellers should be within the interval $(0,\ 1)$, that is

$$\frac{\beta_b+\beta_s}{4}<t_s<\frac{\beta_b+\beta_s}{2} \tag{A10}$$

Under these conditions, we can derive the equilibrium pricing from FOC as

$$\begin{cases} p^i_{SM}=p^{-i}_{SM}=t_b-\alpha_b-\beta_s\dfrac{3\beta_b+\beta_s}{4t_s} \\ w^i_{SM}=w^{-i}_{SM}=\dfrac{\beta_s-\beta_b}{4} \end{cases} \tag{A11}$$

Therefore, the corresponding market share and profit of platform i are

$$n^i_{bSM}=\frac{1}{2}, n^i_{sSM}=\frac{4t_s-\beta_b-\beta_s}{4t_s}, n^{i,-i}_{sSM}=\frac{\beta_b+\beta_s-2t_s}{2t_s} \tag{A12}$$

$$\Pi^i_{SM}=\frac{8t_s(t_b-\alpha_b)-(\beta_b+\beta_s)^2-4\beta_b\beta_s}{16t_s} \tag{A13}$$

■ **Proof of Proposition 3:**

The profit function of platform i in MH-SH is

$$\begin{aligned}\Pi^i_{MS}&=p^i\left(n^i_b+n^{i,-i}_b\right)+w^in^i_s\\ &=p^i\left[\frac{(2t_b-\beta_b)[t_s(t_b-\alpha_b)-\beta_b\beta_s]-(2\alpha_bt_s+\beta_b\beta_s)p^i+(2t_bt_s-\beta_b\beta_s)p^{-i}-\beta_b(t_b+\alpha_b)(w^i-w^{-i})}{2(t_b+\alpha_b)[t_s(t_b-\alpha_b)-\beta_b\beta_s]}+\frac{-(t_b-\alpha_b-\beta_b)-(p^i+p^{-i})}{t_b+\alpha_b}\right]\\ &\quad+w^i\left[\frac{1}{2}-\frac{\beta_s(p^i-p^{-i})+(t_b-\alpha_b)(w^i-w^{-i})}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]}\right]\end{aligned} \tag{A14}$$

Taking the first- and second-order partial derivatives of Π^i_{MS} with respect to p^i and w^i, we have

$$\begin{cases} \dfrac{\partial\Pi^i_{MS}}{\partial p^i}=\dfrac{(2\alpha_b+\beta_b)[t_s(t_b-\alpha_b)-\beta_b\beta_s]-2(2t_bt_s-\beta_b\beta_s)p^i+(2\alpha_bt_s+\beta_b\beta_s)p^{-i}-\beta_b(t_b+\alpha_b)\left(w^i-w^{-i}\right)-\beta_s(t_b+\alpha_b)w^i}{2(t_b+\alpha_b)[t_s(t_b-\alpha_b)-\beta_b\beta_s]} \\ \dfrac{\partial^2\Pi^i_{MS}}{\partial p^{i2}}=-\dfrac{2t_bt_s-\beta_b\beta_s}{(t_b+\alpha_b)[t_s(t_b-\alpha_b)-\beta_b\beta_s]} \\ \dfrac{\partial\Pi^i_{MS}}{\partial w^i}=\dfrac{1}{2}-\dfrac{\beta_s\left(p^i-p^{-i}\right)+(t_b-\alpha_b)\left(2w^i-w^{-i}\right)+\beta_bp^i}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]} \\ \dfrac{\partial^2\Pi^i_{MS}}{\partial w^{i2}}=-\dfrac{t_b-\alpha_b}{t_s(t_b-\alpha_b)-\beta_b\beta_s} \\ \dfrac{\partial^2\Pi^i_{MS}}{\partial p^i\partial w^i}=-\dfrac{\beta_b+\beta_s}{2[t_s(t_b-\alpha_b)-\beta_b\beta_s]} \end{cases} \tag{A15}$$

