Exclusive Dealing in Asymmetric Platform Competition

Jiajia Cong, Yao Huang, Wen Zhou*

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Abstract

This paper studies exclusive dealing imposed on sellers by asymmetric platforms in a setting of cross-side network effects and platform differentiation. We find that exclusivity can be introduced by the strong platform alone, the weak platform alone, or both. In each case, exclusivity appears only when the initiator's service is not very valuable to sellers. Platform asymmetry facilitates the weak platform's adoption of exclusivity and hinders the strong platform's. When few sellers would have multihomed anyway, only the strong platform will introduce exclusivity. This may strengthen the cross-side network effect so much that consumer surplus, social welfare, and sellers' overall profitability all improve. In contrast, welfare and sellers' overall profitability decline when only the weak platform introduces exclusivity.

Keywords: Asymmetric platform competition, multihoming, singlehoming, exclusivity, welfare, regulation policy

JEL code: D43, L12, L13, L14, L42

*Cong (corresponding author): Department of Applied Economics, School of Management, Fudan University, China, jjcong@fudan.edu.cn. Huang: Business School, The University of Hong Kong, Hong Kong, yaohuang@connect.hku.hk. Zhou: Business School, The University of Hong Kong, Hong Kong, wzhou@hku.hk. We would like to thank Gary Biglaiser, Yuk-fai Fong, Xiao Fu, Jin Li, Zhuoran Lu, Noriaki Matsushima, Guofu Tan, Tat-How Teh, Chengsi Wang, Julian Wright, Zenan Wu, and seminar participants at Fudan University, University of Hong Kong, Peking University, National University of Singapore for helpful comments and suggestions. Cong would like to acknowledge the financial support from NSFC (Projects 72003035, 72192845) and Shanghai Pujiang Program (2019PJC007). The usual disclaimer applies.

1 Introduction

A platform provides a marketplace for buyers and sellers to interact. In most industries, multiple platforms coexist, and one way for a platform to compete is to forbid its sellers from operating on rival platforms. For example, Chinese e-commerce giant Alibaba does not allow its sellers to sell on its major competitor, JD.com.[1] In US, UK, and Canada, the large peer-to-peer carsharing company Turo prohibits its car hosts from listing the same vehicle on rivaling platforms.[2] Competing food delivery platforms, such as Foodpanda and Deliveroo in Singapore and Hong Kong, and Meituan and Ele.me in China, impose mutually exclusive deals on their restaurants.[3] Ride-hailing start-up Grab recruited taxies and drivers in Singapore on the condition that they stay away from the more established platform, Uber.[4]

In these examples, platforms compete with asymmetric strength, and exclusivity can be introduced by either the strong platform or the weak one, or both. The practice has raised concerns from regulators recently. In a number of countries, the antitrust authorities have investigated platforms' exclusive dealing and come to different conclusions and regulations.[5]

The competitive behavior and divergent regulation policy suggest the need for a better understanding of exclusive dealing on platforms. In particular, what drives a platform to introduce exclusivity? How do asymmetric platforms differ in their incentives? And what are the welfare consequences?

To study these questions, we build a model of platform competition with cross-side network effects and platform differentiation (Armstrong, 2006; Bakos and Halaburda, 2020). Two platforms are asymmetric in their intrinsic values, referred to as *strength*, and compete with uniform membership fees on sellers.[6] Each platform independently decides whether or not to forbid its sellers from transacting on the rival platform, a practice referred to as exclusivity. If at least one platform enforces exclusivity, no seller can multihome, and exclusivity prevails in equilibrium. Although exclusivity appears regardless of the source, it is still useful to distin-

[1] https://www.reuters.com/article/us-jd-com-alibaba-idUSKCN0SS17820151103

[2] Canadian Competition Bureau's investigation of Turo's exclusivity policy can be found at https://www.competitionbureau.gc.ca/eic/site/cb-bc.nsf/eng/04668.html.

[3] The report on food delivery platforms' exclusive dealing in Singapore can be found at https://www.todayonline.com/singapore/concerns-over-exclusive-deals-between-delivery-services-and-eateries. The report on Hong Kong Competition Commission's investigation of food delivery platforms' exclusivity can be found at https://www.scmp.com/news/hong-kong/society/article/3164987/hong-kong-antitrust-watchdog-investigates-foodpanda. Meituan is fined nearly 1 billion dollars by China's regulators for its exclusivity arrangements with restaurants: https://www.wsj.com/articles/chinas-antitrust-regulator-planning-to-fine-meituan-about-1-billion-11628238951.

[4] https://www.todayonline.com/singapore/grab-signs-exclusive-partnership-smrt-build-largest-car-fleet-singapore

[5] The Competition Commission of Singapore thinks that food delivery platforms' exclusive deals in Singapore are motivated by the vibrant competition for market shares and should not be a concern as long as the market is competitive (https://www.cccs.gov.sg/media-and-consultation/newsroom/media-releases/investigation-of-online-food-delivery-industry). Competition Bureau of Canada and China's antitrust authority believe that a platform's dominance leads to exclusivity, which will further strengthen the platform's market power and hurt its rivals. The Competition Commission in Hong Kong thinks that exclusivity by food delivery platforms may weaken competition and hurt consumers (https://www.compcomm.hk/en/media/press/files/PR_Online_Delivery_Platform_EN.pdf).

[6] Buyer membership fee is assumed to be zero for simplicity; relaxing this assumption will not change any major result. In many industries such as e-commerce, food delivery, and ride-hailing, consumers rarely need to pay in order to join a platform.

guish which platform introduces the policy because the identity may imply different forces and hence different welfare outcomes.

In such a framework, a platform enforces exclusivity if and only if its profit increases, which may be driven by an increased number of sellers or a higher price imposed on sellers. The quantity effect depends mainly on the two platforms' joint strength, while the price effect is largely related to the strength asymmetry between them. When the joint strength is large, many sellers would have multihomed, and both platforms lose substantial market share under exclusivity. When the joint strength is small, exclusivity allows the strong platform to not only keep all multihoming sellers but also encroach upon some sellers who would have preferred the weak platform, allowing the former to gain market shares at the expense of the latter.

In terms of price competition, two opposite forces are at work. If a platform loses market share under exclusivity, it tends to compete more aggressively. At the same time, sellers become less responsive to platform pricing, which tends to make a platform compete less aggressively (Chen and Riordan, 2008; Belleflamme and Peitz, 2019). Between the two platforms, the weaker one is more willing to price aggressively for the simple reason that it is less concerned about cannibalization under uniform pricing.

We find that exclusivity can be introduced by the strong platform alone, the weak platform alone, or both. When the joint strength is small, the strong platform will do it alone because it gains market share by squeezing its rival. When the joint strength is large, the weak platform will do it alone because its smaller market share allows it to compete more aggressively in price. When the joint strength is intermediate, both platforms benefit from exclusivity because price competition is mitigated. Neither platform introduces exclusivity if the joint strength is very large, in which case each platform would have competed aggressively under exclusivity but would still lose substantial market share.

A greater asymmetry between the platforms is conducive to the weak platform's adoption of exclusivity and is against the strong platform's. This is again because of their asymmetric incentive in price competition. When competing for marginal sellers under exclusivity, the strong platform does not necessarily enjoy any advantage over its weaker rival because platform asymmetry and differentiation imply that a marginal seller tends to prefer the weak platform.

Consumer surplus and social welfare can be improved by exclusivity, which happens when the joint strength is small. In that case, exclusivity lures most sellers and buyers to home on the strong platform, which generates strong cross-side network effect and hence higher welfare. That condition also tends to raise sellers' total profits, as few sellers would have multihomed and hence incurred the loss of giving up a second home, while most sellers enjoy a larger network effect and an attractive membership fee at the strong platform. We find that welfare rises only when exclusivity is introduced by the strong platform alone. If only the weak platform had enforced exclusivity, cross-side network effects would have dropped on both platforms and welfare cannot rise.[7]

Some researches have studied platforms' incentive of exclusive dealing on sellers. Armstrong and Wright (2007) consider a setting where platforms are differentiated by buyers but not sellers. A platform's concern is which side to rely on for its revenue. It may use a lower fee on buyers to increase the number of exclusive buyers, and then charge a higher fee to sellers for the access to such "competitive bottleneck." Or it may do the opposite through exclusive dealing: To lower the fee on sellers for them to singlehome, and then raise the fees on buyers. In our study, competitive bottleneck is not the key mechanism. Instead, seller loss and price competition under exclusivity determine a platform's choice of exclusivity. Moreover, sellers also differentiate between the platforms in our study, which allows a platform to even raise the seller fee under exclusivity. Belleflamme and Peitz (2019) assume that buyers always singlehome and the two platforms are symmetric. Our study admits symmetric platforms as a special case. More importantly, our asymmetric setting allows us to study when and why a weak platform may enforce exclusivity and how asymmetric platforms' exclusivity leads to contrasting welfare impacts, which can be useful for antitrust policies.

Some studies focus on a powerful seller's incentive to singlehome. Such seller faces the following tradeoff (Hagiu and Lee, 2011; Weeds, 2016; Carroni et al., 2019). Multihoming intensifies platform competition and lowers the rent that the seller can extract from a platform, while singlehoming facilitates platform differentiation but foregoes the opportunity to reach additional buyers. Ishihara and Oki (2021) show that a seller's singlehoming encourages buyer multihoming, which in turn intensifies platform competition and hence increases the seller's bargaining power over the platform.[8]

In traditional industrial organization, exclusive dealing has been studied in vertical relations without any cross-side network effect. Exclusivity may improve welfare by encouraging relationship-specific investments and effort (Segal and Whinston, 2000a; De Meza and Selvaggi, 2007) or by facilitating entry (Lee, 2013). It may also damage welfare by deterring entry (Aghion and Bolton, 1987; Rasmusen et al., 1991; Bernheim and Whinston, 1998; Segal and Whinston, 2000b).[9] In our setting, cross-side network effect plays a central role. Without such an effect, exclusivity would never have appeared in equilibrium because it always intensifies platform competition. When the network effect is stronger, both platforms' incentive of exclusive dealing is strengthened.

[7]When both platforms enforce exclusivity, consumer surplus and social welfare are hurt in most cases.

[8]Our paper is also related to studies of two-sided endogenous homing (Jeitschko and Tremblay, 2020; Bakos and Halaburda, 2020; Liu et al., 2021), which aim to show how endogenous homing affects platforms' pricing strategy. Our model setting is close to Bakos and Halaburda (2020). They focus on platforms' decision to subsidize, while we focus on platforms' exclusivity to disallow sellers' multihoming. There are some studies on specific industries that involve two-sided endogeneous homing, including Choi (2010), Athey et al. (2018), and Bryan and Gans (2019).

