ESSAYS ON MARKET COMPETITION ON THE INTERNET

By

Soo Jin Kim

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ABSTRACT

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Chapter 1. Paid Peering and Investment Incentives for Network Capacity and Content Diversity

This paper analyzes the effects of industry practice, the "paid peering" agreement, on conflicting incentives to invest in Internet network delivery quality and content diversity and on social welfare. I find that an Internet Service Provider is more likely to invest in network capacity to improve delivery quality under a paid peering agreement. On the other hand, Content Providers tend to invest in content diversity under settlement-free peering regimes because of hold-up problems. Due to the conflicting effects of paid peering on investment incentives, the overall effect on social welfare is ambiguous, depending largely on the extent to which consumers value network quality and content diversity.

Chapter 2. Privacy, Information Acquisition, and Market Competition

This paper analyzes how the endogenous availability of personal information affects market outcomes in a two-sided market where sellers target advertisements to individuals who have varying privacy concerns. I focus on how a market entrant that has worse targeting technology than an incumbent is affected by a lack of information. I show that an entrant is disproportionately affected by consumers' privacy concerns. The welfare analysis shows that privacy concerns and the resulting market outcomes may lower consumer surplus and social welfare. Therefore, individually optimal decisions on data disclosure might not be socially optimal when aggregated. The empirical evidence, which is based on Google Android App Market data, corroborates the hypotheses in the model and the effectiveness of specific policy remedies that are derived from the theoretical findings.

Chapter 3. Zero-Rating and Vertical Content Foreclosure

We study zero-rating, a practice whereby an Internet service provider (ISP) that limits retail data consumption exempts certain content from that limit. This practice is particularly controversial when zero-rated services are provided by an ISP that is vertically integrated into content because the data limit and ensuing overage charges impose an additional cost on rival content. As we show, the incentives to offer zero-rating and the resulting welfare consequences with and without vertical integration depend on two factors (i) the degree of differentiation between content providers' services and (ii) whether or not the ISP can charge zero-rated content providers for exempting their data from the limit.

To Mom and Dad

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CHAPTER 1

PAID PEERING AND INVESTMENT INCENTIVES FOR NETWORK CAPACITY EXPANSION AND CONTENT DIVERSITY

1.1 Introduction

The online video market, such as subscription-based video-on-demand, has been growing at a rapid pace, emerging as a potential substitute for traditional cable TV content. Since Online Video Distributors (OVDs) such as Hulu and Netflix have established themselves as alternative video content providers over the Internet, network quality has become the most significant factors that determines the overall video streaming quality provided by OVDs. This, in turn, affects customer satisfaction: consumers who watch OVD content care about aspects of video quality, such as resolution and smooth streaming.

Because Internet Service Providers (ISPs) control networks, they exert a level of control over OVD service. For example, the streaming video content provided by Netflix experienced poor quality and performance. This has led members of the media to accuse ISPs, such as Comcast, of intentionally slowing Internet traffic for OVDs to degrade video quality. A counter argument is that the congestion resulted from the heavy volume of Netflix traffic rather than an attempt by Comcast to exert its gatekeeper status: Netflix takes up 34% of total ISP traffic during peak hours. Rightly or wrongly, Netflix has consequently agreed to pay Comcast an access fee in order to directly connect to Comcast's network and normalize its performance. After a paid peering deal with Comcast, Netflix entered interconnection agreements with Verizon and other major ISPs to improve the performance of its video streaming service. Figure 1.1 displays Netflix video quality over time on the networks of Comcast and other ISPs. As Figure 1.1 shows, the direct peering agreement (paid peering) between Netflix and major ISPs improved the video quality of Netflix content. According to the graph, Netflix video quality dropped at the end of 2013 and increased from the point that Netflix and Comcast entered into a direct interconnection agreement.

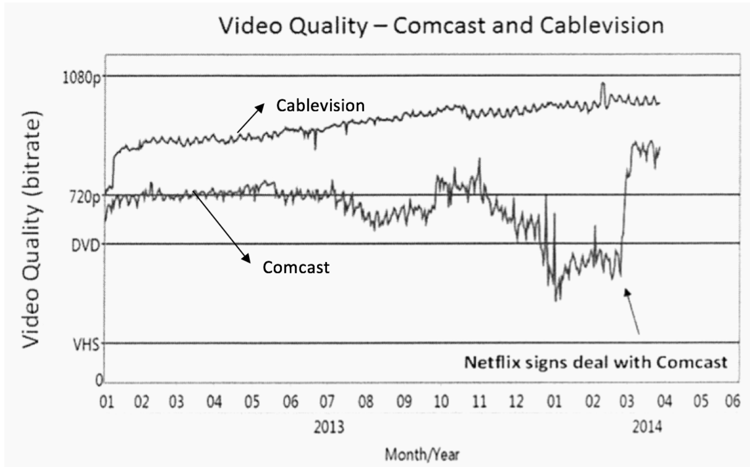

Figure 1.1 Video Quality Over Comcast Network(http://qz.com/256586/the-inside-story-of-how-netflix-came-to-pay-comcast-for-internet-traffic)

The interconnection dispute between Netflix and various ISPs has stirred a debate concerning whether paid peering is an anticompetitive practice. In this study, I investigate how paid peering affects pricing and investment incentives of an ISP and Content Providers (CPs) and shed insight regarding how different peering regimes affect social welfare. In order to study the welfare impact of paid peering, it is important to first understand how CPs deliver content to consumers.[1] CPs deliver content to consumers via their ISPs in two ways: using Content Delivery Networks (CDNs) or via transit providers. The first option requires CPs to pay companies such as Akamai, which provides CDN service by hosting CPs' content on an ISP's server. Under this arrangement, CDNs pay the ISPs for accepting the data they send, something which I refer to as paid peering.

The alternative option is to deliver content through transit providers. In general, ISPs accept any data sent by major transit providers free of charge (as long as the amount of traffic in each direction is similar) because transit providers help connect ISPs to the rest of the Internet. Such interconnection agreements in which no money changes hands are referred to by industry practitioners as settlement-free transit or peering. The debate over the Netflix-Comcast case stems from settlement-free transit. From Comcast's perspective, the transit providers that host Netflix's content send more data than Comcast sends out; therefore, they should pay an

[1]Refer to www.businessinsider.com/paid-peering-explained-2014-2 for details.

interconnection fee like any other CDN. If the transit providers end up paying interconnection fee to Comcast, the extra cost consequently will be passed on to Netflix, which Netflix wants to avoid. After trying different strategies, such as buying transit from multiple providers in response to Comcast's argument, Netflix finally agreed to pay Comcast to connect directly to Comcast's server. This direct connection can be thought of as another form of paid peering in the sense that Netflix uses its own CDN and thus pays Comcast like any other CDN.

In this paper, I find that paid peering agreements lead to a tradeoff between investment incentives for network capacity and content diversity. If ISPs charge for direct interconnection, they may discourage content providers from investing in content, leaving consumers with less diverse viewing options. On the contrary, paid peering may be essential to the growth of the Internet because it leads to better network performance. Since both sides have held fast in their arguments, it is worth examining which argument is more plausible.

To determine the validity of the two conflicting claims mentioned above, I model a two-sided market with one ISP and two competing CPs. Consumers and CPs interact via the ISP, i.e., network. Some consumers endogenously choose whether to consume content from one or both CPs. In the model, the ISP can invest in the network capacity by making a direct interconnection to improve delivery quality, while CPs may invest in content diversity by producing exclusive content. I consider two regimes; *paid peering* and *non-paid peering.* In this paper, paid peering means that each CP pays a direct connection fee to the ISP. In the non-paid peering regime, CPs are not required to pay for a direct connection, but the ISP solely determines whether to invest in network to improve delivery quality. I assume that the direct interconnection for higher network quality guarantees better delivery quality.

I compare the market equilibrium and investment incentives for both regimes. I find that the ISP is more likely to invest in higher network quality under a paid peering regime than under a non-paid peering regime. Intuitively, there is higher demand for content delivered with high network quality, and higher demand induces higher subscription revenues for both the ISP and the CPs. Due to this demand effect, higher network quality is more likely under a paid peering regime wherein the joint profits of the ISP and the CPs are considered. On the other hand, CPs are more likely to invest in content diversity in a non-paid peering regime than in a paid peering regime. This underinvestment in a paid peering regime can be explained by a hold-up problem. Under paid peering, the ISP extracts rents from each CP that chooses high-quality delivery, so any additional revenue from content investment is likely to be *ex post* expropriable by the monopolistic ISP. Due to this hold-up problem, each CP makes a smaller investment in content differentiation under a paid peering regime.

I conduct a welfare analysis to examine the overall effects of these investments on total social welfare. For consumers, better network quality and more diverse content lead to greater consumer surplus. Between better network quality and more diverse content, the relative consumer valuation is ambiguous. However, if consumer's additional utility from using higher network quality exceeds a certain threshold, consumer surplus from higher delivery quality and less diverse content is greater than that from lower delivery quality but more diverse content. Moreover, as the amount of initial exclusive content surpasses a threshold or if sufficient content investment is undertaken, then even under a paid peering regime, consumers value network quality more than content diversity.

The remainder of this paper is organized as follows. In Section 1.2, I show how my work is related to the literature. In Sections 1.3 and 1.4, I respectively introduce the model setup and solve for equilibrium. I conduct the welfare analysis in Section 1.5. Finally, I discuss possible extensions in Section 1.6 and provide some concluding remarks in Section 1.7.

1.2 Related Literature

This paper relates to two interrelated bodies of literature: the literature on net neutrality and literature on interconnection in two-sided markets. The model employs a Hotelling model, which is standard in various models of net neutrality. D'Annunzio and Russo (2015) and Kourandi et al. (2015) investigate the effects of net neutrality on Internet fragmentation. The former shows that ISPs may strategically charge termination fees to induce fragmentation when competition among CPs has a negative impact on advertising rates. The latter considers the effect of a zero-price rule on Internet fragmentation and shows that fragmentation emerges in equilibrium under certain circumstances. Choi and Kim (2010) analyze how net neutrality is related to investment incentives in the Internet market. Using a model with a monopolistic ISP and duopolistic CPs, they find that the overall effect of a discriminatory regime on the capacity investment incentive is ambiguous. Bourreau et al. (2015) relates the impact of net neutrality to market competition and the incentive to invest in capacity. Aside from the model setup itself, this is a major difference between my research and the papers listed above: All of them analyze paid priority, which is illegal under net neutrality, because their main focus is to examine the effects of net neutrality from diverse perspectives. However, my paper focuses on a paid peering agreement between an ISP and CPs and examines how a direct access fee in paid peering affects investment incentives and social welfare. For this purpose, I specify content providers as congestion-sensitive OVDs and establish a link between two different markets: the Internet market and the video distribution market.

The paper also relates to issues on multi-homing trends in two-sided markets. Choi (2010) investigates the effects of tying on market competition and social welfare when consumers are multi-homing on different platforms. Jeitschko et al. (2015) analyze joint marketing by different firms who charge different prices depending on whether consumers buy a single good, i.e., single-homing, or buy a bundle, i.e., multi-homing. Although my paper is similar to those mentioned above in the sense that the model allows consumers to multi-home, the perspective of the analysis is different. In my paper, I adopt the possibility of multi-homing to examine the effects of paid peering on investment incentives for content diversity and for network quality. That is, the measure of exclusive content that affects consumer utility in a positive direction is not only taken into consideration but is endogenously determined.