The constraints of the Hessian Matrix are

$$\begin{cases} H^{MS}_1=\dfrac{\partial^2\Pi^i_{MS}}{\partial p^{i2}}<0\Rightarrow t_s(t_b-\alpha_b)>\beta_b\beta_s \\ H^{MS}_2=\left(\dfrac{\partial^2\Pi^i_{MS}}{\partial p^{i2}}\right)\left(\dfrac{\partial^2\Pi^i_{MS}}{\partial w^{i2}}\right)-\left(\dfrac{\partial^2\Pi^i_{MS}}{\partial p^i\partial w^i}\right)^2>0\Rightarrow 4(t_b-\alpha_b)(2t_bt_s-\beta_b\beta_s)>(t_b+\alpha_b)(\beta_b+\beta_s)^2 \end{cases} \tag{A16}$$

Besides, the number of multi-homing buyers should be within the interval $(0,1)$, that is

$$2{t_b}^2-\alpha_bt_b<(\beta_b+\beta_s)t_b+\alpha_b(\alpha_b+\beta_s)<4{t_b}^2-{\alpha_b}^2 \tag{A17}$$

Under these conditions, we can derive the equilibrium pricing from FOC as

$$\begin{cases} p^i_{MS}=p^{-i}_{MS}=\dfrac{(2\alpha_b+\beta_b)(t_b-\alpha_b)-\beta_s(t_b+\alpha_b)}{2(2t_b-\alpha_b)} \\ w^i_{MS}=w^{-i}_{MS}=t_s-\beta_b\dfrac{2\alpha_b+\beta_b+3\beta_s}{2(2t_b-\alpha_b)} \end{cases} \tag{A18}$$

Therefore, the corresponding market share and profit of platform i are

$$n_{bMS}^{i} = \frac{4t_b^2 - (\beta_b + \beta_s)t_b - \alpha_b(2\alpha_b + \beta_s)}{2(t_b + \alpha_b)(2t_b - \alpha_b)}, n_{bMS}^{i,-i} = \frac{(\alpha_b + \beta_b + \beta_s)t_b - 2t_b^2 + \alpha_b(\alpha_b + \beta_s)}{(t_b + \alpha_b)(2t_b - \alpha_b)}, n_{sMS}^{i} = \frac{1}{2} \tag{A19}$$

$$\Pi_{MS}^{i} = \frac{(2\alpha_b + \beta_b)(t_b - \alpha_b) - \beta_s(t_b + \alpha_b)}{2(2t_b - \alpha_b)} \frac{t_b(2\alpha_b + \beta_b) + \beta_s(t_b + \alpha_b)}{2(t_b + \alpha_b)(2t_b - \alpha_b)} + \frac{2t_s(2t_b - \alpha_b) - \beta_b(2\alpha_b + \beta_b + 3\beta_s)}{4(2t_b - \alpha_b)} \tag{A20}$$

■ **Proof of** Corollary 3**:**

Taking the derivative of p_{MS} with respect to α_b, we have

$$\frac{\partial p_{MS}}{\partial \alpha_b} = \frac{4t_b^2 - (8\alpha_b + \beta_b + 3\beta_s)t_b + 2\alpha_b^2}{2(2t_b - \alpha_b)^2} \tag{A21}$$

Solving by the FOC, we have

$$t_{b1}^{MS} = \frac{(8\alpha_b + \beta_b + 3\beta_s) - \sqrt{(8\alpha_b + \beta_b + 3\beta_s)^2 - 32\alpha_b^2}}{8}, t_{b2}^{MS} = \frac{(8\alpha_b + \beta_b + 3\beta_s) + \sqrt{(8\alpha_b + \beta_b + 3\beta_s)^2 - 32\alpha_b^2}}{8}$$

The former solution is eliminated because it cannot satisfy $t_b > \alpha_b$. Therefore, when $\alpha_b < t_b < t_{b2}^{MS}$, we have $\frac{\partial p_{MS}}{\partial \alpha_b} < 0$; otherwise, when$t_b > t_{b2}^{MS}$, we have $\frac{\partial p_{MS}}{\partial \alpha_b} > 0$.