[9]Rey and Tirole (2007) and Whinston et al. (2006) provide overviews of the literature.

The remainder of the paper is organized as follows. After setting up the model in Section 2 and analyzing the benchmark of multihoming in Section 3, we establish the equilibrium of exclusivity in Sections 4 and discuss its conditions and various impacts including those on welfare. Section 5 provides a number of extensions such as buyer membership fee, personalized pricing, platform investment, and non-compulsory exclusivity. Finally, Section 6 concludes.

2 Model setup

Two platforms, referred to as $i \in \{1,2\}$, locate at the two endpoints of a unit-length Hotelling line. A unit mass of sellers distribute uniformly on the line. If a seller joins platform $i \in \{1,2\}$, his profit from the platform is:

$$\pi_i = v_i + \beta b_i - t_0 x_i - p_i,$$

where v_i is the intrinsic value of joining platform i, b_i is the number of buyers who patronize i, $\beta > 0$ measures the buyer-to-seller cross-side network effect, t_0 is the unit transportation cost for sellers, x_i is the distance from the seller's location to platform i (with $x_2 = 1 - x_1$), and p_i is the seller membership fee charged by platform i. If the seller multihomes by joining both platforms, then his profit is a simple summation of the profit earned from each platform:

$$\pi_m = \pi_1 + \pi_2.$$

Buyers are also uniformly distributed on the Hotelling line. If a buyer singlehomes at platform $i \in \{1,2\}$, she gets a utility of

$$u_i = \alpha s_i - k y_i - f_i$$

where s_i is the number of sellers at platform i, α measures the seller-to-buyer cross-side network effect, k is the unit transportation cost for buyers, y_i is the distance from the buyer's location to platform i (with $y_2 = 1 - y_1$), and f_i is the buyer membership fee charged by platform i. If a buyer multihomes, her utility is the sum of utilities from both platforms with a discount:

$$u_m = u_1 + u_2 - \gamma s_m$$

where $\gamma \in [0, \alpha]$ captures buyers' multihoming discounts, and $s_m \equiv \max\{0, s_1 + s_2 - 1\}$ is the measure of multihoming sellers.

Several features of the model are worth highlighting. This paper studies competition between asymmetric platforms, and the asymmetry is captured by the fact that the two platforms differ in their intrinsic values a seller may derive. Other than providing a virtual market for sellers and buyers to meet, a platform provides many necessary and valuable services to sellers such as platform infrastructure, platform branding, data analytics, logistics services, etc. For example, Alibaba offers sellers digital store decorations, marketing suggestions, consumer targeting services, and microloans. Meituan offers restaurants digital menus and streamlines their online and offline food order systems. Grab provides insurance and car maintenance services to drivers. We assume, without any loss of generality, that platform one provides a more valuable service than platform two: $v_1 \geq v_2$. In what follows, v_i will be referred to as platform i's *strength*.

The model directly specifies a seller's profit and a buyer's utility in joining a platform. This can be regarded as a reduced form of each party's individual choice and performance. By abstracting away from an explicit modeling of the transaction between buyers and sellers, we are better able to focus on platform choice (of exclusivity) rather than seller or buyer choices (of product market transaction). Such abstraction, which is common in platform studies (Rochet and Tirole, 2003, 2006; Armstrong, 2006), does not imply that buyers pay zero to sellers. In fact, the payment must be positive as is captured by the term βb_i in a seller's profit expression.

A seller's payment to a platform takes the form of membership fee, which may include entry fee for accessing the platform, and service charges for platform-specific software and investments. The amount can be substantial in real life. For example, Alibaba's retail platform, Tmall, charges ten thousand to one million RMB per year for necessary software, and JD.com charges about twelve thousand RMB per year for getting access to the platform. The seller profit expression implies that all sellers pay the same amount of membership fee, an assumption that will be relaxed later. In addition to membership fee, a seller may also pay a platform through commissions that are linked to each particular transaction. Such commissions, however, are incorporated in the endogenous membership fee in our model. This is because buyers and sellers are homogeneous in product transaction on a platform (they are heterogeneous only in terms of differentiation between the two platforms), which means that all sellers on a platform sell the same quantity and at the same price, so their commissions, if any, are identical.

For simplicity, the model ignores buyers' intrinsic value from each platform. We have assumed that a buyer incurs some discount from multihoming if some sellers multihome. If no seller multihomes ($s_1 + s_2 \leq 1$), a buyer receives the full additional benefit from joining a second platform. If, however, some sellers multihome ($s_1 + s_2 > 1$), the additional benefit from joining a second platform is discounted because the buyer will encounter some sellers that are already accessible from the first platform.[10]

[10]Buyers' multihoming discount is assumed in many studies (Ambrus et al., 2016; Jeitschko and Tremblay, 2020; Bakos and Halaburda, 2020; Saruta, 2021). The assumption is both sufficient and necessary in our model. If sellers also discount the profits of meeting multihoming buyers, i.e., $\pi_m = \pi_1 + \pi_2 - \delta b_m$ with $b_m = \max\{0, b_1 + b_2 - 1\}$, our analysis shows that the main results do not change qualitatively. This is not surprising, as the discounts are about duplicative transactions, which involve multihoming on both sides, so a one-sided formulation of the discounts is enough to capture the effect. On the other hand, if the buyer discount is absent (i.e., $\gamma = 0$), then a player's (either a buyer's or a seller's) decision to join a platform is independent of the rival platform's pricing strategy. In that case, the two platforms will not be competing, and exclusivity (which creates some competition between the two platforms) can

We make three assumptions to simplify the analysis in the main model.

Assumption 1. $f_1 = f_2 = 0$.

Assumption 2. $\alpha = \beta = k = 1$.

Assumption 3. $t_0 > \frac{\alpha\beta}{k} = 1$, *and* $\gamma < \frac{\alpha}{2} = \frac{1}{2}$.

Assumption 1 says that buyers can join a platform for free, which is the case in many industries including e-commerce, food delivery, and ride-hailing. This assumption is relaxed later in an extension. Assumption 2 is made mainly to simplify the non-essential parameters. A seller's homing decision is affected by the cross-side network effects (as captured by α and β) and platform differentiation (as captured by t_0 and k), or more precisely by the relative strengths of $t_0 k$, $\alpha\beta$, $\frac{\alpha}{k}$, and $\frac{\beta}{t_0}$ (Armstrong, 2006; Armstrong and Wright, 2007; Belleflamme and Peitz, 2019; Bakos and Halaburda, 2020). By normalizing α, β, k and sufficiently varying t_0, we can generate all the forces that are needed.[11] For Assumption 3, the first part says that platform differentiation effect is stronger than cross-side network effects, a typical assumption in the literature, while the second part says that buyers' multihoming discount is not too severe.[12]

3 Benchmark: The multihoming equilibrium

As the benchmark, we first analyze what will happen when sellers are allowed to multihome. The game proceeds as follows. The two platforms simultaneously announce their membership fees p_i, $i \in \{1, 2\}$, for sellers, after which sellers and buyers simultaneously choose which platform(s) to join.

When multihoming is allowed, given $\pi_m = \pi_1 + \pi_2$, a seller's decision of joining a platform is independent of his decision to join the other platform: he joins platform i if and only if $\pi_i \geq 0$. We will focus on an equilibrium where $s_1 + s_2 > 1$ with positive number of sellers on either platform (i.e., $s_1 \in (0, 1)$, and $s_2 \in (0, 1)$), referred to as a *multihoming equilibrium*. Figure 1(a) shows sellers' distribution on the two platforms, with:

$$s_i = \frac{v_i + b_i - p_i}{t_0}. \tag{1}$$

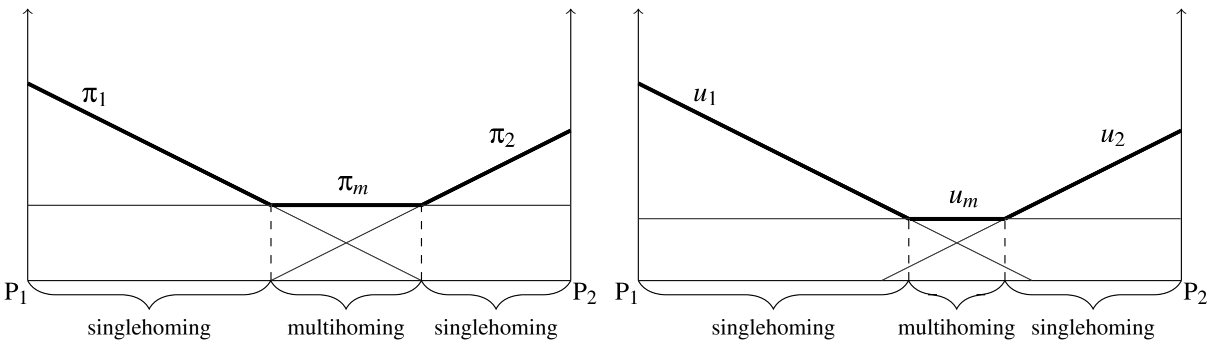
For buyers, given $u_m = u_1 + u_2 - \gamma s_m$, a buyer chooses to singlehome at platform i if and only if $u_i \geq \max\{u_j, u_m, 0\}$, and multihome if and only if $u_m \geq \max\{u_i, u_j, 0\}$. Under Assumption 3, $s_1 + s_2 > 1$ implies $b_1 + b_2 > 1$, meaning that buyers multihome if and only if sellers multihome.[13]

never be profitable.

[11] If the buyer-to-seller network effect β is kept in the model, none of the main results will change qualitatively. In particular, the effects of increasing β are similar to reducing $t \equiv t_0 - \frac{\alpha\beta}{k}$.

[12] This assumption ensures that a buyer joins at least one platform, which simplifies the analysis.

[13] This property comes from the assumption of $\gamma < \frac{\alpha}{2}$ and is not essential for our main results.