In addition, my paper is closely linked to the interconnection-related literature in the sense that it mainly discusses the peering issue in the backbone of the Internet market.[2] First,

[2] There are some research (Laffont et al. (2001), Economides (2005), Carter and Wright (1999), Crémer et al. (2000), Baake and Wichmann (1999)) that only focus on pricing and competition issues in the backbone

Armstrong (1998) discusses how the access fee, i.e. interconnection fee, can be set in networks and provides regulatory implications. He shows that such fees can be used as an instrument of collusion in two-way networks. Hermalin and Katz (2001), Giovannetti (2002), and Laffont et el. (2003) analyze how network interconnection cost affects the final retail market. Gilo and Spiegel (2004) specify competitive transit environment which can alleviate potential anticompetitive market behaviors regarding too high interconnection fees. Mendelson and Shneorson (2003) take into consideration consumer's delay cost and show how the existence of delay cost affects the competitive structure of the backbone industry and the final market structure. Koning and Yankelevich (2017) state that if ISP services are independent, settlement-free interconnection can be optimal. Jahn and Prüfer (2008) also analyze the strategic use of interconnection. They show that paid peering regime can harm consumers. Frieden (2014) reports on current net neutrality issues and suggests potential opportunities for resolution. In doing so, he analyzes the possible consequences of peering arrangements between major ISPs and CPs, including the Netflix-Comcast case. Frieden (2014) raises the possibility of consumer inconvenience, which can arise from an increase in compensation disputes between ISPs and CPs. On the other hand, Gaivoronski et al. (2015) study the relationship between connectivity and CPs in the Internet market. They show that paid peering can be mutually beneficial to both ISPs and CPs under certain circumstances. Though the papers listed above also consider the effect of interconnection fees on the relevant markets, they do not relate it to diverse investment incentives. In that sense, Little and Wright (2000) share a similar implication with my paper in that they find that settlement-free peering leads to underinvestment in network capacity. However, the paper does not see any conflicting of interests, for example, in terms of content diversity investments: my paper focuses on the dynamic implications of paid peering regime rather than static consequences.

industry but do not investigate the effect of market outcomes in the Internet backbone industry on the last mile market.

1.3 The Model

Consider a market environment with one ISP and two CPs. The duopolistic CPs compete for consumer subscription revenues. Both ISP and CPs face zero marginal cost of providing network services or production and distributing content. Consumers have a choice between subscribing to one or both CPs. I assume that a positive measure of consumers always subscribes to both CPs. Consumers are also assumed to be homogeneous with respect to the network quality provided by the ISP.[3] Finally, I assume that both the Internet and the content market are fully covered.

I consider two regimes: *paid peering* and *non-paid peering*. Although paid peering is not unlawful under net neutrality, it is worth examining whether current paid peering practices have adverse effects, especially on innovation in the video content market. Under a *paid peering* regime, the ISP charges CPs fixed fees for direct connections to its network. With these direct connections, the content offered by the CPs can be delivered at a high level of quality that guarantees faster video streaming and less buffering. On the other hand, under a *non-paid peering* regime, the ISP cannot charge CPs fees for using this network, so that it bears the relevant costs of direct connections. Under both regimes, CPs may invest in content diversity.

1.3.1 Consumers

There is a mass of consumers normalized to one. Consumers obtain net utility from an Internet subscription and a separate video content subscription. All consumers are homogeneous with regard to their preferences for the network quality provided by the ISP. Consumer utility from

[3] In Section 1.6, I will extend the analysis to consider consumers with heterogeneous valuations.

the Internet subscription is given by

$$u_{Internet} = U + \mu_I - p_I$$

$$\text{where} \quad \mu_I = \begin{cases} \alpha\mu & \text{if both CPs pay for a higher quality direct connection } (\alpha > 1) \\ \mu & \text{if one of them pays a higher quality direct connection} \\ 0 & \text{if both of them have a lower quality connection to the ISP.} \end{cases} \tag{1.1}$$

The base utility U is assumed to be high enough to cover the market, μ_I is the additional utility from higher quality, and p_I is the Internet subscription fee. $\alpha > 1$ is the additional benefit from having both content to be high quality. To model consumer preferences over content, I adopt a Hotelling framework. Suppose that consumers are uniformly distributed along a line of length 1. Consumers' preferences for content are denoted by x. The two CPs are horizontally differentiated, with CP_1 located at $x = 0$ and CP_2 at x=1. I focus on an equilibrium where some consumers subscribe to both content providers, which I call multi-subscription in the paper: instead, single-subscription is used for the case where a consumer subscribes to only one CP. Intuitively, consumers are more likely to subscribe to both CPs if each CP provides at least some original content that its rival does not offer. Thus, I need to take the degree of content exclusivity into consideration when defining net utility. To do so, I rely on a modification of Choi's (2010) assumption regarding CPs' exclusive and duplicative content. I assume that each CP_j initially provides duplicative content of measure 1 and exclusive content of measure $\bar{\lambda}_j$, so the total initial content is $(1+\bar{\lambda}_j)$. For simplicity, I assume that $\bar{\lambda}_1 = \bar{\lambda}_2 = \bar{\lambda}$. Each CP_j may make an additional investment in original content, which increases the degree of exclusivity λ_j. When consumers decide to subscribe to only one content provider, their utility from content is given by

$$u_j = V(1 + \bar{\lambda} + \lambda_j) + \mu_j - tx - P_j, \tag{1.2}$$

where μ_j is either $\mu > 0$ if content is high quality or 0 if it is low quality, and P_j denotes the subscription fee charged by CP_j. When the consumer subscribes to both CPs, $1 + 2\bar{\lambda} + \lambda_1 + \lambda_2$

content is available and utility is given by

$$u_{12} = V(1 + 2\bar{\lambda} + \lambda_1 + \lambda_2) + \mu_1 + \mu_2 - t - P_1 - P_2. \tag{1.3}$$

Thus, a consumer who subscribes to both content providers receives additional benefits not only from having access to more original content (which is captured by $2\bar{\lambda} + \lambda_1 + \lambda_2$) but from each CP's additional marginal value of delivery quality captured by $\mu_1 + \mu_2$. If content is delivered with higher quality by a direct connection deal, consumers have more options as to how they enjoy video content. For example, they can enjoy video with less concern about quality degradation during peak reviewing hours. If video is delivered with sufficiently high definition, consumers can watch higher quality video on large screens, such as TVs; the recommended Internet quality is much higher for viewing standard definition video on a TV than for viewing the same quality video on a laptop. Thus, the additive specification of μ_j in the utility comes from the fact that consumers may be assured of video quality under any circumstances.

1.3.2 ISP

The monopolistic ISP provides Internet service to consumers who pay a subscription fee p_I and it provides an Internet platform to CPs without a termination fee. The ISP also offers a direct connection to each CP at a fee f. In order to be able to offer higher quality service, the ISP must first invest in network capacity. The investment incurs a fixed cost of K for each direct connection. This leads to four possible quality combinations: (H,H) when both CPs accept the fee where the first and second elements denote CP_1's and CP_2's delivery quality, respectively; (H,L) or (L,H) when only one of CPs accepts; and (L,L) when both reject the ISP's offer to interconnect.

1.3.3 Content Providers

There are two CPs who compete with each other for subscriptions. Here, I view content providers as congestion-sensitive OVDs. Both CPs may invest in content diversity, which increases the degree of content exclusivity λ_j with investment cost $C(\lambda_j)$, where $C'(\lambda_j) > 0$ and $C''(\lambda_j) > 0$. Let D_j represent the sum of the share of consumers who subscribe to CP j's content only together with the share of consumers who subscribe tho both CPs. Therefore, $D_1 + D_2 > 1$. The CP_j profit function is given by

$$\pi_j = P_j D_j - C(\lambda_j) - \mathbb{1}_{PP} f_j, \tag{1.4}$$

where $\mathbb{1}_{PP}$ indicates that CP_j pays for interconnection in a paid peering regime.

I focus on the following four-stage game.

1. In stage 1, each CP chooses its level of investment in content. This investment increases λ_j, which means that content becomes more diverse and exclusive. Also, the investment has a cost $C(\lambda_j)$.

2. In stage 2, the ISP makes a take-it-leave-it offer to charge f_1 to CP_1 for high-quality content delivery, and CP_1 decides whether to accept. If CP_1 rejects, the ISP solely determines whether to make the investment in a direct connection.

3. In stage 3, the ISP makes the same offer to CP_2 (with fee f_2) for high-quality content delivery, and CP_2 decides whether or not to accept. If CP_2 rejects, the ISP solely determines whether to make the investment in a direct connection.

4. In stage 4, the ISP and the CPs set their subscription fees for Internet service and online video services, respectively. Consumers choose the CP to which they subscribe with some consumers choosing to subscribe to both.

Under a non-paid peering regime, there is no stage 2 or 3. Instead, the ISP solely decides whether or not to invest in direct connections; thus, the equilibrium quality specifications are determined by the ISP's incentive to invest.

The sequential offer assumption here is motivated by the highly publicized interconnection dispute between *Comcast* and *Netflix*. However, I relax the assumption to take into consideration a simultaneous offer game in Section 1.6. The results of both models are the same.

1.4 Equilibrium

In this section, working backward I derive the subgame perfect equilibrium.

1.4.1 Paid Peering

1.4.1.1 Stage 4

In the last stage, the ISP and CPs choose their respective subscription fees. I assume that the Internet market is fully covered. All Internet subscribers are assumed to subscribe to at least one of the two video content services provided by the CPs. The equilibrium subscription fee the ISP charges to consumer p_I is then given by

$$p_I = \begin{cases} U + \alpha\mu & \text{if (H,H)} \\ U + \mu & \text{if (H,L) or (L,H)} \\ U & \text{if (L,L).} \end{cases} \tag{1.5}$$

Thus, the equilibrium profit for the ISP is

$$\pi_{ISP} = \begin{cases} U + \alpha\mu + \mathbb{1}_{PP}(f_1^{HH} + f_2^{HH}) - 2K & \text{if (H,H)} \\ U + \mu + \mathbb{1}_{PP}(f_1^{HL}) - K & \text{if (H,L)} \\ U + \mu + \mathbb{1}_{PP}(f_2^{LH}) - K & \text{if (L,H)} \\ U & \text{if (L,L)} \end{cases}, \tag{1.6}$$

where $\mathbb{1}_{PP}$ indicates a paid peering regime. Here, f_j^Q indicates a fixed fee for CP_j under a specific quality specification Q, where $Q \in \{HH, HL, LH, LL\}$. The ISP earns the highest subscription revenue by providing (H,H) quality. As such, the ISP has an incentive to invest in network capacity by providing direct connections to CPs even under a non-paid peering regime.