■ **Proof of** Proposition 4**:**

The profit function of platform i in MH-MH is

$$\begin{aligned}\Pi_{MM}^{i} = p^i\left(n_b^i + n_b^{i,-i}\right) + w^i\left(n_s^i + n_s^{i,-i}\right) = p^i\Bigg[&\frac{t_s(t_b - \beta_b)(t_bt_s - \beta_b\beta_s - \alpha_bt_s) - \alpha_bt_st_sp^i + t_s(t_bt_s - \beta_b\beta_s)p^{-i} - \beta_b(t_bt_s - \beta_b\beta_s)w^i + \alpha_b\beta_bt_sw^{-i}}{(t_bt_s - \beta_b\beta_s + \alpha_bt_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s)}\\ &+ \frac{(2\beta_bt_s + \alpha_bt_s - \beta_b\beta_s - t_bt_s) - t_s\left(p^i + p^{-i}\right) + \beta_b\left(w^i + w^{-i}\right)}{t_bt_s - \beta_b\beta_s + \alpha_bt_s}\Bigg]\\ +w^i\Bigg[&\frac{(t_bt_s - \beta_st_b + \alpha_bt_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s) - \beta_s(t_bt_s - \beta_b\beta_s)p^i + \alpha_b\beta_st_sp^{-i} - \alpha_b\beta_b\beta_sw^i + [t_b(t_bt_s - \beta_b\beta_s) - \alpha_b\alpha_bt_s]w^{-i}}{(t_bt_s - \beta_b\beta_s + \alpha_bt_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s)}\\ &+ \frac{(2\beta_st_b - \alpha_bt_s - \beta_b\beta_s - t_bt_s) + \beta_s(p^i + p^{-i}) - (t_b + \alpha_b)(w^i + w^{-i})}{t_bt_s - \beta_b\beta_s + \alpha_bt_s}\Bigg]\end{aligned} \tag{A22}$$

Taking the first- and second-order partial derivatives of Π_{MM}^{i} with respect to p^i and w^i, we have

$$\begin{cases} \dfrac{\partial \Pi_{MM}^{i}}{\partial p^i} = \dfrac{(\beta_bt_s + \alpha_bt_s - \beta_b\beta_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s) - 2t_s(t_bt_s - \beta_b\beta_s)p^i + \alpha_bt_st_sp^{-i} - \alpha_bt_s(\beta_b + \beta_s)w^i + \beta_b(t_bt_s - \beta_b\beta_s)w^{-i}}{(t_bt_s - \beta_b\beta_s + \alpha_bt_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s)} \\ \dfrac{\partial^2 \Pi_{MM}^{i}}{\partial p^{i2}} = -\dfrac{2t_s(t_bt_s - \beta_b\beta_s)}{(t_bt_s - \beta_b\beta_s + \alpha_bt_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s)} \\ \dfrac{\partial \Pi_{MM}^{i}}{\partial w^i} = \dfrac{(\beta_st_b - \beta_b\beta_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s) - \alpha_bt_s(\beta_b + \beta_s)p^i + \beta_s(t_bt_s - \beta_b\beta_s)p^{-i} - 2[t_s(t_b + \alpha_b)(t_b - \alpha_b) - \beta_b\beta_st_b]w^i + \alpha_b\beta_b\beta_sw^{-i}}{(t_bt_s - \beta_b\beta_s + \alpha_bt_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s)} \\ \dfrac{\partial^2 \Pi_{MM}^{i}}{\partial w^{i2}} = -\dfrac{2[t_s(t_b + \alpha_b)(t_b - \alpha_b) - \beta_b\beta_st_b]}{(t_bt_s - \beta_b\beta_s + \alpha_bt_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s)} \\ \dfrac{\partial^2 \Pi_{MM}^{i}}{\partial p^i\partial w^i} = -\dfrac{\alpha_bt_s(\beta_b + \beta_s)}{(t_bt_s - \beta_b\beta_s + \alpha_bt_s)(t_bt_s - \beta_b\beta_s - \alpha_bt_s)} \end{cases} \tag{A23}$$