(a) Sellers' distribution

(b) Buyers' distribution

Figure 1: Seller and buyer distribution

Then the cutoff b_1 is solved from $u_m(b_1) = u_2(b_1)$ and b_2 from $u_m(1-b_2) = u_1(1-b_2)$ (see Figure 1(b)):

$$b_i = s_i - \gamma(s_i + s_j - 1). \tag{2}$$

Based on (1), we have $b_i \in (0,1)$, and $b_i + b_j - 1 = (1-2\gamma)(s_i + s_j - 1)$. Note that not every buyer will multihome even though joining a platform is free of charge. This is because of platform differentiation: a buyer incurs some loss of utility (in the form of transportation cost) when doing transactions on a non-ideal platform.[14]

The seller and buyer homing choices (given p_1 and p_2) are solved simultaneously from equations (1) and (2). It will be convenient to use the following parameters:

$$t \equiv t_0 - \frac{\alpha\beta}{k} = t_0 - 1 > 0 \text{ and } \theta \equiv \frac{\gamma}{t+\gamma} \in (0,1).$$

The parameter t represents platform differentiation relative to cross-side network effect. A smaller t indicates a (relatively) stronger cross-side network effect. The parameter θ represents buyers' multihoming discount relative to t. Given the two platforms' prices, the amount of sellers at platform i is $s_i = \frac{(v_i - p_i) - \theta(v_j - p_j) + t\theta}{t(1+\theta)}$. Each platform's profit is $\Pi_i = p_i s_i$. The equilibrium prices are

$$p_i^m = \frac{(2-\theta^2)v_i - \theta v_j}{4-\theta^2} + \frac{\theta t}{2-\theta},$$

where the superscript m indicates multihoming equilibrium, and $s_i^m = p_i^m/(t(1+\theta))$ sellers choose platform i. Apparently, $s_1^m \geq s_2^m$, with equality if and only if $v_1 = v_2$. Platform i's profit in the multihoming equilibrium is

$$\Pi_i^m = \frac{(p_i^m)^2}{t(1+\theta)}. \tag{3}$$

[14]Assumption 2 has fixed the unit transportation cost for buyers as $k = 1$. Even if the normalization is relaxed, Assumption 3 does not allow k to approach zero.

Define

$$v \equiv v_1 + v_2, \quad \text{and} \quad \mu \equiv \frac{v_1}{v_1 + v_2}, \tag{4}$$

where v is the two platforms' joint strength, and μ measures their strength asymmetry with $\mu \in \left[\frac{1}{2}, 1\right)$.

In order for this to be a proper multihoming equilibrium, the joint strength should be neither too large nor too small:[15]

$$v > \underline{v} \equiv t(2+\theta), \tag{5}$$

$$v < \overline{v} \equiv \frac{2t(2+\theta)}{\theta + d(4-\theta^2) + [(2-\theta) - d(4-\theta^2)]\mu}, \tag{6}$$

where $d \equiv \frac{\sqrt{1-\theta^2}-1}{\theta} < 0$. When v is smaller than $\underline{v}$, no seller multihomes. When v is larger than $\overline{v}$, platform two has very limited singlehoming sellers and has to use mixed strategies in pricing. A joint strength satisfying (5) and (6) allows us to focus on pure-strategy multihoming equilibrium. Figure 2 shows $\underline{v}$ and $\overline{v}$ in the space of μ and v, given any pair of t and θ. Note that the lower bound $\underline{v}$ is independent of the strength distribution μ, while the upper bound $\overline{v}$ is decreasing in μ.

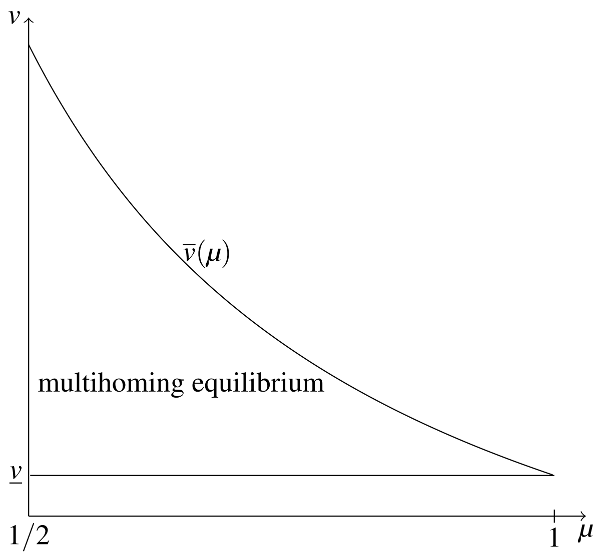


Figure 2: The region of multihoming equilibrium

In the multihoming equilibrium, the measure of multihoming sellers is $s_m \equiv s_1^m + s_2^m - 1 = \frac{(1-\theta)[v-t(2+\theta)]}{t(1+\theta)(2-\theta)}$. It depends only on the joint strength but not the strength asymmetry. Platform one always has more singlehoming sellers than platform two, with equality only when $\mu = \frac{1}{2}$. As the strength asymmetry μ increases, the number of singlehoming sellers increases at platform

[15]See section A.1 in Appendix for the calculation. The characterization of all possible equilibria when sellers can multihome is in Section 1 of Online Appendix.

one and decreases at platform two.[16]

Lemma 1. *In the multihoming equilibrium,*

(i) the number of multihoming sellers increases with the joint strength and is independent of the strength asymmetry;

(ii) fixing the joint strength, a greater strength asymmetry increases the number of singlehoming sellers at platform one and decreases it at platform two.

Platforms' joint strength and strength asymmetry are the two most important parameters for equilibrium, but they cannot be directly observed. Lemma 1 relates the non-observable strength to the observable measure of multihoming and singlehoming sellers.

4 Equilibrium exclusivity

Suppose each platform can force its sellers to singlehome, a policy referred to as *exclusivity*.[17] The game starts with stage zero, in which the two platforms simultaneously decide whether or not to enforce exclusivity. If at least one platform adopts exclusivity, then a seller can choose at most one platform; if neither platform adopts exclusivity, then a seller can multihome. Afterward, the game proceeds in the same way as before: platforms decide membership fees before sellers' and buyers' homing choices. We focus on the parameter space where the equilibrium is multihoming if no platform enforces exclusivity (i.e., conditions (5) and (6) hold), which has been solved in the previous section.

Suppose that at least one platform adopts exclusivity. Under exclusivity, anticipating buyers' homing decisions, seller x singlehomes at platform i if and only if $\pi_i \geq \max\{\pi_j, 0\}$. A buyer y's utility from singlehoming is either $u_1 = s_1 - y$ or $u_2 = s_2 - (1 - y)$. Since no seller can multihome under exclusivity, buyer y's utility from multihoming is $u_m = u_1 + u_2 - \gamma s_m = u_1 + u_2$, which means y joins a platform if and only if her net utility from the platform is non-negative. Specifically, anticipating sellers' homing decisions, buyers $y \leq s_1$ singlehome at platform one and buyers $y \geq 1 - s_2$ singlehome at platform two, which leads to $b_i = s_i$, and therefore no buyer multihome.

Depending on the parameters, the equilibrium expressions under exclusivity may take two forms,[18] which are shown in the following table.

[16] To see why the curve $\overline{v}(\mu)$ in Figure 2 is downward sloping, note that platform two uses pure-strategy pricing in equilibrium when its singlehoming sellers are above some minimum amount. As μ increases, the multihoming segment shifts closer to platform two. To make sure platform two has some singlehoming sellers under a larger μ, the number of multihoming sellers should be smaller, which requires $\overline{v}$ to be lower.

[17] Exclusivity is enforced as a compulsory policy in several antitrust cases, including JD.com vs. Alibaba, Ele.me vs. Meituan, Canadian Competition Bureau vs. Turo, and Shanghai Administration for Market Regulation vs. Sherpa's.

[18] In the first case (i.e., $3t < v < \bar{v}$), the seller who is indifferent between the two platforms obtains positive profit. In the second case, the indifferent seller gets zero profit.

Table 1: Equilibrium under exclusivity

	p_1^u	p_2^u	s_1^u	s_2^u	π_1^u	π_2^u
if $3t < v < \bar{v}$	$t + \frac{v_1 - v_2}{3}$	$t + \frac{v_2 - v_1}{3}$	$\frac{1}{2} + \frac{v_1 - v_2}{6t}$	$\frac{1}{2} + \frac{v_2 - v_1}{6t}$	$\frac{[3t+(2\mu-1)v]^2}{18t}$	$\frac{[3t-(2\mu-1)v]^2}{18t}$
if $\underline{v} < v < 3t$	$v_1 + \frac{v_2}{3} - t$	$\frac{2v_2}{3}$	$1 - \frac{v_2}{3t}$	$\frac{v_2}{3t}$	$\frac{[(2\mu+1)v-3t][-(1-\mu)v+3t]}{9t}$	$\frac{2(1-\mu)^2 v^2}{9t}$

Note: In the equilibrium, $b_i^u = s_i^u$ holds.

4.1 Equilibrium exclusivity and platform profits

A platform enforces exclusivity policy if and only if it benefits from exclusivity. We compare a platform's profit under exclusivity with its profit in the multihoming equilibrium to determine the condition of equilibrium exclusivity.

We find that platform one enforces exclusivity, i.e., $\Pi_1^u = \Pi_1^m$, if and only if:[19]

$$v < v_s^u \tag{7}$$

where the superscript u indicates uniform pricing and the subscript s indicates the strong platform. The condition says that the strong platform enforces exclusivity when the two platforms' joint strength v is not too large. Exclusivity influences a platform's business in two ways. First, the platform loses some multihoming sellers who now singlehome on its rival platform. Second, sellers become less sensitive to the platform's price because a seller now compares its profit from this platform with the profit from the rival platform rather than with zero, so a lower membership fee wins fewer sellers than before. The first effect makes the two platforms compete more aggressively, while the second effect makes them compete less aggressively. When the two platforms' joint strength v is large, there were many multihoming sellers to begin with, and the first effect tends to dominate. The strong platform competes fiercely but still loses a substantial amount of sellers, and its profit tends to drop under exclusivity.

As shown in the left panel of Figure 3, the cutoff v_s^u decreases in μ. That is, fixing the joint strength, platform one is more likely to be hurt by exclusivity when the two platforms become more asymmetric. Regardless of multihoming policy, a platform's lower price brings some new sellers at the margin but cannibalizes inframarginal sellers. The marginal sellers are those who multihome, while inframarginal sellers are mainly those who singlehome. When μ is larger, the measure of singlehome sellers in the multihoming equilibrium will rise at platform one and drop at platform two. This means that platform one will compete less aggressively under exclusivity (the "fat cat" effect), while platform two will compete more aggressively. As a result, platform one is more likely to be hurt by exclusivity.

[19]Detailed expressions of v_s^u and other subsequent cutoffs can be found in the appendix.