As a result of the CP's profit maximization problem, it is worth noting that two sets of assumptions are necessary for the multi-subscribing equilibrium to exist. The first assumption on the consumer side is $V(2\bar{\lambda}+\lambda_1+\lambda_2)+\mu_1+\mu_2>2t$. This means that the additional utility from multi-subscribing should be higher than the transportation cost. The second assumption on the CP side guarantees that neither CP has an incentive to deviate from providing enough original content to guarantee multi-subscription. This assumption derived from $\pi_j^{MS}>\pi_j^{SS}$ is $V(\bar{\lambda}+\lambda_j)^2>\frac{2(\mu_1-\mu_2+3t+V(\lambda_1-\lambda_2))^2}{9}$ where the superscripts MS and SS denote multi-subscription (subscribe to both CPs) and single-subscription (subscribe to one CP), respectively. the equilibrium content subscription fees and total market share of each CP are characterized by

$$P_j=\frac{V(\bar{\lambda}+\lambda_j)+\mu_j}{2};\quad D_j=\frac{V(\bar{\lambda}+\lambda_j)+\mu_j}{2t}. \tag{1.7}$$

The equilibrium fees that the ISP charges can now be derived using the CP profits equation. Because the ISP makes take-it-or-leave-it offers to both CPs, the equilibrium fees are determined by the level at which each CP becomes indifferent between accepting and rejecting the offer. The equilibrium fees are

$$f_1^{HH}=f_1^{HL}=\frac{\mu(2V(\bar{\lambda}+\lambda_1)+\mu)}{4t},\quad f_2^{HH}=f_2^{LH}=\frac{\mu(2V(\bar{\lambda}+\lambda_2)+\mu)}{4t}. \tag{1.8}$$

In a paid peering regime, the resulting equilibrium profits for each CP_j are symmetric no matter which quality level each CP_j chooses because the ISP charges the fee at the level in which CPs become indifferent. Given the equilibria, I can proceed to stages 3 and 2 to characterize the equilibrium quality specifications. Table 1.1 summarizes the equilibrium profit for each CP for each quality specification.

Table 1.1 Equilibrium Profits for CP under Paid Peering

	H	L
H	$\left(\frac{(V(\bar{\lambda}+\lambda_1))^2}{4t}-c(\lambda_1),\ \frac{(V(\bar{\lambda}+\lambda_2)^2}{4t}-c(\lambda_2)\right)$	$\left(\frac{(V(\bar{\lambda}+\lambda_1))^2}{4t}-c(\lambda_1),\ \frac{(V(\bar{\lambda}+\lambda_2))^2}{4t}-c(\lambda_2)\right)$
L	$\left(\frac{(V(\bar{\lambda}+\lambda_1))^2}{4t}-c(\lambda_1),\ \frac{(V(\bar{\lambda}+\lambda_2))^2}{4t}-c(\lambda_2)\right)$	$\left(\frac{(V(\bar{\lambda}+\lambda_1))^2}{4t}-c(\lambda_1),\ \frac{(V(\bar{\lambda}+\lambda_2))^2}{4t}-c(\lambda_2)\right)$

1.4.1.2 Stage 3

In this stage, CP_2 decides whether to accept the high-quality offer with fee f_2. There are two subgames for CP_2 depending on CP_1's quality choice in stage 2. If CP_1 chose high quality, CP_2 chooses between (H,H) and (H,L). On the other hand, if CP_1 chose low quality, the choice sets will be either (L,H) or (L,L). For each subgame, CP_2 chooses high quality — either (H,H) or (L,H) — if the joint profits of the ISP and CP_2 from high quality are greater than those from low quality.[4] Here, the ISP and CP_2 achieve (H,H) if the investment cost is sufficiently low compared to the total gain (i.e., K < $\tilde{K}$) while they achieve (L,L) if the cost is relatively high (K > $\hat{K}$). The asymmetric quality specification — either (H,L) or (L,H) — arises when the cost is in the middle range, i.e., $\tilde{K} < K < \hat{K}$.

1.4.1.3 Stage 2

Given two thresholds $\widetilde{K}$ and $\widehat{K}$, I consider four different regions: $K > \max\{\tilde{K}, \hat{K}\}$, $\tilde{K} < K < \hat{K}$, $\hat{K} < K < \tilde{K}$ and $K < \min\{\tilde{K}, \hat{K}\}$. For each case, it is easy to find the equilibrium by comparing the joint profits of the ISP and CP_1 under each quality specification.[5] From the equilibrium results, I can derive the following proposition.

Proposition 1.1. *Under paid peering regime, (i) When $\alpha < \bar{\alpha}$, (L,L) emerges in equilibrium if $K > \hat{K}$, while (H,H) emerges in equilibrium if $K < \tilde{K}$. Either one of the asymmetric quality specifications, (H,L) or (L,H), emerges in equilibrium if $\tilde{K} < K < \hat{K}$. (ii) When $\alpha > \bar{\alpha}$, (L,L) emerges in equilibrium if $K > \bar{K}$, and (H,H) emerges otherwise.*

The relevant thresholds are as follows.

$$\bar{\alpha} = 2;\ \hat{K} = \mu + \frac{\mu(2V(\bar{\lambda}+\lambda_2)+\mu)}{4t};$$

$$\tilde{K} = \mu(\alpha - 1) + \frac{\mu(2V(\bar{\lambda}+\lambda_2)+\mu)}{4t};\ \bar{K} = \frac{\alpha\mu}{2} + \frac{\mu(V(2\bar{\lambda}+\lambda_1+\lambda_2)+\mu)}{4t}$$

[4] Since f is a fixed fee, I can derive the results by comparing the joint profits only.

[5] The detailed proof is in the appendix.

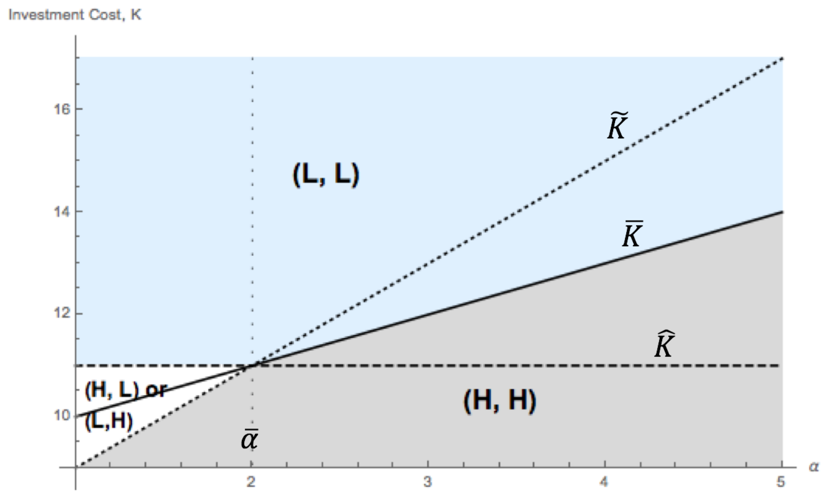

Figure 1.2 Equilibrium Quality Outcome under Paid Peering

Figure 1.2 shows the thresholds and the corresponding equilibrium outcomes in a numerical example where $V = 4, \mu = 2, \bar{\lambda} = \lambda_1 = \lambda_2 = 1$, and $t = 1$. In $(\alpha,\ K)$ space, where α represents the additional benefit from providing (H,H) quality content, (L,L) emerges if the investment cost K is relatively high, whereas (H,H) emerges if the cost is low. The intuition behind this finding is simple. When high-quality service is provided, both the ISP and the CPs earn greater revenue from consumer subscription fees. Due to this demand effect, the ISP and CPs obtain some benefits, so both parties have incentives to comply with a high-quality agreement. However, when the cost is too high, it dominates the joint benefits of the ISP and CP_j from providing better network quality to consumers. Therefore, when the cost is too high, no agreement is made, whereas both CPs can deliver high-quality content when the cost is low. When it comes to asymmetric quality specifications, the reasoning is similar. If the investment cost is too high or too low compared to the demand effect of (H,H) service, no asymmetric quality specification emerges. However, if the investment cost is in the middle range and the marginal benefit of providing (H,H), which is denoted by α, is relatively small, then an asymmetric equilibrium emerges.[6]

[6] When consumers are assumed to be heterogeneous in terms of quality, the asymmetric quality specification does not emerge.

1.4.1.4 Stage 1

In this stage, each CP chooses an investment in content diversity. The symmetric maximization problem when the CP chooses a high-quality specification no matter what the rival chooses is given by

$$\pi_1^{HH} = \pi_1^{HL} = \frac{(V(\bar{\lambda} + \lambda_1^H))^2}{4t} - C(\lambda_1^H). \tag{1.9}$$

The first order condition with respect to λ is

$$\underbrace{\frac{V^2(\bar{\lambda} + \lambda_1^H)}{2t}}_{\text{MB}} = \underbrace{C'(\lambda_1^H)}_{\text{MC}}. \tag{1.10}$$

Similarly, the symmetric maximization problem when the CP chooses a low-quality specification no matter what the rival chooses is given by

$$\pi_1^{LL} = \pi_1^{LH} = \frac{(V(\bar{\lambda} + \lambda_1^L))^2}{4t} - C(\lambda_1^L). \tag{1.11}$$

The first order condition here takes the same form as (1.10). Therefore, by the equilibrium, $\lambda_1^H = \lambda_1^L$. The case of CP_2 can be obtained in a symmetric way.[7]

1.4.2 Non-paid Peering

Under a non-paid peering regime, the ISP no longer makes a take-it-or-leave-it-offer because a monetary transfer between the ISP and the CP is not allowed. Thus, the game now has three stages. In stage 1, each CP chooses its investment in content. This investment increases λ_j, which means that content becomes more diverse and exclusive. Also, the investment has a cost $c(\lambda_j)$. In stage 2, the ISP solely chooses the investment in network capacity to improve delivery quality. In stage 3, the ISP and the CPs set their subscription fees for internet service and

[7] The second-order condition is assumed to be satisfied. That is, $\frac{V^2}{2t} < C''(\lambda)$ is assumed.

online video services, respectively. Consumers choose the CP to which they subscribe. Some consumers always multi-subscribe to content. As before, the equilibrium is solved by backward induction. From the equilibrium results, I can derive the following proposition.

Proposition 1.2. *Under non-paid peering regime, (i) When $\alpha < \bar{\bar{\alpha}}$, (L,L) emerges in equilibrium if $K > \widehat{\widehat{K}}$, while (H,H) emerges in equilibrium if $K < \tilde{\tilde{K}}$. Either of the asymmetric quality specifications, (H,L) or (L,H), emerges in equilibrium if $\tilde{\tilde{K}} < K < \widehat{\widehat{K}}$. (ii) When $\alpha > \bar{\bar{\alpha}}$, (L,L) emerges in equilibrium if $K > \bar{\bar{K}}$, while (H,H) emerges in equilibrium if $K < \bar{\bar{K}}$.*

The relevant thresholds are given as follows.

$$\bar{\bar{\alpha}} = 2;\ \widehat{\widehat{K}} = \mu;\quad \tilde{\tilde{K}} = \mu(\alpha - 1);\ \bar{\bar{K}} = \frac{\alpha\mu}{2}$$

In the first stage, each CP chooses an investment in content diversity. For the ease of notation, $\widehat{\pi}$ (or $\widehat{\lambda}$) denotes the profit levels (or content investment levels) under non-paid peering regime. The symmetric maximization problem when the CP chooses a high-quality specification no matter what its rival chooses is given by

$$\widehat{\pi}_1^{HH} = \widehat{\pi}_1^{HL} = \frac{(V(\bar{\lambda} + \widehat{\lambda}_1^H) + \mu)^2}{4t} - C(\widehat{\lambda}_1^H). \tag{1.12}$$

The first order condition with respect to λ is

$$\underbrace{\frac{V(V(\bar{\lambda} + \widehat{\lambda}_1^H) + \mu)}{2t}}_{\text{MB}} = \underbrace{C'(\widehat{\lambda}_1^H)}_{\text{MC}}. \tag{1.13}$$

Similarly, the symmetric maximization problem when the CP chooses low-quality specification no matter what its rival chooses is given by

$$\widehat{\pi}_1^{LL} = \widehat{\pi}_1^{LH} = \frac{(V(\bar{\lambda} + \widehat{\lambda}_1^L))^2}{4t} - C(\widehat{\lambda}_1^L). \tag{1.14}$$

The first order condition here is the same as in (1.10).