The constraints of the Hessian Matrix are

$$\begin{cases} H_1^{MM} = \dfrac{\partial^2 \Pi_{MM}^{i}}{\partial p^{i2}} < 0 \Rightarrow t_s(t_b - \alpha_b) > \beta_b\beta_s \\ H_2^{MM} = \left(\dfrac{\partial^2 \Pi_{MM}^{i}}{\partial p^{i2}}\right)\left(\dfrac{\partial^2 \Pi_{MM}^{i}}{\partial w^{i2}}\right) - \left(\dfrac{\partial^2 \Pi_{M}^{i}}{\partial p^i\partial w^i}\right)^2 > 0 \Rightarrow 4t_b(t_bt_s - \beta_b\beta_s)^2 > \alpha_b^2t_s\left[4t_bt_s + (\beta_b - \beta_s)^2\right] \end{cases} \tag{A24}$$

Under these conditions, if the numbers of multi-homing users are both within the interval $(0,1)$, we can derive the equilibrium pricing from FOC as

$$\begin{cases} p_{MM}^{i} = p_{MM}^{-i} = \dfrac{(M - \alpha_bt_s)[\beta_bM(t_bt_s - \beta_st_b + M) - \alpha_bN(\alpha_bt_s + \beta_bt_s - \beta_b\beta_s) - \alpha_bt_s[\beta_s(\beta_b + \beta_s)(t_b - \beta_b) - 2t_bM]]}{(4t_bt_s - \beta_b\beta_s)M^2 - \alpha_bt_s\left[2M(t_bt_s + N) - \alpha_bt_sN - (M - \alpha_bt_s)(\beta_b + \beta_s)^2\right]} \\ w_{MM}^{i} = w_{MM}^{-i} = \dfrac{(M - \alpha_bt_s)[\beta_sM(t_bt_s - \beta_bt_s + M) - \alpha_bt_s[\beta_st_s(t_b - \beta_b) - \beta_sM + (\beta_b + \beta_s)(\alpha_bt_s + \beta_bt_s - \beta_b\beta_s)]]}{(4t_bt_s - \beta_b\beta_s)M^2 - \alpha_bt_s\left[2M(t_bt_s + N) - \alpha_bt_sN - (M - \alpha_bt_s)(\beta_b + \beta_s)^2\right]} \end{cases} \tag{A25}$$

Among them, $M = t_bt_s - \beta_b\beta_s$, $N = 2\alpha_bt_s + \beta_b\beta_s$.

■ **Proof of Corollary 4:**

Taking the derivative of $\widetilde{p}_{MM}$ with respect to β_b, we have

$$\frac{\partial\widetilde{p}_{MM}}{\partial\beta_b}=\frac{8{t_b}^2{t_s}^2-4\beta_s{t_b}^2t_s-8\beta_b\beta_st_bt_s+{\beta_b}^2{\beta_s}^2}{(4t_bt_s-\beta_b\beta_s)^2} \quad \text{(A26)}$$

Solving by the FOC, we have

$$t_{b1}^{MM}=\frac{\beta_b\beta_s\left(2t_s-\sqrt{t_s(2t_s+\beta_s)}\right)}{2t_s(2t_s-\beta_s)},t_{b2}^{MM}=\frac{\beta_b\beta_s\left(2t_s+\sqrt{t_s(2t_s+\beta_s)}\right)}{2t_s(2t_s-\beta_s)}$$

The former solution is eliminated because it cannot satisfy $t_b>\beta_b$. Therefore, when $\beta_b<t_b<t_{b2}^{MM}$, we have $\frac{\partial\widetilde{p}_{MM}}{\partial\beta_b}<0$; otherwise, when$t_b>t_{b2}^{MM}$, we have $\frac{\partial\widetilde{p}_{MM}}{\partial\beta_b}>0$.

Similarly, taking the derivative of $\widetilde{w}_{MM}$ with respect to β_s, we have

$$\frac{\partial\widetilde{w}_{MM}}{\partial\beta_s}=\frac{8{t_b}^2{t_s}^2-4\beta_bt_b{t_s}^2-8\beta_b\beta_st_bt_s+{\beta_b}^2{\beta_s}^2}{(4t_bt_s-\beta_b\beta_s)^2} \quad \text{(A27)}$$

Solving by the FOC, we have

$$t_{s1}^{MM}=\frac{\beta_b\beta_s\left(2t_b-\sqrt{t_b(2t_b+\beta_b)}\right)}{2t_b(2t_b-\beta_b)},t_{s2}^{MM}=\frac{\beta_b\beta_s\left(2t_b+\sqrt{t_b(2t_b+\beta_b)}\right)}{2t_b(2t_b-\beta_b)}$$