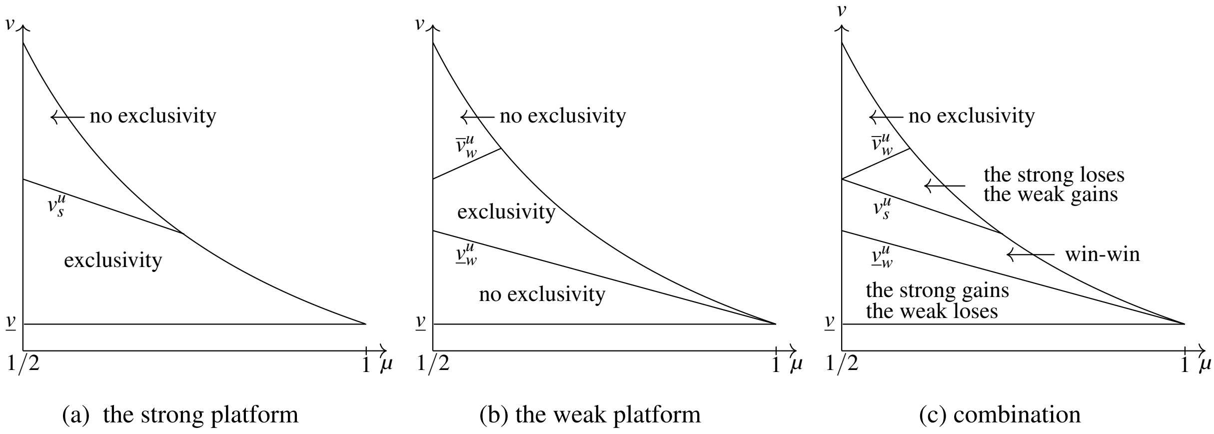


Figure 3: Equilibrium exclusivity

Platform two enforces exclusivity if and only if:[20]

$$\underline{v}_w^u < v < \bar{v}_w^u, \tag{8}$$

where the subscript w indicates the weak platform. The condition says that the weak platform enforces exclusivity when the joint strength v is moderate.

When the joint strength is very large (i.e., $v > \bar{v}_w^u$), there are many multihoming sellers. Exclusivity means a loss of many sellers, which tends to hurt the weak platform, similar to the effect on the strong platform. Unlike for the strong platform, however, here the boundary $\bar{v}_w^u$ increases in μ, meaning that platform two is more likely to benefit from exclusivity when the two platforms are more asymmetric. As explained above, when μ is larger, the measure of singlehoming sellers decreases at platform two and increases at platform one, making the former to compete more aggressively and the latter less aggressively. Platform two tends to gain at the expense of platform one.

When the joint strength is very small (i.e., $v < \underline{v}_w^u$), there are few multihoming sellers. Exclusivity will allow platform one to recruit not only all multihoming sellers through attractive fees but also some sellers that used to singlehome at platform two,[21] which will therefore suffer a loss. This lower boundary $\underline{v}_w^u$ decreases in μ. When μ becomes larger, platform two has fewer singlehoming sellers to begin with. It will compete more aggressively under exclusivity and tends to gain from it. The following proposition summarizes the conditions of equilibrium exclusivity.

[20]The upper boundary $v < \bar{v}_w^u$ is established from the weak platform's profit comparison $\Pi_2^u > \Pi_2^m$, in which Π_2^u is the equilibrium of $3t < v < \bar{v}$ in Table 1. The lower boundary $\underline{v}_w^u < v$ comes from the weak platform's profit comparison $\Pi_2^u > \Pi_2^m$, in which Π_2^u is the equilibrium of $\underline{v} < v < 3t$ in Table 1.

[21]This result is fueled by platform two's high price in the equilibrium of $\underline{v} < v < 3t$ because both platforms believe platform one would charge the most aggressive price. This is consistent with the favorable beliefs toward the strong platform in the literature (Caillaud and Jullien, 2001, 2003; Halaburda and Yehezkel, 2016, 2019). This result remains, except the belief in the equilibrium is very unfavorable toward the strong platform. That is, all game participants believe the weak platform two would charge a very aggressive price and the strong platform one would charge a high price.

Proposition 1. *When each platform charges a uniform fee to its sellers,*

(i) exclusivity appears in equilibrium if and only if the platforms' joint strength is not too large;

(ii) the strong platform enforces exclusivity when the joint strength is below a threshold, and it is more likely to enforce exclusivity when the two platforms become less asymmetric;

(iii) the weak platform enforces exclusivity when the joint strength is moderate, and it is more likely to enforce exclusivity when the two platforms become more asymmetric.

Each platform's strength v_i contributes to the joint strength v, so a platform's strength tends to hinder its adoption of exclusivity rather than facilitating it. For a platform with mighty strength, the following corollary is obvious.

Corollary 1. *A very strong platform never enforces exclusivity with uniform pricing, regardless of the strength asymmetry.*

A platform always benefits from its own exclusivity, but may benefit or suffer from the exclusivity enforced by the rival. We can show that the weak platform's upper boundary, $\overline{v}_w^u$, is always above the strong platform's, v_s^u (see Figure 3). In the region between $\overline{v}_w^u$ and v_s^u, only the weak platform enforces exclusivity, and the strong platform is hurt. In the region below $\underline{v}_w^u$, only the strong platform enforces exclusivity, and the weak platform is hurt. Therefore, a larger joint strength favors exclusivity by the weak platform rather than the strong platform. In the region between v_s^u and $\underline{v}_w^u$, both platforms enforce exclusivity, and both benefit from it. Such a win-win is possible because exclusivity weakens the price competition between the two platforms given that the joint strength v is not very small, and each platform's loss of sellers is limited given that v is not very large.

Proposition 2. *Conditional on equilibrium exclusivity,*

(i) if the joint strength is large (i.e., $v_s^u < v < \overline{v}_w^u$), only the weak platform enforces exclusivity, and the strong platform is hurt;

(ii) if the joint strength is moderate (i.e., $\underline{v}_w^u < v < v_s^u$), both platforms enforce exclusivity and the win-win outcome arises;

(iii) if the joint strength is small (i.e., $\underline{v} < v < \underline{v}_w^u$), only the strong platform enforces exclusivity, and the weak platform is hurt;

(iv) fixing the joint strength, as the two platforms' strength asymmetry becomes larger, it is more likely for the weak platform to benefit from exclusivity, and less likely for the strong platform to benefit (i.e., v_s^u decreases in μ).

Therefore, equilibrium exclusivity can result in a lose-win and a win-win for the two platforms, but never a lose-lose, i.e., it is impossible to have a prisoners' dilemma.

4.2 The impact of cross-side network effect

Figure 3 is drawn for a particular strength of cross-side network effect, which is captured by the parameter $t \equiv t_0 - \frac{\alpha\beta}{k}$. In particular, it shows a situation where the cross-side network effect is strong relative to platform differentiation (i.e., $t < \frac{3+\sqrt{17}}{2}\gamma$). When the network effect becomes weaker (i.e., t increases given $t > \frac{3+\sqrt{17}}{2}\gamma$), equilibrium exclusivity becomes less likely, as the strong platform's cutoff v_s^u shifts closer to $\underline{v}$, and the weak platform's cutoffs $\overline{v}_w^u$ and $\underline{v}_w^u$ shift to the right. When the network effect is very weak ($t > 8\gamma$), the weak platform never enforces exclusivity.

If the buyer-to-seller network effect is zero (i.e., $\beta = 0$),[22] a seller's decision to join a platform in a multihoming equilibrium will depend only on that platform's fee level but not its rival's. This means the two platforms are not competing, each earning a monopoly profit.[23] In that case, exclusivity forces the two platforms to compete, and neither can earn a profit that is greater than its monopoly profit. No platform has any incentive to enforce exclusivity. Therefore, the existence of cross-side network effects is a necessary condition for exclusivity appearing in equilibrium.

Proposition 3. *A buyer-to-seller network effect (i.e., a positive β) is necessary for equilibrium exclusivity. When the network effect weakens relative to platform differentiation (i.e., t increases), exclusivity is*

(i) less likely to appear in equilibrium;

(ii) enforced only by the strong platform if the network effect is sufficiently weak.

4.3 Exclusivity reshapes platforms' asymmetry

Exclusivity will change the two platforms' relative strength, which can be measured by the gap between their seller shares ($s_1 - s_2$) or buyer shares ($b_1 - b_2$). The strong platform becomes stronger if:[24]

$$\mu < \tilde{\mu} \equiv \frac{3t(\theta + 2) - (2\theta + 1)v}{2(1 - \theta)v}. \tag{9}$$

The curve $\tilde{\mu}$ is downwards sloping in the space of μ and v and lies between curves v_s^u and $\underline{v}_w^u$. The condition (9) implies that two platforms become more asymmetric under equilibrium exclusivity when their initial asymmetry is small, and less asymmetric when their initial asymmetry is large.

[22] In our model, the seller-to-buyer network effect (i.e., α) cannot be zero, otherwise buyers will not join any platform, as the network effect is the only benefit they derive.

[23] When sellers benefit from the cross-side network effects, a seller's operating profit depends on the number of buyers on that platform, which in turn depends on how much the rival platform is charging to sellers because buyers discount the marginal utility of meeting multihoming sellers. In that case, the two platforms engage in price competition even in the multihoming equilibrium.

[24] The condition is the same for both the seller share and buyer share. Similar condition exists when the relative strength is measured by the profit gap, $\Pi_1 - \Pi_2$.

Basically, a platform gains if it introduces exclusivity. As a result, the two platforms will become less asymmetric when only the weak platform enforces exclusivity, and more asymmetric when only the strong platform enforces exclusivity. In the win-win outcome, the asymmetry can go either way.

In equilibrium exclusivity, the strong platform never forecloses the weak rival by attracting all sellers and buyers, regardless of the strength asymmetry. With uniform pricing, the strong platform has to balance the benefit of winning more sellers (hence more buyers) and the cost of cannibalizing inframarginal sellers. Competing aggressively to win all sellers is too costly for the strong platform. So platforms continue to compete even after they introduce exclusivity.

Proposition 4. *Exclusivity makes the two platforms:*

(i) more asymmetric when only the strong platform enforces exclusivity;

(ii) less asymmetric when only the weak platform enforces exclusivity;

(iii) more asymmetric in the win-win outcome when μ and v are small.

(iv) No platform is foreclosed (i.e., losing all sellers and buyers).

4.4 Welfare and seller profits

We now study the impacts of equilibrium exclusivity on consumer surplus, sellers' total profits, and social welfare. When multihoming is allowed, buyers on $[0, 1-b_2^m]$ singlehome at platform one, buyers on $[1-b_2^m, b_1^m]$ multihome, and buyers on $[b_1^m, 1]$ singlehome at platform two. The total consumer surplus is

$$CS^m = \int_0^{1-b_2^m} (s_1^m - y)dy + \int_{1-b_2^m}^{b_1^m} (1-\gamma)(s_1^m + s_2^m - 1)dy + \int_{b_1^m}^{1} (s_2^m - (1-y))dy.$$

Under exclusivity, buyers on $[0, b_1^u]$ singlehome at platform one and buyers on $[1-b_2^u, 1]$ singlehome at platform two. The total consumer surplus is

$$CS^u = \int_0^{b_1^u} (s_1^u - y)dy + \int_{1-b_2^u}^{1} (s_2^u - (1-y))dy. \tag{10}$$

Buyer surplus consists of cross-side network effects and mismatch disutility (i.e., transportation costs). Both will be changed by exclusivity. Few buyers change their homing decisions after exclusivity, so the corresponding welfare impact of is minor. When v is relatively large, each platform loses many sellers and hence experiences a substantial drop in network effects. In order for exclusivity to enhance consumer surplus, a necessary condition is that the network effect is strengthened at platform one, which happens when v is small so that the strong platform attracts all multihoming sellers and some of the rival's singlehoming sellers under exclusivity. Formally, equilibrium exclusivity enhances consumer surplus if and only if

$$v < v_{cs}^u, \tag{11}$$

in which v_{cs}^u is a function of μ, t, and θ. Figure 4 shows the curve of v_{cs}^u.