1.4.3 Investment Incentives

Here, I compare the investment incentives under a paid peering regime to those under a non-paid peering regime. Under both regimes, the ISP and the CPs may invest in network capacity and content diversity, respectively. Obviously, their investment incentives depend on the market environment, i.e., on whether or not monetary transfers between the ISP and CPs are allowed. The following propositions identify which regime incentivizes more investment for the ISP and CPs.

Proposition 1.3. *Given μ, t, V, λ, consider the Cartesian product representing all possible pairs of α and K that form an (H,H) quality specification. It can be shown that $(H,H)^{NPP} \subset (H,H)^{PP}$. In other words, an (H,H) quality specification is more likely to emerge under paid peering than under non-paid peering.*

The relevant sets are defined as follows: A $:= \{\alpha \,|\, \alpha \in \mathbb{R},\ \alpha > 1\}$, $B_1 := \{K \,|\, K \in \mathbb{R},\ K < \mu(\alpha-1) + \frac{\mu(2V(\bar{\lambda}+\lambda_2)+\mu)}{4t}$ for $\alpha < 2$, $K < \frac{\alpha\mu}{2} + \frac{\mu(V(2\bar{\lambda}+\lambda_1+\lambda_2)+\mu)}{4t}$ for $\alpha > 2\}$, $B_2 := \{K \,|\, K \in \mathbb{R},\ K < \mu(\alpha-1)$ for $\alpha < 2$, and $K < \frac{\alpha\mu}{2}$ for $\alpha > 2\}$. Thus, $(H,H)^{PP} := A \times B_1$, and $(H,H)^{NPP} := A \times B_2$

Proposition 1.4. *The equilibrium investment level for content diversity under non-paid peering is greater than or equal to that under paid peering. Underinvestment in a paid peering regime can be explained by the hold-up problem.*[8]

Propositions 1.3 and 1.4 show that there are two conflicting effects in a specific regime in terms of investment incentives. As for the ISP's network quality investment, paid peering induces the network to provide higher delivery quality. The intuition behind this finding is related to the demand effect of higher quality content. As shown above, both the ISP and the CPs obtain higher subscription revenues from better network delivery quality. Consequently, due to the larger demand effect, (H,H) is more likely under paid peering as the joint profits are considered.

[8] The ranking of λ under each quality specification and regime is $\lambda_L = \lambda_H = \widehat{\lambda}_L < \widehat{\lambda}_H$

On the other hand, the investment incentives for CPs in content diversity are higher under a non-paid peering regime than under a paid peering regime. This underinvestment in a paid peering regime can be explained by the hold-up problem. Under paid peering, the ISP extracts rents from each CP that chooses high-quality delivery, so there is a concern that a CP's investment in content is *ex post* expropriable by a monopolistic ISP. Thus, the hold-up problem weakens each CP's investment incentive in content diversity. To obtain a closed-form solution to this problem, I consider $C(\lambda_j) = \frac{\gamma\lambda_j^2}{2}$, assuming that γ is sufficiently large. By solving (1.10) and (1.13), it is easy to find that the equilibrium $\lambda_L = \lambda_H = \widehat{\lambda}_L = \frac{V(V\bar{\lambda})}{2\gamma t - V^2}$, while $\widehat{\lambda}_H = \frac{V(V\bar{\lambda}+\mu)}{2\gamma t - V^2}$, meaning that $\widehat{\lambda}_H$ is always greater than all the others.[9]

1.5 Welfare Analysis

In this section, I compare consumer surplus and total social welfare under each regime. By comparing the social welfare under a paid peering regime to that under the non-paid peering regime, I can discuss policy implications.

First, consumer surplus comes from video content services, which is given by

$$\begin{aligned} CS = &\int_0^{d_1} (V(1+\bar{\lambda}+\lambda_1) + \mu_1 - tx - P_1)dx + \int_{d_1}^{d_2} (V(1+2\bar{\lambda}+\lambda_1+\lambda_2) + \mu_1 + \mu_2 - t - P_1 - P_2)dx \\ &+ \int_{d_2}^{1} (V(1+\bar{\lambda}+\lambda_2) + \mu_2 - t(1-x) - P_2)dx, \end{aligned} \tag{1.15}$$

where d_j denotes the market share for single-subscription and d_{12} denotes that for multi-subscription. It is easy to check that $\frac{\partial CS}{\partial \lambda_j} = \frac{V\left(\mu_j + V\left(\gamma+\lambda_j\right)\right)}{4t} > 0$. Consequently, consumers are always better off with higher λ even if they need to pay higher subscription fees for more diverse content. That is, given a specific network quality specification, the effect of more diverse content on consumer surplus is positive: non-paid peering regime that leads to more content investment makes consumers better off given a network quality.

[9]The second-order condition here requires $\frac{V^2}{2t} < \gamma$, which is assumed to be satisfied.

However, I need to take into consideration another effect stemming from the difference in network investment incentives to see the overall effect of each regime on consumer surplus and total social welfare. From Proposition 1.3, it is shown that a higher quality specification is more likely to emerge in equilibrium under paid peering than under non-paid peering. Therefore, if consumer surplus under a higher quality specification is greater than that under a lower quality specification, it is better for consumers to be in a paid peering regime from a network quality perspective. To analyze the effect of a high-quality network on consumer surplus, it is necessary to compare consumer surplus under each quality specification. By doing some algebra, it is easy to show that

$$CS_R^{HH} - CS_R^{HL} = CS_R^{HL} - CS_R^{LL} = \frac{(V\lambda_R^H + \mu)(V\lambda_R^H + \mu + 2\bar{\lambda}(2-V))}{8t} > 0, \tag{1.16}$$

where the subscript R denotes either paid peering or non-paid peering regime. Thus, I can say that consumers are always better off with higher network quality given a regime.

Now, I need to examine the overall effects of network quality and content diversity on consumer surplus by comparing the consumer surplus for each quality specification under each regime. Denoting $CS_{NPP} = \widehat{CS}$, while $CS_{PP} = CS$, it is easy to find that $CS_{LL} = \widehat{CS}_{LL}$. Here, I focus on (H,H) and (H,L).[10] First, it is easy to show that the consumer surplus from (H,H) under a non-paid peering regime, denoted by $\widehat{CS}_{HH}$, is the highest, whereas $\widehat{CS}_{LL} = CS_{LL}$ is the lowest, and CS_{HL} is slightly higher than the lowest. This means that consumers are unambiguously better off with a combination of higher quality and more diverse content. When ranking consumer surplus for each quality specification and regime, the only ambiguous part is comparing CS_{HH} to $\widehat{CS}_{HL}$: the relative size of consumer surplus from asymmetric network quality from non-paid peering (low network quality but more diverse content) and that from the highest network quality under paid peering (high network quality but less diverse content) is ambiguous because it depends on how much consumers value one more than the other. If additional utility from using high network quality (μ) is higher, consumers become better off from the highest network quality but with less diverse content under paid peering

[10] As for (L,H), it can be derived in a symmetric way as (H,L).

regime. Proposition 1.5 summarizes this finding.[11] Note that $\lambda_L = \lambda_H = \widehat{\lambda}_L < \widehat{\lambda}_H$ from Proposition 1.4.

Proposition 1.5. *A consumer becomes better off as higher network quality and more diverse content are provided. When choosing between network quality and diverse content, if the additional utility from using better network quality is higher than a certain threshold (if $\bar{\mu} < \mu$), a consumer values network quality more than diverse content. The threshold $\bar{\mu}$ is given as follows:*
$\sqrt{V^2\left(\bar{\lambda}^2 + 2\bar{\lambda}\lambda_L + 2\widehat{\lambda}_H^2 - 4\widehat{\lambda}^H\lambda_L + 3\lambda_L^2\right)} + V(-\bar{\lambda} + \widehat{\lambda}_H - 2\lambda_L) \equiv \bar{\mu}$

From the comparative statics on $\bar{\mu}$ with respect to $\bar{\lambda}$, $\widehat{\lambda}_H$, and λ_L, it is easy to check that $\frac{\partial\bar{\mu}}{\partial\bar{\lambda}} < 0$, $\frac{\partial\bar{\mu}}{\partial\lambda_L} < 0$, and $\frac{\partial\bar{\mu}}{\partial\widehat{\lambda}_H} > 0$. The results suggest some implications that are summarized in Corollary 1.1.

Corollary 1.1. *If either the initial exclusive amount of content ($\bar{\lambda}$) or the amount of content investment under paid peering regime (λ_L) increases, a consumer is more likely to value network quality than content diversity ($\bar{\mu}$ decreases). However, if the amount of content investment under non-paid peering ($\widehat{\lambda}_H$) increases, a consumer is more likely to value content diversity than network quality ($\bar{\mu}$ increases).*

Intuitively, if CPs provide sufficient amount of initial exclusive content or invest quite a lot even under paid peering regime in which the hold-up problem exists, a consumer's valuation with respect to additional amount of original content becomes lower. On the other hand, if CPs invest much more when high network quality is provided, the additional benefit from enjoying more diverse content becomes larger, thereby valuing content diversity more.

Next, total social welfare is defined as $SW = \pi_{ISP} + \pi_1 + \pi_2 + CS$. As in the analysis of consumer surplus, social welfare can be divided into the welfare from each quality specification. Since a major interest is whether SW is higher or lower than $\widehat{SW}$, it is necessary to examine $SW - \widehat{SW}$ under each quality specification.

[11] In other words, I can rank consumer surplus levels under different combinations of network quality specification and regimes as follows: $\widehat{CS}_{HH} > \underbrace{CS_{HH}\ ?\ \widehat{CS}_{HL}}_{ambiguous\,part} > CS_{HL} > CS_{LL} = \widehat{CS}_{LL}$.

$$
\begin{aligned}
SW_{HH} - \widehat{SW}_{HH} = \quad & \underbrace{2(\Upsilon^{HH}_{CP} - \widehat{\Upsilon}^{HH}_{CP})}_{\text{(1) the effect of content investment on CP revenue (-)}} \\
+ \quad & \underbrace{2\big(C(\widehat{\lambda}_H) - C(\lambda_H)\big)}_{\text{(2) the difference in CP investment costs for content (+)}} \\
+ \quad & \underbrace{\big(CS_{HH} - \widehat{CS}_{HH}\big)}_{\text{(3) the effect of } \lambda \text{ on consumer surplus (-)}} .
\end{aligned}
\tag{1.17}
$$

where Υ denotes the revenue from subscription fees. Likewise, $SW_{HL} - \widehat{SW}_{HL}$ is obtained as follows.

$$
\begin{aligned}
SW_{HL} - \widehat{SW}_{HL} = \quad & \underbrace{(\Upsilon^{HL}_{1} - \widehat{\Upsilon}^{HL}_{1}) + (\Upsilon^{HL}_{2} - \widehat{\Upsilon}^{HL}_{2})}_{\text{(1) the effect of content investment on CP revenue (-)}} \\
+ \quad & \underbrace{\big(C(\widehat{\lambda}_H) - C(\lambda_H)\big) + \big(C(\widehat{\lambda}_L) - C(\lambda_L)\big)}_{\text{(2) the difference in CP investment costs for content (+)}} \\
+ \quad & \underbrace{\big(CS_{HL} - \widehat{CS}_{HL}\big)}_{\text{(3) the effect of } \lambda \text{ on consumer surplus (-)}} .
\end{aligned}
\tag{1.18}
$$

As seen from (1.17) and (1.18), there are three effects determining the relative size of social welfare across these two regimes. First, the investment in content diversity has a positive effect on consumer utility from content services; therefore, the CPs' revenue increases with higher investments in content. Since $\widehat{\lambda}$ (under non-paid peering) is higher than λ (under paid peering), the first term is negative. Second, because the investment cost is increasing in λ, $C(\widehat{\lambda})$ is higher than $C(\lambda)$. Thus, the second term is positive here. Finally, because the investment in content diversity unambiguously increases consumer surplus, the third term is negative because $\lambda_H < \widehat{\lambda}_H$ and $\lambda_L = \widehat{\lambda}_L$. The results from the asymmetric quality specification can be obtained in a similar way. Lemma 1.1 summarizes the findings.