Similarly, the former solution is eliminated because it cannot satisfy $t_s>\beta_s$. Therefore, when $\beta_s<t_s<t_{s2}^{MM}$, we have $\frac{\partial\widetilde{w}_{MM}}{\partial\beta_s}<0$; otherwise, when$t_s>t_{s2}^{MM}$, we have $\frac{\partial\widetilde{w}_{MM}}{\partial\beta_s}>0$.

■ **Proof of Conclusion 2 & 3:**

(Conclusion 2) When buyers single-home, $w_{SS}^i=t-\beta_b>\frac{\beta_b+\beta_s}{2}-\beta_b=\frac{\beta_s-\beta_b}{2}$ and $w_{SM}^i=\frac{\beta_s-\beta_b}{4}$; thus, we have $w_{SM}^i<w_{SS}^i$. Similarly, we can proof that $p_{MS}^i<p_{SS}^i$.

(Conclusion 3) Taking the derivative of w_{MS}^i with respect to t, we have $\frac{\partial w_{MS}^i}{\partial t}=\frac{4t^2+\beta_b(\beta_b+3\beta_s)}{4t^2}>0$. Taking the derivative of w_{MM}^i with respect to t, we have $\frac{\partial w_{MM}^i}{\partial t}=\frac{\beta_b\beta_s(4t^2+4\beta_st+\beta_b\beta_s)}{(4t^2-\beta_b\beta_s)^2}>0$.

Let $w_{MS}^i<0$, we have $t<\frac{\sqrt{\beta_b(\beta_b+3\beta_s)}}{2}$, or equivalently, $t<\frac{\sqrt{{\beta_b}^2+2\beta_b\beta_s+\beta_b\beta_s}}{2}$. The upper limit of t is $t<\frac{\beta_b+\beta_s}{2}$, or equivalently, $t<\frac{\sqrt{{\beta_b}^2+2\beta_b\beta_s+{\beta_s}^2}}{2}$. When $\beta_b>\beta_s$, platforms will always subsidize sellers; otherwise, when $\beta_b<\beta_s$, platforms will either subsidize or charge sellers. Therefore, the condition for platforms to subsidize sellers is $\sqrt{\beta_b\beta_s+\frac{(\beta_b-\beta_s)^2}{8}}<t<\min\left(\frac{\beta_b+\beta_s}{2},\frac{\sqrt{\beta_b(\beta_b+3\beta_s)}}{2}\right)$.

Let $w_{MM}^i<0$, we have $\frac{\beta_b-\sqrt{\beta_b(\beta_b+8\beta_s)}}{4}<t<\frac{\beta_b+\sqrt{\beta_b(\beta_b+8\beta_s)}}{4}$. Since the feasible region of t in this case is $\sqrt{\beta_b\beta_s}<t<\sqrt{\beta_b\beta_s+\frac{(\beta_b-\beta_s)^2}{8}}$, the condition for platforms to subsidize sellers is $\sqrt{\beta_b\beta_s}<t<\min\left(\frac{\beta_b+\sqrt{\beta_b(\beta_b+8\beta_s)}}{4},\sqrt{\beta_b\beta_s+\frac{(\beta_b-\beta_s)^2}{8}}\right)$.

Similarly, let $p_{SM}^i<0$ and $p_{MM}^i<0$, we can have the condition for platforms to subsidize buyers when they single-home and partially multi-home as $\sqrt{\beta_b\beta_s+\frac{(\beta_b-\beta_s)^2}{8}}<t<\min\left(\frac{\beta_b+\beta_s}{2},\frac{\sqrt{\beta_s(3\beta_b+\beta_s)}}{2}\right)$ and $\sqrt{\beta_b\beta_s}<t<\min\left(\frac{\beta_s+\sqrt{\beta_s(8\beta_b+\beta_s)}}{4},\sqrt{\beta_b\beta_s+\frac{(\beta_b-\beta_s)^2}{8}}\right)$, respectively.

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