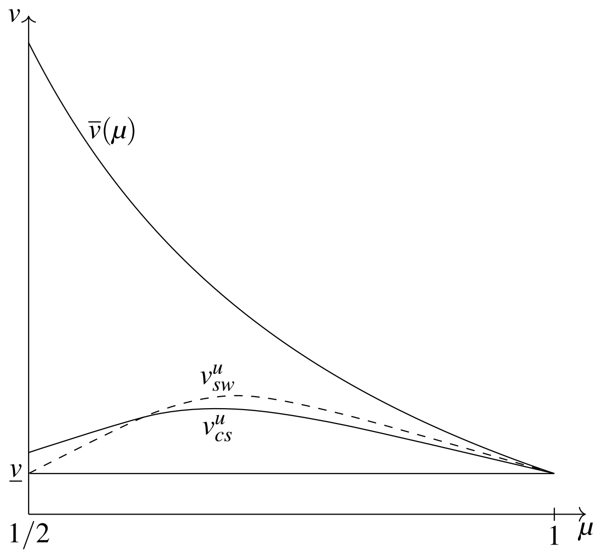


Figure 4: The impacts of equilibrium exclusivity on welfare

Equilibrium exclusivity enhances social welfare if and only if $v < v_{sw}^u$. The curve v_{sw}^u is shown in Figure 4. This intuition is similar to what is behind (11). In order for exclusivity to increase social welfare, the network effect at platform one must be enhanced.

Sellers' total profits are

$$\pi^i = \int_0^{s_1^i} (v_1 + b_1^i - t_0 x - p_1^i)dx + \int_{1-s_2^i}^1 (v_2 + b_2^i - t_0(1-x) - p_2^i)dx, \ i \in \{m, u\}. \tag{12}$$

The superscript $i = m$ indicates the multihoming equilibrium and $i = u$ indicates the exclusivity equilibrium under uniform pricing. We find that exclusivity increases sellers' total profit (i.e., $\pi^u > \pi^m$) if and only if $v < v_\pi^u$, in which v_π^u is a function of μ, t, and θ.[25] When the joint strength is large, many sellers multihome originally and their loss from giving up a second home is significant. A large joint strength v (slightly below $\overline{v}_w^u$ in Figure 3(c) such that exclusivity appears in equilibrium) also mitigates platforms' price competition so that sellers have to pay a higher fee under exclusivity.

Proposition 5. *Exclusivity increases consumer surplus, sellers' total profits, and social welfare when the joint strength is small.*

[25]The curve of v_π^u is similar to the curve v_{cs}^u, and is not shown in Figure 4.

According to Proposition 5, beneficial exclusivity (for consumers, sellers, or society) requires the same condition: a relatively small joint strength. Under this condition, exclusivity lures most sellers and buyers to converge onto the strong platform, resulting in a stronger network effect. The cutoff of v_{cs}^u is affected by the strength of cross-side network effects. When t becomes smaller, v_{cs}^u shifts closer to the lower boundary $\underline{v}$.

Corollary 2. *When cross-side network effect strengthens relative to platform differentiation (i.e., t decreases), equilibrium exclusivity is less likely to enhance consumer surplus.*

We also find that the welfare impacts of equilibrium exclusivity can be linked to its initiator. When only the weak platform enforces exclusivity, both platforms lose some multihoming sellers (and buyers) and offer weaker cross-side network effects. Consumers, sellers, and society are always hurt in this scenario.

Proposition 6. *When only the weak platform benefits from exclusivity, consumer surplus, sellers' total profits, and social welfare are always hurt.*

When both platforms enforce exclusivity (i.e., win-win region in Figure 3(c)), consumer surplus, sellers' total profits, and social welfare decrease in most cases, except in the corner near $\mu = 1$.[26] When only the strong platform benefits from exclusivity, consumer surplus, sellers' total profits, and social welfare may increase or decrease.

5 Extensions and discussions

5.1 Buyer membership fee

The main model has assumed that buyers do not pay any membership fee when joining a platform. Now suppose that buyers pay f_i for joining platform $i \in \{1, 2\}$. The game proceeds the same as in Section 3 except that platforms simultaneously decide (p_i, f_i). It turns out that in the multihoming equilibrium, platform i charges a positive p_i^m to sellers but subsidizes buyers with a negative price f_i^m. This is because when multihoming is allowed, the platforms directly compete for buyers while not for sellers.[27] Therefore, platforms subsidize buyers and recover the loss by charging high prices to sellers. This is close to the "competitive bottleneck" scenario studied by Armstrong (2006).[28] The equilibrium distributions of buyers and sellers are similar to Figure 1 except that multihoming is now chosen by more buyers and sellers.

[26]The exception vanishes when t is large.

[27]More specifically, given the market share on the other side, a buyer's homing decision depends on both platforms' prices, and whether a seller joins platform i depends on p_i^m only.

[28]In the typical competitive bottleneck scenario, sellers multihome and buyers singlehome. Since platforms can monopolize sellers' access to singlehoming buyers, they compete aggressively for buyers and charge high prices for sellers. In our model, platforms compete aggressively for buyers and possess strong market power over the pricing for sellers. So our setting can be regarded as a modified version of the competitive bottleneck.

Under exclusivity, $f_i^u = 0$, and the p_i^u is the same as in the main model. The comparison between p_i^u and p_i^m is similar to that in the main model and has the same intuition. Buyers are no longer subsidized. The reason is that exclusivity compels platforms to compete directly for sellers, leading to increased prices for buyers (similar to the result obtained by Armstrong (2006)). As before, exclusivity enhances consumer surplus, social welfare and sellers' total profits only when the joint strength is relatively small, but there is less scope for welfare improvement because welfare would have been high in the multihoming equilibrium due to the larger scale of multihoming and hence stronger network effect.

Proposition 7. *When buyers pay an endogenous membership fee, exclusivity*

(i) mitigates the platforms' price competition for buyers;

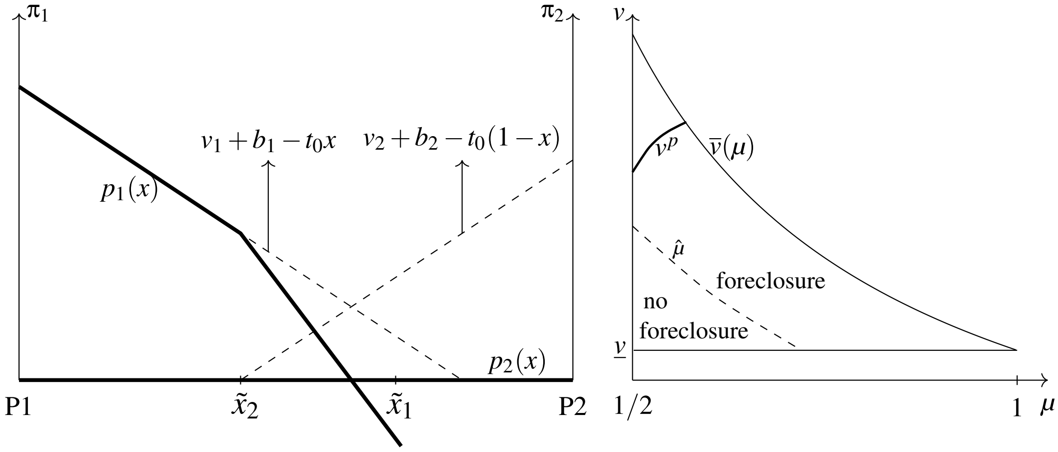
(ii) is less likely to enhance consumer surplus and social welfare than when buyer fee is zero.

5.2 Personalized pricing

Under uniform pricing, the concern of cannibalizing inframarginal sellers prevents the strong platform from competing aggressively. Platforms in real life often charge discriminatory prices to merchants (Liu and Serfes, 2013; Ding and Wright, 2017) . How will discriminatory pricing affect the results in Section 4? We now turn to a situation where each seller is charged a personalized membership fee under exclusivity (it is still uniform pricing when exclusivity is not enforced). Denote by $p_i(x)$ as the price charged by platform i to seller $x \in [0, 1]$. A personalized price can be negative. Subsidizing some sellers allows a platform to attract more buyers, which in turn allows the platform to raise the prices for other sellers. We make the assumption $p_2(x) \geq 0$ throughout this section, which is reasonable because strong and weak platforms differ significantly in their financial resources (Kahn, 2017).[29]

Given sellers' homing strategies, a buyer's homing strategy is the same as in Section 4. The left panel of Figure 5 characterizes two platforms' equilibrium prices for sellers. The seller-by-seller price competition drives $p_2(x) = 0$ for any seller in the equilibrium. Platform one charges $p_1(x) = v_1 + b_1 - t_0 x$ for sellers with $x < \max\{\tilde{x}_2, 0\}$ because they get strictly negative profit from platform two even though the platform's price is zero, and charges $p_1(x) = v_1 + b_1 - t_0 x - (v_2 + b_2 - t_0(1 - x))$ for sellers on $[\max\{\tilde{x}_2, 0\}, \min\{\tilde{x}_1, 1\}]$. Platform one gives up sellers on $[\min\{\tilde{x}_1, 1\}, 1]$ because the subsidies needed are too costly and, at the same time, sets the aggressive off-equilibrium-path prices, which are slightly higher than $p_1(x) = v_1 + b_1 - t_0 x - (v_2 + b_2 - t_0(1 - x))$. As a result, the amounts of sellers on the two platforms are $s_1^p = \min\{\tilde{x}_1, 1\}$ and $s_2^p = 1 - \min\{\tilde{x}_1, 1\}$, where the superscript p indicates personalized pricing.

[29]Our results do not change if this assumption is relaxed to $p_2(x) \geq \underline{p}$, in which $\underline{p} \leq 0$ and its absolute value is small.