Lemma 1.1. *When the network quality specification is (L,L), total social welfare is the same in both regimes. When the network quality specification is either (H,H) or (H,L) (or (L,H)),* *total social welfare depends on three effects of content investment: the profit-increasing effect, the cost effect and consumer surplus effect. The overall effect is ambiguous. If the CP revenue-increasing effect of content investment is greater than the cost-increasing effect, I obtain* $SW_{NPP} \geq SW_{PP}$.

Similarly, I compare total social welfare for each quality specification given a specific regime.

$$\begin{aligned} SW_R^{HH} - SW_R^{HL} = \quad & \underbrace{(\pi_{ISP,R}^{HH} - \pi_{ISP,R}^{HL})}_{\text{(1) the effect on ISP profit (?)}} + \underbrace{(\Upsilon_{CP,R}^{HH} - \Upsilon_{CP,R}^{HL})}_{\text{(2) the effect on CP revenue (+)}} \\ & + \underbrace{\big(-C(\lambda_R^H) + C(\lambda_R^L)\big)}_{\text{(3) the difference in CP costs (zero or (-))}} + \underbrace{\big(CS_R^{HH} - CS_R^{HL}\big)}_{\text{(4) the effect of } \lambda \text{ and } \mu \text{ on consumer surplus (+)}} . \end{aligned} \tag{1.19}$$

$SW_R^{HL} - SW_R^{LL}$ is obtained in a similar way. There are four forces that determine the signs of (1.19). First, the higher network quality has an ambiguous effect on the ISP's profit because it depends on α, μ and investment cost K. If the revenue-increasing effect of the ISP's investment dominates the cost-increasing effect, I can have either $\pi_{ISP,R}^{HH} > \pi_{ISP,R}^{HL}$ or $\pi_{ISP,R}^{HL} > \pi_{ISP,R}^{LL}$. Second, the effects of higher network quality on CP profits are also ambiguous. Although the CP's revenue increases in μ and λ, the investment has a cost $C(\lambda)$, which also increases in λ. If the investment cost is relatively low, a higher quality specification leads to an increase in CP's profits. Finally, as shown in (1.16), consumer surplus increases when a higher quality specification is offered. Lemma 1.2 summarizes those findings.

Lemma 1.2. *Assuming that a regime is given, total social welfare depends on three effects of network capacity investment: the ISP profit effect, the CP profit effect and the consumer surplus effect. The overall effect is ambiguous, so it is unknown whether total social welfare is higher or lower under a certain quality specification. If the revenue-increasing effects of the investments of both the ISP and the CPs dominate the cost-increasing effects,* $SW_R^{HH} > SW_R^{HL} > SW_R^{LL}$ *holds—the higher network quality, the better in terms of social welfare.*

As in the analysis of consumer surplus, total social welfare for each quality specification under each regime can be also ranked. For the sake of discussion, I assume that following two conditions hold: $\widehat{SW} \geq SW$ given network quality specification and $SW_{HH} > SW_{HL} > SW_{LL}$ given content diversity investment level.[12] It is easy to show that $\widehat{SW}_{HH}$ is the highest, whereas $\widehat{SW}_{LL} = SW_{LL}$ is the lowest, and SW_{HL} is slightly higher than the lowest. The only ambiguous part comes from comparing SW_{HH} to $\widehat{SW}_{HL}$. Intuitively, the choice between SW_{HH} and $\widehat{SW}_{HL}$ depends on the relative size of the total benefits from higher network quality and those from more diverse content. If the total benefits of higher network quality are greater than those from more diverse content, $SW_{HH} > \widehat{SW}_{HL}$. Proposition 1.6 summarizes these findings.

Proposition 1.6. *The overall effects of higher network quality and more diverse content on total social welfare are ambiguous.*

1.6 Discussions

In this section, I consider two possible extensions which can be made by relaxing some of the assumptions; consumer heterogeneity and simultaneous offer game. Also, I intuitively discuss how net neutrality regulation affects the equilibrium results in the paper.

1.6.1 Heterogeneous Consumer

First, the basic model assumes that consumers have homogeneous preference in terms of network quality. However, each consumer is likely to be heterogeneous with respect to network quality because some consumers are more tolerant of low quality content delivery. Here, consumer's utility from Internet subscription is given by

[12] The conditions imply that the investments' revenue-increasing effects outweigh the cost-increasing effects.

$$
\begin{aligned}
u_{Internet} &= \tau_i \mu_I - p_I \\
&\qquad \text{where} \quad \mu_I = \alpha\mu \;\; \text{if both content are high quality} \, (\alpha > 1) \\
&\qquad\qquad\qquad = \mu \quad \text{if only one content is high quality} \\
&\qquad\qquad\qquad = 0 \quad \text{if both content are low quality} \\
&\qquad\qquad\quad \tau_i \sim U[0,1].
\end{aligned} \tag{1.20}
$$

Consumers prefer higher quality for a given price. This can be interpreted as obtaining higher utility with higher average quality of content delivered over the Internet network. Therefore, consumers with high τ_i are more likely to pay more for a higher quality.

When consumers are heterogeneous in terms of network quality, ISP faces downward sloping demand functions for different quality specifications as follows.

$$
D_H = 1 - \frac{P_I^H - P_I^M}{\mu_I^H - \mu_I^M}, \quad D_M = \frac{P_I^H - P_I^M}{\mu_I^H - \mu_I^M} - \frac{P_I^M}{\mu_I^M}, \quad D_L = \frac{P_I^M}{\mu_I^M}. \tag{1.21}
$$

As for content providers, because CPs can have access to consumers only through ISP's network, their total market shares necessarily depend on the demand of Internet service. Given that the demand of Internet service is denoted as D_I^Q where $Q \in \{HH, HL, LH, LL\}$, the total market share of each CP denoted as N_j is $D_I^Q D_j$ where $D_j = CP_j$'s consumer share.

The equilibrium results from this extension show that our basic results with homogeneous consumers are robust because the qualitative results still hold. The only notable difference is that no asymmetric quality specification emerges when consumers are assumed to be heterogeneous. This finding can be partly explained by that the investment cost is too high or too low compared to the demand effect of (H,H) service. Since the demand for Internet becomes higher when provided with higher quality, so does the demand for content. Because of this demand effect, marginal benefit from (H,L) to (H,H) is always greater than that from (L,L) to (L,H), meaning that the demand effect of moving from asymmetric quality to (H,H) is larger than that of moving from (L,L) to another asymmetric quality. In other words, when the investment cost is low but the marginal benefit of providing (H,H) is high, CPs would not choose asymmetric quality but choose (H,H). Similarly, when the cost is high but the marginal benefit of providing (H,L) or (L,H) instead of providing (L,L) is relatively low, they would just choose (L,L). Thus, no asymmetric quality specification emerges when there are demand effects from consumer heterogeneity.

1.6.2 Simultaneous Offer Game

The basic model assumes that ISP makes a take-it-or-leave-it offer sequentially to CP_1 first and CP_2 last. Although the sequential offer assumption can be justifiable by a real case example in which *Comcast* offers a direct connection to *Netflix* before making any deal with other CPs, it is worth examining how results would change with simultaneous offer game. In this case, the timing of game needs to be adjusted accordingly. In stage 1, each CP chooses investment in content. This investment is to increase λ, which means that content becomes more diverse and exclusive. Also, the investment incurs a cost of $c(\lambda)$. In stage 2, ISP makes take-it-leave-it offers to both of CPs simultaneously for a high quality content delivery and both CPs decide whether to accept, respectively. In stage 3, ISP and CPs set the subscription fees for internet service and on-line video services, respectively. Consumers choose to which CP they subscribe. Some consumers are always multi-subscribing for content. In order to solve the simultaneous offer game, let me describe the second stage in a normal form as below.

Table 1.2 Equilibrium Profits under Paid Peering

	H	L
H	$\frac{(V(\bar{\lambda}+\lambda_1)+\mu)^2}{4t} - f_1^{HH} - c(\lambda_1)$, $\frac{(V(\bar{\lambda}+\lambda_2)+\mu)^2}{4t} - f_2^{HH} - c(\lambda_2)$	$\frac{(V(\bar{\lambda}+\lambda_1)+\mu)^2}{4t} - f_1^{HL} - c(\lambda_1)$, $\frac{(V(\bar{\lambda}+\lambda_2))^2}{4t} - c(\lambda_2)$
L	$\frac{(V(\bar{\lambda}+\lambda_1))^2}{4t} - c(\lambda_1)$, $\frac{(V(\bar{\lambda}+\lambda_2)+\mu)^2}{4t} - f_2^{LH} - c(\lambda_2)$	$\frac{(V(\bar{\lambda}+\lambda_1))^2}{4t} - c(\lambda_1)$, $\frac{(V(\bar{\lambda}+\lambda_2))^2}{4t} - c(\lambda_2)$

Since monetary transfer f is determined at the level which makes each CP becomes indifferent between accepting and rejecting offer as in the sequential move game, the resulting revenue from subscription of each CP will be the same in all cases. Given this, it is necessary to find the relevant conditions for each quality specification to be a Nash Equilibrium. It is easy to check that those conditions are exactly the same as in sequential offer game. Therefore, the basic setup is very robust in this regard.

1.6.3 The Effect of Net Neutrality

Net neutrality imposes non-discrimination requirements on Internet Service Providers (ISPs) by requiring them to treat all types of information flows (voice, data, video, etc.) equally in the last mile. That is, any type of peering agreements which are made in the Internet backbone industry is not regulated under net neutrality regulation. However, since the Internet space is all connected from the backbone to the last mile, it is worth discussing how this regulation affects the results.

With no net neutrality, the ISP can technically discriminate at the point of termination. Suppose the ISP can charge a fixed termination fee. Without this paid prioritization, there will be additional network quality degradation at termination. However, if a CP chooses paid peering earlier, there is no additional harm or benefit from paid prioritization: any CP choosing not to pay for the peering will decide whether to have paid prioritization later on. If its termination fee is sufficiently lower than the paid peering fee, any CP will not have any incentive to pay for paid peering in the first place — rather, they are more willing to pay for a termination fee and enjoy better network quality. However, if two different fees are comparable, it is ambiguous to see how a termination fee affects the paid peering results. Given that its rival paid for peering which means high network quality, if CP with non paid peering does not pay for termination fee, its network delivery quality will be much worse. This would make the CP lose more consumers, which induces him to pay either termination fee or paid peering fee in the first place.

In other words, if there is no net neutrality, it would give the ISP additional leverage, which makes CPs pay more money to the ISP to have better network quality. Thus, with no net neutrality, it could be much easier to observe better network quality (through paid prioritization with a termination fee) but less diverse content due to an extra burden toward

CPs.[13]

1.7 Conclusion

This paper analyzes the effects of a paid peering regime on incentives to invest in network quality and content diversity and on social welfare. By using a simple model, I have shown that a paid peering regime encourages the ISP to invest in network delivery quality, whereas it discourages CPs from investing in content diversity. Since there are two conflicting effects in terms of investment incentives, I concluded that the overall effects of a paid peering regime on total social welfare are ambiguous.

As the effects of a paid peering regime on investment incentives and social welfare are ambiguous, there is no universally valid claim that paid peering decreases investment in content diversity or that it promotes investment in network quality. Therefore, a specific policy tool needs to be implemented on a case-by-case basis to attain higher levels of social welfare or consumer surplus. For example, if the aim of a policy is to benefit consumers, policy makers need to regulate current paid peering practice to some extent. Although the authorities cannot prohibit a long-lasting paid peering agreement, any policy to reduce the burden for CPs who pay for interconnection will help them invest in producing original content. A policy that attracts voluntary cost-sharing is an example. Another example is any supportive policy that confers benefits on ISPs that invest even with smaller or no monetary transfers. From the social welfare perspective, I have shown that the equilibrium in which network quality is the highest and content is the most diverse generates the highest social welfare under the assumption of relatively low investment costs. Therefore, any policy related to investment cost reduction would be desirable in addition to policies that encourage ISPs to share some of the burden of peering costs.

Although this paper does not provide unambiguous results in terms of the welfare analysis, the results are still significant in the sense that they identify various key conditions on the model

[13] The detailed analysis with mathematical approach is in Appendix.

parameters for more beneficial welfare consequences. As long as which conditions lead to higher consumer surplus and social welfare is known, then policymakers can draw up appropriate policies that satisfy the relevant conditions.

CHAPTER 2

PRIVACY, INFORMATION ACQUISITION, AND MARKET COMPETITION

2.1 Introduction

It is well known that platforms such as Internet service providers (ISPs) and social media also serve as data intermediaries that collect and sell users' personal information. These data intermediaries sell data directly to third parties or use it to deliver more targeted advertising (ads) to consumers.[1] Each consumer's privacy concerns determine the total amount of personal data the consumer makes available to the platform, and thus, such concerns play an important role in the business of the platforms, the sellers or the advertisers, as well as in consumers' buying decisions. A platform can earn more money when it has more information because each seller or data holder who purchases data from the platform can attract more consumers through better targeting. Importantly, because the amount of information available determines the overall effectiveness of each seller's ad targeting, thereby impacting the overall consumer shopping experience, consumers themselves must also balance privacy concerns with convenience: better targeting based on more information comes at a price through the loss of privacy. Indeed, as I show in Section 2.6, a lack of confidence in data collection and data usage policies exacerbates consumers' privacy concerns: when more privacy-sensitive permissions are requested by a less trustworthy mobile application (app), we can observe a lower willingness to download the app.

Due to this trade-off between the benefits and the cost of privacy loss, regulators have engaged in efforts to balance firms' profit-seeking behaviors and consumers' privacy protection. However, it is always debatable where we should place more emphasis, which leads to the continuing amendment of privacy-related regulations. For example, a set of privacy rules approved by the Federal Communications Commission in October 2016, requiring ISPs to conspicuously

[1] For example, AT&T sells advertising based on customer data via AdWorks, which is its own ad network; therefore, there is no need to sell subscribers' data to third parties so that they can sell targeted ads. However, small ISPs who do not own their own ad networks could contract with third parties and share customer data for revenue generating purposes.

ask for permission before collecting and selling personal data, such as browsing histories, was overturned in April 2017. The rationale for this change, which is in the industry's favor, was that privacy-related matters should be regulated on a case-by-case basis when each company violates its own privacy policies. In response to this revocation, California tried to revive the broadband privacy rules to protect consumers' privacy rights; however, this attempt ultimately failed to become law.[2] Motivated by the privacy debate, in this paper, I seek to inform researchers and policy makers how privacy sensitivity and protection can impact market outcomes and welfare.

If each seller has the most recent information about potential customers, it can target its ads to better attract them. When a seller's targeted ads become more effective, consumers face lower mismatch costs from that seller: consumers will spend less time searching for the most suitable product because they immediately obtain the relevant information from these targeted ads. This potential benefit from a loss of privacy may also be asymmetric. A consumer is likely to face a much higher mismatch cost from small sellers or from market entrants that have weaker initial targeting skills: incumbents have better initial targeting technology that has been developed based on previous sales experience or existing customer data, whereas entrants lack such experience. For example, suppose that a major retailer such as Walmart.com (as the incumbent) and a new retailer (as the entrant) buy the same set of data from a platform. Walmart.com will be better able to target consumers than the entrant because it can combine the new data with its existing customer data.

This asymmetry raises several important research questions. How does the total amount of personal information available affect market competition when an entrant with weaker targeting skills demands considerably more personal data than the incumbent? How do such privacy concerns affect market outcomes? Does an increase in privacy concerns have a greater adverse effect on market entrants? How does it ultimately affect social welfare?

To answer these questions, I develop a model in which sellers are asymmetric with respect to

[2] Refer to Assembly Bill 375: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB375

their initial targeting technology and their overall product quality. These sellers decide whether to purchase consumer data from the platform and subsequently engage in price competition. In the model, a consumer is a two-dimensional type with respect to sensitivity to privacy and the valuation of product quality. Depending on his privacy type, each consumer decides whether to disclose personal information to the platform by comparing the benefit arising from interacting with the others on the platform and a nuisance cost arising from a loss of privacy. The platform aggregates all available detailed personal data and sells it to any seller who wants to use it to create targeted ads.

The main result shows that the entrant with weaker targeting skills always wants to buy data from the platform, whereas the incumbent buys only when privacy concerns exceed a certain threshold. In equilibrium, the entrant suffers from lower market share and revenue when the incumbent also buys data. Since the incumbent wants to buy data if less data become available due to greater privacy concerns, consumers' privacy concerns could disproportionately harm the entrant, which can be an anti-competitive threat.

Another important market outcome related to privacy concerns is data-driven vertical integration. In a two-sided market, in particular, there are multiple instances of vertical integration between the platform and a downstream firm, such as a content provider or an online retailer. Vertical integration can also be motivated by sellers' desire to obtain a greater collective amount of exclusive data. For example, when AT&T and Time Warner Media company announced their intention to merge in October 2016, they noted that the merger would benefit consumers by providing better targeted ads based on extensive customer data. By maintaining exclusive use of these data, Time Warner can target consumers much more effectively, thereby attracting more advertisers to choose Time Warner's content as a channel for advertising. By conferring an unfair advantage upon the integrated downstream firm, the merger may lead to antitrust concerns. In particular, data-driven vertical integration is related to consumers' privacy concerns in that the amount of information available plays a key role in attracting more customers.[3]

[3] In this example, however, Time Warner Media company itself is a platform, so the merger can be regarded as a horizontal platform-to-platform merger rather than as vertical integration. Still, the primary message about

The results of the vertical integration model considered in this paper indicate that if consumers are more likely to be privacy-sensitive such that less personal information becomes available, the platform and the incumbent will vertically integrate and prevent the entrant from obtaining access to customer data. This implies that privacy concerns have disproportionate negative effects for the entrant. The welfare analysis results show that such integration not only harms the entrant but also lowers consumer surplus and total social welfare: individually optimal decisions on data disclosure might not be socially optimal when aggregated because consumers could also be harmed by the lack of competition.

I further motivate this study by using Google Android app market data to propose more plausible policy remedies. Specifically, the evidence indicates that consumers' privacy concerns are affected by a data collector's reputation. Considering this evidence for the effect of data collectors' reputation on lowering privacy concerns in conjunction with the theoretical findings, I suggest a specific policy, exemplified by a government-backed privacy certification program, that encourages more consumers to voluntarily disclose their personal information, which is socially optimal in this model.

Previous Literature The stream of literature most closely related to my work is research on the effect of privacy on a market's competitive structure.[4] In models with symmetric firms, Taylor and Wagman (2014) examine how privacy enforcement leads to different competitive market outcomes depending on the individual context and industries. Shy and Stenbacka (2016) suggest that there is a non-monotonic relationship between the degree of privacy protection and equilibrium profits. Casadesus-Masanell and Hervas-Drane (2015) also study similar issues; in their model, as in Koh et al. (2017), consumers decide how much information to provide.

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the effect of collective and exclusive user data on better targeting remains valid. Another example that may be more relevant is the integration of Time Warner Inc. and HBO. As the integrated firm, HBO can better target customers of premium television content compared to other rival content providers such as Showtime. The Amazon-Whole Foods acquisition deal can be another example of data-driven integration: by using the extensive amount of transaction data on Amazon, Whole Foods is able to suggest better products to consumers, thereby attracting consumers away from less informed competitors such as Kroger.

[4] Taylor (2004), Acquisti and Varian (2005), Conitzer et al. (2012), Belleflamme and Vergote (2016), and Koh et al. (2017) allow consumers to actively decide how much information to disclose. However, these papers assume a monopolistic seller and thus do not examine how privacy concerns or information availability affect market competition.

Montes et al. (2016) also endogenize privacy by allowing consumers to anonymize themselves for a cost and analyze how privacy concerns and the resulting information availability affect competing firms' price discrimination and data acquisition decisions, consumer surplus, and social welfare. However, in the real world, asymmetries between firms are persistent for a variety of reasons arising from different previous sales experience or scope of products. By taking into account such asymmetries, my paper leads to important implications not present in a symmetric setting: privacy concerns may disproportionately harm the entrant through data-driven vertical integration, for example. In this sense, Campbell et al. (2015), who demonstrate that small firms or entrants, as specialists rather than generalists, can be adversely affected by privacy regulation that imposes unit costs on all firms, share one of the main implications of this paper. Unlike Campbell et al. (2015), however, my primary concern is further asymmetries in the sellers' market in terms of initial targeting technology, product quality and heterogeneous consumer privacy sensitivity. By including such asymmetries and heterogeneity, I offer a microfoundation for understanding how consumers react differently to potential privacy risk and how sellers are disproportionately affected by privacy concerns. Braulin and Valletti (2016) also model vertically differentiated sellers to determine how exclusive data sales affect consumer and social welfare. However, they do not study the potential anti-competitive effects that arise when a seller lacks customer information. Also, none of the papers focuses on more diverse market outcomes related to privacy concerns, such as data-driven vertical integration, which I consider in this paper. Although Kim et al. (2016) analyze how access to consumer data that enables personalized pricing affects the overall welfare of horizontal mergers, the focus is different; I focus on dynamic relationship between privacy concerns and data-driven vertical integration market outcomes under asymmetric seller setup.

This paper also relates to research on privacy and online targeted advertising. Goldfarb (2014) emphasizes that targeted ads and information availability can be more important to small advertisers with a focus on the difference between online and offline advertising. This finding of disproportionate effects from less information availability on small advertisers shares similarities with the findings of my paper. D'Annunzio and Russo (2017) find that if consumers overly block their personal information without considering the effect of their privacy concerns on advertisers' and publishers' decisions, then the tracking in equilibrium would be too low and could harm consumers and society.[5]

Finally, my paper contributes empirical evidence that corroborates the assumptions and hypotheses made implicitly throughout the paper. In a related study that further corroborates my work, Kummer and Schulte (2017) examine a money-for-privacy trade-off in the smartphone applications market by using Google Android app market data.