(a) Equilibrium prices

(b) Equilibrium exclusivity

Figure 5: Equilibrium personalized prices and equilibrium exclusivity

We find that platform two never enforces exclusivity because its profit would drop to zero. Platform one enforces exclusivity if and only if $\Pi_1^p > \Pi_1^m$, leading to the condition $v < v^p$ (see the right panel of Figure 5). Consistent with uniform pricing, here exclusivity appears in equilibrium when the joint strength is not very large. This result can be attributed to two effects. First, given strength asymmetry μ, when v increases, platform one achieves first-degree price discrimination to fewer or even no sellers because fewer sellers earn negative profit from platform two. Second, platform one's profit in the multihoming equilibrium increases rapidly with v, making exclusivity profit more difficult to exceed.

The threshold v^p increases with μ. When μ is larger, platform two is weaker, and the seller-by-seller competition is less costly for platform one. Therefore, strength asymmetry is conducive to the strong platform's exclusivity under personalized pricing, whereas it is a barrier under uniform pricing. Under equilibrium exclusivity, platform one acquires all sellers and buyers when $\mu > \hat{\mu}(v,t)$, implying platform two is foreclosed. The curve of $\hat{\mu}$ is shown in the right panel of Figure 5.

Proposition 8. *When exclusivity is combined with personalized pricing on sellers,*

(i) exclusivity appears in equilibrium if and only if the joint strength is not too large, i.e., $v \leq v^p$;

(ii) the strong platform always benefits from equilibrium exclusivity, and the weak platform is always hurt;

(iii) fixing the joint strength, a greater asymmetry makes the strong platform more likely to enforce exclusivity;

(iv) the weak platform is foreclosed when the asymmetry is sufficiently large, i.e., $\mu > \hat{\mu}$.

Equilibrium exclusivity always increases the strong platform's market share and profitability. When the cross-side network effect is stronger, exclusivity and foreclosure become more likely in the sense that the threshold v^p moves up and the no foreclosure region shrinks in Figure 5. A stronger network effect (i.e., t decreases) allows platform one to attract sellers and buyers with smaller subsidies. When t is sufficiently small, exclusivity is the equilibrium for any v and μ, and foreclosure is the unique outcome under equilibrium exclusivity.

The impacts of equilibrium exclusivity on consumer surplus and social welfare are similar to Proposition 5. However, different to the exclusivity under uniform pricing, equilibrium exclusivity here increases sellers' total profits when platforms' strength asymmetry is small, which results in fierce seller-by-seller competition.

Suppose that platforms are allowed to enforce exclusivity but must charge uniform prices, a policy referred to as PP ban. Compared to exclusivity with personalized pricing as the benchmark, this policy makes exclusivity less likely to appear in equilibrium (i.e., $v^p > \overline{v}^u_w$ always holds, as shown in the left panel of Figure 6). Specifically, the strong platform's region of enforcing exclusivity shrinks significantly, but the weak platform can enforce exclusivity under the ban.

The PP ban can harm and benefit welfare, depending on the joint strength and strength asymmetry (i.e., v and μ). The policy declines the possibility for the strong platform to attract more buyers and sellers and generate greater network effects, which harms welfare. In addition, the weak platform can enforce welfare-damaging exclusivity under the ban. As shown in Figure 6(a), the PP ban hurts consumer surplus in the blue and green regions and hurts social welfare in the green region. On the other hand, the PP ban can prevent the strong platform from enforcing welfare-damaging exclusivity and protect consumer surplus and social welfare. In particular, the consumer surplus is protected in the red region of Figure 6, and social welfare gets protected in the blue and red regions.

Without the ability to price discriminate, the strong platform cannot foreclose its rival and monopolize the market with exclusivity. This preserves market competition and can be beneficial to welfare in the long run.

Corollary 3. *Suppose platforms are allowed to enforce exclusivity but must charge uniform prices. Compared to allowing exclusivity with personalized pricing,*

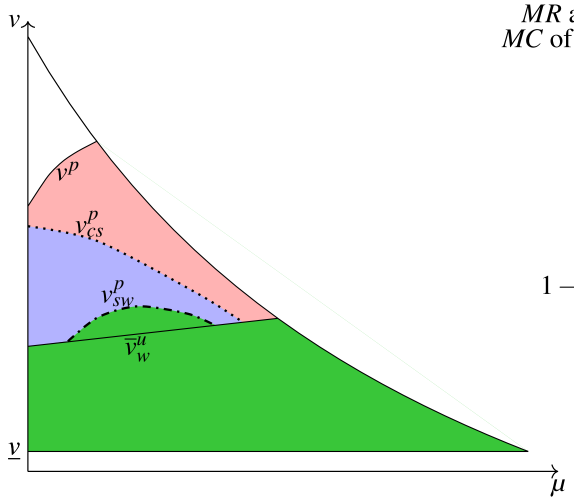
(i) exclusivity is less likely to appear in equilibrium;

(ii) consumer surplus and social welfare are reduced when the joint strength is relatively small, but platform competition is maintained.

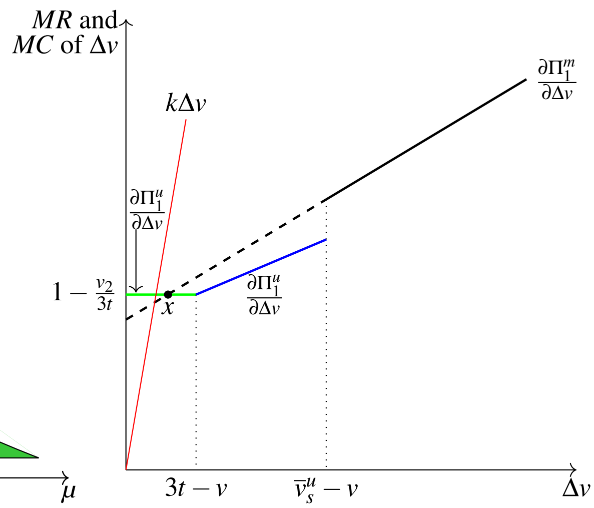
5.3 Platform investment

A number of studies have shown that exclusive dealing can spur firms' investments in the vertical relationship (Segal and Whinston, 2000a; De Meza and Selvaggi, 2007), implying exclusive dealing can be pro-competitive.[30] We now analyze how the strong platform's investment is affected by exclusivity policy. Suppose the strong platform can invest in raising its intrinsic value (for example, by improving platform infrastructure). In particular, v_1 can be raised by Δv at the cost of $\frac{k}{2}(\Delta v)^2$ for some positive k. We compare two scenarios: exclusivity is banned, and it is allowed. The game in each scenario proceeds as follows. At the very beginning, the strong platform decides its investment Δv. If exclusivity is allowed, the two platforms simultaneously decide whether to enforce exclusivity and then decide their prices p_i^e (when at least one platform enforces exclusivity) or p_i^m (when neither platform enforces exclusivity) at the same time. If exclusivity is banned, they simultaneously decide their prices p_i^m. Sellers and buyers make their homing decisions simultaneously after observing platforms' prices. Since the marginal cost of investment does not change with exclusivity, how exclusivity affects the investment depends on its impacts on the marginal benefits of investment.

In the scenario of banning exclusivity, platform one's profit function Π_1^m is the same as (3) in the multihoming equilibrium except that platform one's strength is now $v_1 + \Delta v$. Its optimal Δv^m is uniquely determined by the intersection between marginal revenue $\frac{\partial \Pi_1^m}{\partial \Delta v}$ and marginal cost $k\Delta v$. The right panel of Figure 6 shows the lines of marginal revenue and the marginal cost of investment.



(a) Banning personalized pricing



(b) Exclusivity and platform's investment

Figure 6: Policy discussions on exclusivity

[30] In the antitrust case of Shanghai Administration for Market Regulation vs. Sherpa's, Sherpa's, the leading food-delivery platform for foreigners in Shanghai, defends its exclusivity policy on restaurants that exclusivity motivates it to invest more on the seller side to enhance consumers' experience at the platform.

Suppose exclusivity is allowed. If platforms compete with uniform prices, platform one's profit function Π_1^e consists of three parts depending on the joint strength $v+\Delta v$:

$$\Pi_1^e = \begin{cases} \Pi_1^m \text{ in (3)} & \text{when } v+\Delta v > \overline{v}_w^u, \\ \Pi_1^u \text{ in Table 1} & \text{when } 3t < v+\Delta v < \overline{v}_w^u, \\ \Pi_1^u \text{ in Table 1} & \text{when } \underline{v} < v+\Delta v < 3t. \end{cases}$$

Platform one's optimal Δv^e under exclusivity is uniquely determined by the intersection between $\frac{\partial \Pi_1^e}{\partial \Delta v}$ and $k\Delta v$.

Exclusivity increases the platform's investment (i.e., $\Delta v^e > \Delta v^m$) only in the following scenario. When the line $k\Delta v$ is very steep (above the point x), as shown in Figure 6, $\Delta v^e > \Delta v^m$ holds. Besides a large k, $\Delta v^e > \Delta v^m$ also requires the line $\frac{\partial \Pi_1^m}{\partial \Delta v}$ crosses the line $\frac{\partial \Pi_1^u}{\partial \Delta v}$. This condition is equivalent to the joint strength is not large: $v < v^I$.

Suppose platforms enforce exclusivity with personalized pricing. Platform one's marginal investment revenue $\frac{\partial \Pi_1^e}{\partial \Delta v}$ under exclusivity is always (weakly) larger than its marginal revenue $\frac{\partial \Pi_1^m}{\partial \Delta v}$ when exclusivity is banned. Therefore, platform one always invests (weakly) more under exclusivity.

Proposition 9. *Compared with banning exclusivity policy, allowing exclusivity increases the strong platform's investment*

(i) when exclusivity accompanies personalized pricing, or

(ii) when the joint strength is not large and the marginal cost of investment is very high if platforms compete with uniform pricing.

When the conditions in Proposition 9 fail, equilibrium exclusivity either decreases or does not change the strong platform's investment.

5.4 Non-compulsory exclusivity

In the analysis so far, exclusivity is enforced by imposing it as a condition for a seller to join a platform (along with the seller membership fee). We now discuss how platforms may use price menus or manipulate sellers' cross-side network effects to induce sellers' exclusivity. It turns out that these inconspicuous tools can achieve the same equilibrium as the mandatory exclusivity and bring the same welfare impacts.

Suppose platform i sets the following price menu for sellers: p_i^s if the seller singlehomes on i and p_i^m if he multihomes, as in Shekhar (2021) and Chica et al. (2021).[31] The stage zero and

[31] In the antitrust cases of JD.com vs. Alibaba and Ele.me vs. Meituan, the strong platforms Alibaba and Meituan

stage one of the games in Sections 4 are replaced with platforms simultaneously designing the menu (p_i^s, p_i^m). Since multiple equilibria may exist in the menu competition, we focus on the equilibrium that no seller multihomes in the following analysis. Note that all sellers singlehome when at least one platform chooses a sufficiently high price p_i^m. Without loss of generality, we set $p_i^m \geq v + 1$. Then the two platforms compete for sellers with p_i^s. Platform i's equilibrium price p_i^s is characterized by Table 1. The impacts of equilibrium price menus on welfare follow naturally as in Section 4.

If a platform can control the magnitude of network effect on individual sellers, it may induce a seller's exclusive dealing with different network effects contingent on whether the seller singlehomes or multihomes. For example, Alibaba diverts buyer attentions to sellers who delist from its rival JD.com, and hinders the search for sellers who sell on both platforms.[32] Suppose that platform $i \in \{1, 2\}$ chooses network effect multiplier $\delta_i^j(x)$ on seller x depending on the seller's homing choice, such that the seller's profit is $\pi_i^s = \delta_i^s(x)(v_i + b_i) - t_0 x_i - p_i(x)$ if singlehoming at platform i, and $\pi_m = \delta_1^m(x)(v_1 + b_1) - t_0 x_1 - p_1(x) + \delta_2^m(x)(v_2 + b_2) - t_0 x_2 - p_2(x)$ if multihoming.

Without loss of generality, we assume $\delta_i^s(x) \in \{0, 1\}$ and $\delta_i^m(x) \in \{0, 1\}$. The stage zero of games in Sections 4 and 5.2 are replaced with platforms simultaneously designing $(\delta_i^s(x), \delta_i^m(x))$. In the following analysis, we focus on the equilibrium that no seller multihomes. Note that all sellers will singlehome if platform i chooses $\delta_i^m(x) = 0$, in which case the other platform's choice of $\delta_j^m(x)$ becomes irrelevant. A platform's choice of $\delta_i^s(x)$ for potential singlehoming sellers must equal to one. Therefore, the subsequent game under $\delta_i^m(x) = 0$ is equivalent to the game under mandatory exclusivity. The equilibrium and welfare impacts are the same as in Section 4.

6 Conclusion

This paper studies the conditions under which asymmetric platforms enforce exclusivity and its impacts on welfare. We show that exclusivity appears in equilibrium only when platforms' joint strength is not large. Therefore, a platform's strength hinders its adoption of exclusivity rather than facilitating it. The strength asymmetry encourages the weak platform to enforce exclusivity whereas it constrains the strong platform. In other words, under equilibrium exclusivity, a larger strength asymmetry tends to benefit the weak platform and hurt the strong platform. So it can be the weak platform that enforces exclusivity rather than the stronger one.

charge discriminatory prices to multihoming sellers who promise to singlehome and those who continue to multihome. Food delivery platforms in Hong Kong charge a significantly lower commission for eateries which are the platform's exclusive partners.

[32] In the antitrust case of Ele.me vs. Meituan, Meituan refuses to host the restaurants or makes consumers harder to find them if the restaurants refuse to singlehome at Meituan. Another example of a platform manipulating sellers' cross-side network effects can be found in the antitrust case of District of Columbia vs. Amazon (https://oag.dc.gov/sites/default/files/2021-05/Amazon-Complaint-.pdf). Amazon manipulates third-party sellers' access to the Buy Box and declines their chances to make the sale if they offer lower prices outside Amazon.

There are also some situations (i.e., intermediate joint strength) in which both platforms gain from exclusivity, resulting in a win-win outcome. Exclusivity in turn will reshape platforms' asymmetry: a platform gains relative salience when it is the only platform that enforces exclusivity. Last but not least, equilibrium exclusivity can enhance consumer surplus and social welfare, but that happens only when platforms' joint strength is relatively low.

Our paper sheds light on public policies regarding platforms' exclusivity. First, a platform's enforcement of exclusivity does not necessarily indicate its dominance in market competition, and the practice's welfare consequence needs to be evaluated carefully. Second, banning a weak platform's exclusivity is likely to improve consumer surplus and social welfare, but such a ban on a strong platform may hurt welfare when few sellers multihome to begin with. Third, a necessary condition for exclusivity to improve welfare is that a platform obtains a large number of buyers and sellers. Fourth, discriminatory pricing may enable a strong platform to foreclose its weak rival under exclusivity, which may not necessarily hurt welfare in the short run. However, a platform may be willing to sacrifice short-term profits to establish market monopolization. In that case, a ban on discriminatory pricing can maintain competition and improve welfare in the long run.

The research can be further extended in several directions: platforms may endogenously require some but not all multihoming sellers to singlehome, the distribution of sellers and buyers can be more general, and the two platforms may differ in their cross-side network effects rather than the intrinsic values. We will leave these for future work.

A Appendix

More detailed proofs can be found at the corresponding author's personal website https://sites.google.com/site/jiajiacong/research.

A.1 Conditions of the multihoming equilibrium in Section 3

When sellers can multihome, we focus on the multihoming equilibrium in which multihoming sellers exist and each platform has some singlehoming sellers (i.e., $s_m > 0$ and $s_1, s_2 \in (0,1)$). Therefore, the marginal seller (and buyer) of platform i is indifferent between multihoming and singlehoming at platform j ($j \neq i$), suggesting $s_i = (v_i + b_i - p_i)/t_0$ and $b_i = s_i - \gamma(s_i + s_j - 1)$. Then we have $s_i = \frac{(v_i - p_i) - \theta(v_j - p_j) + t\theta}{t(1+\theta)}$. Under Assumption 2 and 3, $s_m > 0$ implies both $u_m > 0$ and $b_1 + b_2 - 1 > 0$. To satisfy $s_m > 0$ and $s_1, s_2 \in (0,1)$, we need

$$(p_1 - v_1) + (p_2 - v_2) < -t, \quad -t\theta < (v_1 - p_1) - \theta(v_2 - p_2) < t, \quad -t\theta < (v_2 - p_2) - \theta(v_1 - p_1) < t. \quad (13)$$

The best response of platform i is $p_i(p_j) - v_i = [\theta(p_j - v_j) - v_i + \theta t]/2$. Combining two best response functions, we can solve the equilibrium prices, each platform's amount of sellers and buyers, and platforms' profits. Condition (13) becomes

$$\underline{v} < v < \frac{(2-\theta^2)t(\theta+2)}{(2-\theta)(\theta+1)\mu - \theta}.$$

However, when v approaches $\frac{(2-\theta^2)t(\theta+2)}{(2-\theta)(\theta+1)\mu-\theta}$, platform one's number of sellers s_1 approaches one, and platform two has very few singlehoming sellers. In this case, platform two has a global deviation strategy to mix between (i) charging high uniform price for multihoming sellers and giving up attracting singlehoming sellers, and (ii) charging a low uniform price to attract more singlehoming sellers. Given any μ, we need the joint strength v to satisfy $v < \bar{v}(\mu)$ to avoid such deviation, in which $\bar{v}(\mu)$ is defined by (6) and $\bar{v}(\mu) < \frac{(2-\theta^2)t(\theta+2)}{(2-\theta)(\theta+1)\mu-\theta}$. When $v < \bar{v}(\mu)$ holds, the value of s_1 is bounded such that it would not be so close to one.

A.2 The cutoffs in Section 4

Platform one's condition of enforcing exclusivity is

$$v < v_s^u \equiv \begin{cases} \frac{t \cdot h(\theta)}{g(\theta)-1+\mu} & \text{when} \quad v \geq 3t, \\ w(\mu, \theta, t) & \text{when} \quad v < 3t, \end{cases}$$

in which $h(\theta) \equiv \frac{3(4-\theta^2)\sqrt{1+\theta}-3\sqrt{2}\theta(2+\theta)}{3\sqrt{2}(2+\theta-\theta^2)-2(4-\theta^2)\sqrt{1+\theta}}$, $g(\theta) \equiv \frac{3\sqrt{2}(2-\theta^2)-(4-\theta^2)\sqrt{1+\theta}}{3\sqrt{2}(2+\theta-\theta^2)-2(4-\theta^2)\sqrt{1+\theta}}$, and $w(\mu,\theta,t)$ is defined implicitly by $\delta_2 w^2+\delta_1 w+\delta_0=0$ where $\delta_2 = 9[(2+\theta-\theta^2)\mu-\theta]^2+(1+\theta)(4-\theta^2)^2(2\mu+1)(1-\mu), \delta_1 = 18t\theta(2+\theta)[(2+\theta-\theta^2)\mu-\theta]-3t(2+\mu)(1+\theta)(4-\theta^2)^2$, and $\delta_0 = 9t^2\theta^2(2+\theta)^2+9t^2(1+\theta)(4-\theta^2)^2$. Platform two's condition of enforcing exclusivity is

$$\underline{v}_w^u < v < \overline{v}_w^u, \text{ in which } \overline{v}_w^u \equiv \frac{t\cdot h(\theta)}{g(\theta)-\mu} \text{ and } \underline{v}_w^u \equiv \frac{t\cdot n(\theta)}{l(\theta)+\mu}.$$

We have $n(\theta) = \frac{3\theta(2+\theta)}{3(2+\theta-\theta^2)-\sqrt{2(1+\theta)}(4-\theta^2)} > 0$ and $l(\theta) = \frac{\sqrt{2(1+\theta)}(4-\theta^2)-3(2-\theta^2)}{3(2+\theta-\theta^2)-\sqrt{2(1+\theta)}(4-\theta^2)} > 0$.

Exclusivity widens two platforms' profit gap if and only if

$$v < \tilde{v}^u \equiv \begin{cases} 2t(\theta+4)/3, & \text{when } t<\gamma \\ y(\mu,\theta,t), & \text{when } t\geq\gamma, \end{cases}$$

where $y(\mu,\theta,t)$ is defined implicitly by $\zeta_2 y^2+\zeta_1 y+\zeta_0=0$, where $\zeta_2 = \mu(\theta^2-6\theta+2)-\theta^2+3\theta+1$, $\zeta_1 = \mu(\theta^2+12\theta-4)-2(\theta+1)(4-\theta)$, and $\zeta_0 = 3t^2(2-\theta)(\theta+2)$.

Consumer surplus in the multihoming equilibrium is $CS^m = \frac{\xi_2 v^2+\xi_1 v+\xi_0}{2t^2(1+\theta)^2(\theta+2)^2(\theta-2)^2}$, in which $\xi_2 = 2\mu(\mu-1)(1+\theta)^2(-2+\theta)^2+(2t^2\theta^4+8t^2\theta^3+2t\theta^4+8t^2\theta^2+6t\theta^3+\theta^4-8t\theta-3\theta^2+4), \xi_1 = [-2t\theta(\theta+2)^2 t(6t\gamma(\gamma-1)+4t^2(\gamma-1)-\gamma-t)]/(\gamma+t)^2$, and $\xi_0 = 2t^2\theta(\theta+2)^2(t^2\theta^3+4t^2\theta^2+t\theta^3+4t^2\theta+3t\theta^2-4t+\theta)$. Consumer surplus under equilibrium exclusivity is

$$CS^u = \begin{cases} \frac{(2\mu-1)^2v^2+9t^2}{36t^2} & \text{when } v\geq 3t \\ \frac{4(1-\mu)^2v^2-12t(1-\mu)v+18t^2}{36t^2} & \text{when } v<3t. \end{cases}$$

We can prove that $CS^u > CS^m$ is equivalent to $v < v_{cs}^u$, in which v_{cs}^u is defined by $CS^u = CS^m$.