The remainder of the paper is organized as follows. In Section 2.2, the theoretical model is provided. The no vertical integration and the vertical integration games are solved in Sections 2.3 and 2.4, respectively. In Section 2.5, the welfare implications are drawn. Section 2.6 provides the empirical evidence demonstrating the effectiveness of specific policy remedies. Section 2.7 considers possible model extensions and checks the robustness of the main model. Finally, Section 2.8 concludes by suggesting additional policy implications.

2.2 Model

The players in this game are as follows: a monopoly platform as a data collector, an incumbent seller, an entrant seller, and a unit mass of consumers. All consumers are registered with the platform, and all firms (platform and sellers) have basic information, such as the email address, gender, and date of birth, for all consumers. The amount of basic information is normalized to one.

Consumer There is a continuum of consumers indexed by $i \in [0,1] \times [0,1]$. Each consumer $i \in [0,1] \times [0,1]$ has a two-dimensional type τ_i and θ_i, where both types are exogenously given and independently distributed. First, τ_i denotes each consumer's privacy sensitivity,

[5] Regarding the unexpected costs of privacy regulations, Goldfarb and Tucker (2011) also empirically show that privacy regulation increases the intrusiveness of advertising. Calzolari and Pavan (2006), Kim and Choi (2010) and Kim and Wagman (2015) argue that information disclosure is not always harmful to the individual and may contribute to improving welfare.

which is horizontally distributed over $[0, 1]$ with distribution function F and density f. Consumer i becomes more privacy-sensitive as τ_i increases. For notational convenience, let $\mathcal{D}$ denote the set of privacy-insensitive consumers who disclose as much personal information as possible and $\mathcal{ND}$ denote the set of privacy-sensitive consumers who do not disclose any additional personal information. The portion of each set is endogenously determined by consumers' decisions: each consumer on a continuum of τ_i compares the benefits and privacy nuisance costs from disclosing personal information to the platform and makes an optimal decision. Second, θ_i denotes consumer i's valuation of the overall quality of the products provided by sellers, and this is uniformly distributed over the vertical unit line. Again, each consumer on a continuum of θ_i decides which seller to purchase a product from given that each seller provides different product quality levels. As above, let $\mathcal{H}$ denote a set of high-valuation consumers and $\mathcal{L}$ denote a set of low-valuation consumers.[6] Depending on his type (τ_i, θ_i), each consumer who has unit demand for a product makes two independent decisions: (a) whether to disclose his personal information to the platform ($\mathcal{D}$ or $\mathcal{ND}$) and (b) whether to purchase a product from a high- or a low-quality seller ($\mathcal{H}$ or $\mathcal{L}$).[7] Therefore, each consumer obtains net utility from two sources.

First, any consumer obtains immediate benefit from enjoying the platform's services: e.g., Facebook users enjoy the social networking service. Furthermore, as more users disclose more information to the platform, all other users benefit due to the network effect. In that sense, the immediate benefit is increasing in the total amount of detailed information available on the platform, which is an increasing function of the portion of consumers who disclose information, $P(i \in \mathcal{D})$. In addition, any user $i \in \mathcal{D}$ who provides detailed personal information obtains greater benefit than $i \in \mathcal{ND}$ who only provides basic information: if a user shares his information with others on the platform, he will obtain greater networking benefit than the inactive users. However, $i \in \mathcal{D}$ faces a much higher nuisance cost from privacy loss than $i \in \mathcal{ND}$, which

[6] The overall quality captures not only the product quality itself, which is related to its functions, but also the service quality that sellers provide when their products are sold. I assume that targeted ads play a role in improving service quality. That said, if the seller of a low-quality product can better target its ads, it could overcome its product quality disadvantage to some extent by offering the consumer better service.

[7] Again, a consumer takes into consideration product quality and targeted ads when identifying himself as part of the *High* or *Low* valuation group.

increases in privacy sensitivity τ_i. I assume that the negative effect of the nuisance cost is mitigated, as the data collector has a stronger reputation in that privacy concerns are trust-based. In other words, if the platform has a better reputation, consumers have less concern about data breaches.[8] Normalizing both the benefit and cost of $i \in \mathcal{ND}$ to zero, the utility for each consumer i from the platform is given as follows.

$$v_i^p = \begin{cases} v(P(i \in \mathcal{D})) - \dfrac{\psi(\tau_i)}{r} & \text{if } i \in \mathcal{D} \\ 0 & \text{if } i \in \mathcal{ND}, \end{cases} \tag{2.1}$$

where the superscript p denotes the platform, $v(P(i \in \mathcal{D}))$ denotes the immediate benefit from disclosing information, with $v' > 0$ and $v'' \geq 0$; $\frac{\psi(\tau_i)}{r}$ denotes the nuisance cost, with $\psi' > 0$ and $\psi'' \geq 0$; and r represents the platform's reputation. I also assume that $\psi(\tau_i)$ is continuous in τ_i. Because it is strictly increasing and continuous in τ_i, it is invertible.[9]

Since seller j's targeting effectiveness increases in the amount of consumer data, a consumer's information disclosure decision also affects the utility from product purchase: any $i \in \mathcal{ND}$ whose detailed information is not available is likely to suffer from a higher mismatch cost than any $i \in \mathcal{D}$ who provides personal information, as targeted ads suggest products that are better suited to consumers. Normalizing the mismatch cost for $i \in \mathcal{D}$ to zero, the utility specification is given as follows.[10]

$$u_{ij} = V + \theta_i s_j - P_j - \mathbb{1}_{\{i \in \mathcal{ND}\}} \left(\frac{1}{\gamma_j D_j} \right), \tag{2.2}$$

[8] In Section 2.6, I show that a consumer is more willing to disclose information when the data collector has a stronger market reputation. Choi et al. (2016) also discuss the role of reputation in reducing privacy nuisance costs.

[9] If a consumer discloses his information ($i \in \mathcal{D}$), he enjoys the benefit of $v(P(i \in \mathcal{D}))$, which includes immediate benefits, such as networking with friends. Simultaneously, he faces the utility loss from a nuisance cost, which might arise from either direct economic losses (e.g., a threat of identity theft) or a negative psychological feeling about disclosing personal information.

[10] One might argue that any consumer $i \in \mathcal{D}$ should face some positive mismatch cost in the case when seller j does not purchase detailed information. However, as long as the mismatch cost for $i \in \mathcal{ND}$ is higher than that from $i \in \mathcal{D}$, the qualitative results from the current specification always hold but generate much simpler equations.

where V denotes the reservation value (base utility), which is assumed to be large enough to fully cover the market, and the valuation of consumer i with respect to product quality is given by $\theta_i \sim U[0,1]$. The overall product quality is denoted as s_j, P_j denotes the price of products from seller j, and $\frac{1}{\gamma_j D_j}$ is the mismatch cost where γ_j denotes seller j's initial targeting technology and D_j denotes the amount of consumer data possessed by seller j. The indicator function $\mathbb{1}_{\{i \in \mathcal{ND}\}}$ is one if a consumer i does not disclose personal information. A consumer is more likely to incur a lower mismatch cost from a seller that has better targeting skills—higher γ_j. Finally, I assume that a consumer's mismatch cost decreases as seller j obtains more consumer information for creating targeted ads and that the effect of data on reducing mismatch costs is non-increasing as D_j increases.[11]

In this specification, consumers who do not provide any additional personal information to the platform also benefit as seller j obtains more aggregate information from the platform. This scenario is plausible due to *information externalities*. For example, firms can categorize consumers into subgroups based on gender and age. In each consumer category, some people provide considerable information about themselves, while others provide nothing. Such information can be transferred to other members of the peer group, such that consumers who do not provide any further personal information are still likely to receive some promotional emails.[12]

Lastly, one might question the additive separable utility specification of information disclosure and product purchasing. In this setup, consumers only consider the immediate benefits from disclosing information to the platform and do not take into consideration any potential future benefits arising from better targeted ads. This assumption makes sense for many real case examples of platforms, such as social media. For example, when a consumer posts news of the birth of his baby on Facebook, he is more likely to do so to spread good news to his friends

[11]The following is a more intuitive explanation of the mismatch cost. A consumer knows that there are two sellers (retailers) I and E that have identical product sets but that differ in overall product quality. A consumer does not have a preference for one specific brand (seller) over the other but has different needs for a specific type of product that both sellers sell. Thus, if each seller has the most recent information about potential customers, it can target its ads to be more attractive to them. Then, consumers will spend less time finding the most suitable product because they are immediately obtaining the relevant information from these targeted ads.

[12]See Choi et al. (2016) for a more detailed description of such information externalities.

than in hopes of seeing more relevant ads on baby products.[13]

Platform The platform gathers personal information about customers while providing diverse services to them. The amount of data available depends on how likely each consumer is to disclose his information to the platform, i.e., whether a consumer is privacy-sensitive or privacy-insensitive. Although both types of consumers provide basic information to the platform to enjoy the services it offers, the platform sells only detailed information, such as users' relationship status. Normalizing the total amount of detailed demographic information that the platform obtains from each consumer to one, the platform sells $P(i \in \mathcal{D})$ amount of detailed information to any seller that wants to buy. The platform earns profits only from selling user data to any seller. By optimally setting the per unit data price C, the platform solves the following profit maximization problem.

$$\max_{C} \quad \pi_p(C|P(i \in \mathcal{D})) = \begin{cases} 0 & \text{if no seller buys data} \\ P(i \in \mathcal{D})C & \text{if one seller buys data} \\ 2P(i \in \mathcal{D})C & \text{if both sellers buy data,} \end{cases} \tag{2.3}$$

where the subscript p denotes the *platform*.[14]

Sellers Each seller j ($j \in \{I\text{ncumbent}, E\text{ntrant}\}$) sells a set of products to consumers. The set of products offered by each seller is vertically differentiated in terms of product quality, which is denoted by s_j, and service quality in terms of targeting quality, denoted by $\gamma_j D_j$, where D_j is equal to $1 + P(i \in \mathcal{D})$ if seller j buys data from the platform or one otherwise. The set of products for each seller overlaps, but overall quality—in terms of product and service—is different. The overall product quality increases in s_j, whereas service quality in terms of targeting increases in γ_j and in D_j. If a seller decides to buy data from the platform, he pays per unit data price C. Whether or not he does so depends on the relative magnitudes of C and

[13] For those who are interested in the case of consumers with perfect foresight, see Section 2.7.1.

[14] The choice variable C can be considered to be the data price if the platform sells data to third parties. If it is not allowed to sell data but is only able to use the data to create targeted ads, C can be regarded as a per unit advertising (intermediation) fee.

γ_j which captures previous sales experience and the existing customer information. Without loss of generality, I first assume that $\gamma_I \geq \gamma_E$: seller I has better targeting technology than seller E. For simplicity, I normalize γ_E to one and denote γ_I as γ where $\gamma > 1$.[15] Regarding product quality, either I or E can provide a high-quality product. I focus on the case in which I is better at initial targeting (service quality) but E is better at product quality, and thus, $s_I < s_E$ is assumed throughout the paper. Each seller's profit maximization problem is defined as follows.

$$\max_{P_j, D_j} \quad \pi_j = P_j X_j(P_j, D_j|\gamma, s) - \mathbb{1}_{\{\text{buy}\}} C \times P(i \in \mathcal{D}), \tag{2.4}$$

where P_j is the price that seller j charges to consumers and $X_j(P_j, D_j|\gamma, s)$ is j's aggregate market share. If j buys data from the platform, it needs to pay the price C set by the platform. The indicator function $\mathbb{1}_{\{\text{buy}\}}$ is one if seller j buys data from the platform.