In the multihoming equilibrium, sellers' total profits are $\pi^m = \frac{(1+t)(\iota_2 v^2+\iota_1 v+\iota_0)}{2t^2(1+\theta)^2(4-\theta^2)^2}$, where $\iota_2 = [(2+\theta-\theta^2)\mu-\theta]^2+[2-\theta^2-(2+\theta-\theta^2)\mu]^2, \iota_1 = 2t\theta(1-\theta)(2+\theta)^2$, and $\iota_0 = 2t^2\theta^2(2+\theta)^2$. The platforms' profits are $\Pi_1^m+\Pi_2^m = \frac{t(1+\theta)}{t^2(1+\theta)^2(4-\theta^2)^2}(\iota_2 v^2+\iota_1 v+\iota_0)$. Therefore, social welfare is $SW^m = (\kappa_2 v^2+\kappa_1 v+\kappa_0)/[2t^2(1+\theta)^2(4-\theta^2)^2]$, where $\kappa_i = \xi_i+(1+3t+2t\theta)\iota_i$. Under equilibrium exclusivity, sellers' total profits are

$$\pi^u = \begin{cases} \frac{(t+1)(2\mu-1)^2v^2}{36t^2}+\frac{v}{2}-\frac{5t-1}{4} & \text{when } v\geq 3t \\ \frac{(1+t)[2v^2(\mu-1)^2+6tv(\mu-1)+9t^2]}{18t^2} & \text{when } v<3t. \end{cases}$$

The platforms' profits are $\Pi_1^u + \Pi_2^u = 2t[(s_1^u)^2 + (s_2^u)^2]$. Therefore, social welfare is

$$SW^u = \begin{cases} \frac{(5t+2)(2\mu-1)^2v^2+18t^2v+9t^2(2-t)}{36t^2} & \text{when } v \geq 3t \\ \frac{(1-\mu)[4(1+t)(1-\mu)-6t\mu]v^2+[18t^2\mu-6t(2-t)(1-\mu)]v+9t^2(2-t)}{18t^2} & \text{when } v < 3t. \end{cases}$$

We have $SW^u > SW^m$ if and only if $v < v_{sw}^u$ holds and v_{sw}^u is defined by $SW^u = SW^m$.

A.3 The cutoffs in Section 5.2

Platform one acquires all sellers in equilibrium when $\mu > \hat{\mu}(v,t)$ holds, in which

$$\hat{\mu}(v,t) \equiv \begin{cases} \frac{1}{2} + \frac{t-2}{2v} & \text{when } v > 3t \\ \frac{t^2+vt-1}{v(2t+1)} & \text{when } v \leq 3t. \end{cases}$$

Platform one's equilibrium profit is

$$\Pi_1^p = \begin{cases} (2\mu-1)v+1, & \text{when } v \geq \max\left\{\frac{t+1}{1-\mu}, \frac{t-2}{2\mu-1}\right\} \\ \frac{[(2\mu-1)v+t]^2}{4(t-1)}, & \text{when } \frac{(2t-1)t}{2t(1-\mu)-1} < v < \frac{t-2}{2\mu-1} \\ \mu v - \frac{(1-\mu)^2v^2}{2(t+1)} + \frac{1-t}{2}, & \text{when } \frac{t^2-1}{(t+1)\mu-t(1-\mu)} \leq v \leq \frac{t+1}{1-\mu} \\ \frac{\mu v[(t+1)\mu v+2t^2]-2t\mu(1-\mu)v^2+(t-1)(1-\mu)v[2t-(1-\mu)v]-(t-1)t^2}{4t^2-2}, & \text{when } v \leq \min\left\{\frac{(2t-1)t}{2t(1-\mu)-1}, \frac{t^2-1}{(t+1)\mu-t(1-\mu)}\right\}. \end{cases}$$

Platform one enforces exclusivity if and only if $\Pi_1^p > \Pi_1^m$ or equivalently $v < v^p$ holds, in which v^p is determined by $\Pi_1^p = \Pi_1^m$.

Consumer surplus under exclusivity is

$$CS^p = \begin{cases} 1/2, & \text{when } v \geq \max\left\{\frac{t^2-1}{(t+1)\mu-t(1-\mu)}, \frac{t-2}{2\mu-1}\right\} \\ \frac{(2\mu v+t-v)^2}{8(t-1)^2} + \frac{(2\mu v-t-v+2)^2}{8(t-1)^2}, & \text{when } \frac{(2t-1)t}{2t(1-\mu)-1} < v < \frac{t-2}{2\mu-1} \\ \frac{(2\mu tv+\mu v+t^2-tv)^2}{2(2t^2-1)^2} + \frac{(2\mu tv+\mu v-t^2-tv+1)^2}{2(2t^2-1)^2}, & \text{when } v \leq \min\left\{\frac{(2t-1)t}{2t(1-\mu)-1}, \frac{t^2-1}{(t+1)\mu-t(1-\mu)}\right\}. \end{cases}$$

Equilibrium exclusivity enhances consumer surplus if and only if $v < v_{cs}^p$ holds, in which v_{cs}^p is the value of v such that $CS^m = CS^p$ and $v < v^p$ hold.

Sellers' total profits are

$$\pi^p = \begin{cases} (1-\mu)v - \frac{t+1}{2}, & \text{when } v \geq \max\left\{\frac{t+1}{1-\mu}, \frac{t-2}{2\mu-1}\right\} \\ -\frac{2\mu tv+t^2-2tv-t+v+1}{2(t-1)}, & \text{when } \frac{(2t-1)t}{2t(1-\mu)-1} < v < \frac{t-2}{2\mu-1} \\ \frac{(1-\mu)^2v^2}{2(1+t)}, & \text{when } \frac{t^2-1}{(t+1)\mu-t(1-\mu)} \leq v \leq \frac{t+1}{1-\mu} \\ \frac{(1+t)(2\mu tv-2tv-t+v+1)^2}{2(2t^2-1)^2}, & \text{when } v \leq \min\left\{\frac{(2t-1)t}{2t(1-\mu)-1}, \frac{t^2-1}{(t+1)\mu-t(1-\mu)}\right\}. \end{cases}$$

Platforms' profits are

$$\Pi_1^p + \Pi_2^p = \begin{cases} (2\mu - 1)v + 1, & \text{when } v \geq \max\left\{\frac{t+1}{1-\mu}, \frac{t-2}{2\mu-1}\right\} \\ \frac{[(2\mu-1)v+t]^2}{4(t-1)}, & \text{when } \frac{(2t-1)t}{2t(1-\mu)-1} < v < \frac{t-2}{2\mu-1} \\ \mu v - \frac{(1-\mu)^2 v^2}{2(t+1)} + \frac{1-t}{2}, & \text{when } \frac{t^2-1}{(t+1)\mu - t(1-\mu)} \leq v \leq \frac{t+1}{1-\mu} \\ \frac{\mu v[(t+1)\mu v + 2t^2] - 2t\mu(1-\mu)v^2 + (t-1)(1-\mu)v[2t-(1-\mu)v] - (t-1)t^2}{4t^2-2}, & \text{when } v \leq \min\left\{\frac{(2t-1)t}{2t(1-\mu)-1}, \frac{t^2-1}{(t+1)\mu - t(1-\mu)}\right\}. \end{cases}$$

Therefore, social welfare is

$$SW^p = \begin{cases} 1 + v\mu - t/2, & v \geq \max\left\{\frac{t^2-1}{(t+1)\mu - t(1-\mu)}, \frac{t-2}{2\mu-1}\right\} \\ \frac{4\mu^2 tv^2 - 4\mu tv^2 - t^3 + 2t^2 v + tv^2 + 4\mu v + 4t^2 - 4tv - 6t + 4}{4(t-1)^2}, & \frac{(2t-1)t}{2t(1-\mu)-1} < v < \frac{t-2}{2\mu-1} \\ \frac{2(2\mu t + \mu - t)(2\mu t^2 + 3\mu t - t^2 - 2t + 1)v^2 + (4t^4 + 6\mu t - 4t^2 + 2\mu - 4t + 2)v - (t-2)(2t^4 - 2t^2 + 1)}{2(2t^2-1)^2}, & v \leq \min\left\{\frac{(2t-1)t}{2t(1-\mu)-1}, \frac{t^2-1}{(t+1)\mu - t(1-\mu)}\right\}. \end{cases}$$

Equilibrium exclusivity enhances social welfare if and only if $v < v_{sw}^p$ holds, in which v_{sw}^p is the value of v such that $SW^m = SW^p$ holds.

A.4 The cutoff in Section 5.3

Suppose exclusivity is allowed and platforms compete with uniform prices. When $v + \Delta v > \overline{v}_w^u$, no platform enforces exclusivity. We have

$$\frac{\partial \Pi_1^m}{\partial \Delta v} = \frac{2(2-\theta^2)^2}{t(1+\theta)(4-\theta^2)^2} \Delta v + \frac{2(2-\theta^2)}{t(1+\theta)(4-\theta^2)^2}[(2-\theta^2)\mu v - \theta(1-\mu)v + t\theta(2+\theta)].$$

When $3t < v + \Delta v < \overline{v}_w^u$, the equilibrium is similar to the first row in Table 1. We have $\frac{\partial \Pi_1^u}{\partial \Delta v} = \frac{3t + \Delta v + (2\mu-1)v}{9t}$. When $\underline{v} < v + \Delta v < 3t$, the equilibrium is similar to the second row in Table 1. We have $\frac{\partial \Pi_1^u}{\partial \Delta v} = 1 - \frac{(1-\mu)v}{3t}$. As shown in Figure 6, the line of $\frac{\partial \Pi_1^m}{\partial \Delta v}$ crosses the line $\frac{\partial \Pi_1^u}{\partial \Delta v}$ if and only if $v < v^I = \frac{t\phi(\theta)}{\psi(\theta) + \eta(\theta)\mu}$, in which $\phi(\theta) = 3(\theta+2)(\theta^4 + \theta^3 - 6\theta^2 + 8)$, $\psi(\theta) = (1+\theta)(4-\theta^2)^2 - 6\theta(2-\theta^2)$ and $\eta(\theta) = (2-\theta)(1+\theta)(\theta^3 - 4\theta^2 - 4\theta + 4)$.

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