As for the other case, $s_I > s_E$, the qualitative results in the paper still hold, but it generates less embracive results than the case of $s_I < s_E$. If the incumbent has advantages in targeting as well as product quality, the room for the entrant to overcome his disadvantage by obtaining consumer data is very limited. This leads to an equilibrium in which only the incumbent benefits from data acquisition, which is less interesting because targeting has a limited effect on the competitive structure. See Appendix for details.[16]

Timing and Solution Concept All information, including the distribution of τ_i and θ_i, is common knowledge, while the true realizations of τ_i and θ_i for each i are private information. I investigate two games: with and without data-driven vertical integration. In both games, firms form beliefs about consumers' valuations given their identification status: $\mathcal{D}$ or $\mathcal{ND}$ for τ_i and $\mathcal{H}$ or $\mathcal{L}$ for θ_i. In the no vertical integration case, the timing of the game follows Figure 2.1. In the vertical integration game, I add an additional stage in which the platform decides with

[15] The assumption of γ is based on the fact that I has the existing customer information and thus has established stronger data analytic skills combined with previous sales experience. See Appendix for a detailed discussion.

[16] Walmart.com is a representative example of an incumbent firm. Because Walmart.com sells various products in many categories, it is a generalist. Any specialist retailers that sell various products in a specific category, such as apparel, can be considered high-quality entrants in that they specialize in their own business area. Campbell et al. (2015) made a similar assumption.

whom to vertically integrate at the beginning of the second stage, as in $2'$ in the parenthesis. Thereafter, the game proceeds as before, except that in the third stage, the affiliated seller freely obtains data from the platform, while the unaffiliated seller decides whether to buy data. After each stage, the consumer's choice of action is observed by every agent.

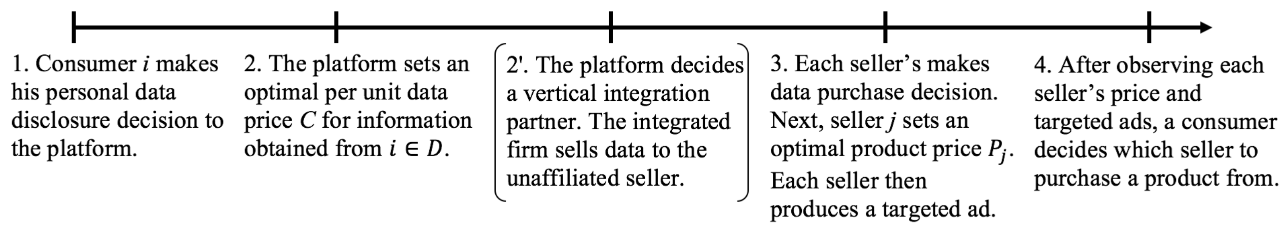

Figure 2.1 Timing

The solution concept I use for this game is the Perfect Bayesian Nash Equilibrium (PBE) for multi-period games with observed action as in Fudenberg and Tirole (1991): PBE consists of a strategy profile for all players and a set of beliefs. These constitute a PBE if all strategies are sequentially rational given the beliefs and the beliefs are consistent given the strategies.[17]

2.3 No Vertical Integration

2.3.1 Equilibrium

In the first stage, each consumer compares the utility levels from disclosure and decides whether to disclose information. Depending on τ_i, any consumer who has $\frac{\psi(\tau_i)}{r} < v(P(i \in \mathcal{D}))$ will disclose. The portions of privacy-sensitive consumers (not disclosing information) and privacy-insensitive consumers (disclosing) are implicitly determined by the following Proposition.[18]

[17] According to Fudenberg and Tirole (1991), if each player has only two possible types that are independent, and both types have non-zero prior probabilities, as in my model, the PBE coincides with the sequential equilibrium.

[18] Note that when each consumer makes his optimal decision on information disclosure, he forms a rational expectation about the proportion of consumers who disclose information. In equilibrium, consumers take these probabilities as given by $P(i \in \mathcal{D}) = \tau_a^c$ and $P(i \in \mathcal{ND}) = 1 - \tau_a^c$, where subscript a denotes the *anticipated* proportion. In equilibrium, τ_a^c should be consistent with the true τ^c, which is aggregately determined by consumers. For notational convenience, I drop the subscript a.

Proposition 2.1. *There exists a critical point, τ^c, that satisfies the following equation.*

$$\begin{aligned} P(i \in \mathcal{D}) = P(\tau_i < \psi^{-1}(r \times v(\tau^c))) = F(\psi^{-1}(r \times v(\tau^c))) = \tau^c \\ P(i \in \mathcal{ND}) = 1 - F(\psi^{-1}(r \times v(\tau^c))) = 1 - \tau^c. \end{aligned} \tag{2.5}$$

A parametric example Let $\tau_i \sim U[0,1]$, $\psi(\tau_i) = \lambda\tau_i^2$ where $\lambda > 2$, and $v(\tau^c) = 1 + \tau^c$. In this case, τ^c is the solution to $\tau^c = \psi^{-1}(r(1+\tau^c)) = \sqrt{\frac{r(1+\tau^c)}{\lambda}}$. Thus, $\tau^c = \frac{\sqrt{r(4\lambda+r)}+r}{2\lambda}$. Obviously, as λ increases, i.e., as the nuisance cost increases, more people are reluctant to disclose information, so τ^c decreases. As r increases, τ^c also increases.

Given $P(i \in \mathcal{D}) = \tau^c$, the amount of aggregated detailed data, I solve for the PBE using backward induction to obtain sequentially rational strategies. From the utility specification in (2.2), the indifference condition is $\theta^c_{\mathcal{ND}} = \frac{P_E - P_I + (\frac{1}{D_E} - \frac{1}{\gamma D_I})}{s_E - s_I}$ for $i \in \mathcal{ND}$ and $\theta^c_{\mathcal{D}} = \frac{P_E - P_I}{s_E - s_I}$ for $i \in \mathcal{D}$. The weighted indifference condition can be rewritten in a simple way as follows.

$$P(i \in \mathcal{L}) = \theta^c = \frac{P_E - P_I + (1-\tau^c)\Delta}{s}, \tag{2.6}$$

where $\Delta = (\frac{1}{D_E} - \frac{1}{\gamma D_I})$ and $s = s_E - s_I$.[19] The market share for each seller is given by $X_I = \theta^c = P(i \in \mathcal{L})$ and $X_E = 1 - \theta^c = P(i \in \mathcal{H})$ under $s_I < s_E$. Given X_I and X_E, the solutions to the profit maximization problem with respect to P_j are given by

$$P_I = \frac{s + (1-\tau^c)\Delta}{3}; \quad P_E = \frac{2s - (1-\tau^c)\Delta}{3}; \quad X_I = \frac{s + (1-\tau^c)\Delta}{3s}; \quad X_E = \frac{2s - (1-\tau^c)\Delta}{3s}. \tag{2.7}$$

To guarantee an interior solution, I assume throughout the paper that $\frac{\Delta(1-\tau^c)}{2} < s$: seller E's quality s_E is large enough to have positive demand. Note that the sufficient condition for the interior solution is $s \geq \frac{1}{2}$, which is assumed to be satisfied throughout the paper.

[19] Note that Δ can be negative if τ^c is large enough and E is the only data holder, which indicates the (N, B) data acquisition case.

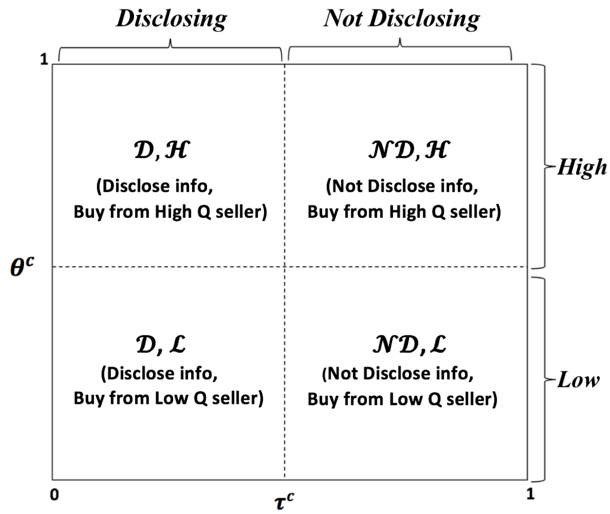

Figure 2.2 Endogenously derived thresholds, τ^c and θ^c, on τ_i and θ_i

Given the equilibrium price and quantity in (2.7), each seller decides whether to purchase data from the platform. The gap between the mismatch costs from two sellers, denoted by Δ, differs depending on each seller's choices regarding D_j: either $1 + \tau^c$ (if purchasing) or 1 (otherwise), which can be derived as follows.

$$\Delta = \begin{cases} \dfrac{1}{1+\tau^c}(1 - \dfrac{1}{\gamma}) \equiv \Delta_{BB} & \text{if both sellers buy data} \\ 1 - \dfrac{1}{\gamma(1+\tau^c)} \equiv \Delta_{BN} & \text{if only seller } I \text{ buys data} \\ \dfrac{1}{1+\tau^c} - \dfrac{1}{\gamma} \equiv \Delta_{NB} & \text{if only } E \text{ buys data} \\ 1 - \dfrac{1}{\gamma} \equiv \Delta_{NN} & \text{if both do not buy data} \end{cases} \tag{2.8}$$

One can rank different Δ as $\Delta_{NB} < \Delta_{BB} < \Delta_{NN} < \Delta_{BN}$,[20] where the first and second subscripts denote I's and E's decisions, respectively. Using (2.7) and (2.8), each seller's equilibrium profit level is realized. By comparing profits under the two choices, I can derive thresholds of C that guarantee that one seller will buy data, given the rival's decision. The thresholds are

[20] $\Delta_{BB} = \Delta_{NN}$ and $\Delta_{NB} < 0$ if $\gamma = 1$, which means that the two sellers' initial targeting technology is symmetric.

$$\begin{cases} \text{Given } E \text{ buys, } I \text{ buys if} \quad C < \dfrac{(1-\tau^c)(\Delta_{BB}-\Delta_{NB})(2s+(1-\tau^c)(\Delta_{BB}+\Delta_{NB}))}{9s\tau^c} \equiv \bar{C}_I \\ \text{Given } E \text{ does not buy, } I \text{ buys if} \quad C < \dfrac{(1-\tau^c)(\Delta_{BN}-\Delta_{NN})(2s+(1-\tau^c)(\Delta_{BN}+\Delta_{NN}))}{9s\tau^c} \equiv \bar{\bar{C}}_I \\ \text{Given } I \text{ buys, } E \text{ buys if} \quad C < \dfrac{(1-\tau^c)(\Delta_{BN}-\Delta_{BB})(4s-(1-\tau^c)(\Delta_{BN}+\Delta_{BB}))}{9s\tau^c} \equiv \bar{C}_E \\ \text{Given } I \text{ does not buy, } E \text{ buys if} \quad C < \dfrac{(1-\tau^c)(\Delta_{NN}-\Delta_{NB})(4s-(1-\tau^c)(\Delta_{NN}+\Delta_{NB}))}{9s\tau^c} \equiv \bar{\bar{C}}_E. \end{cases}$$

Unambiguously, $\bar{\bar{C}}_I > \bar{C}_I$ and $\bar{\bar{C}}_E > \bar{C}_E$: provided that the rival does not buy, it is more likely that the other firm will buy. In other words, data acquisition is a strategic substitute, since $\frac{\partial^2 \pi_j}{\partial D_I D_E} = \frac{-2(1-\tau^c)^2}{9sD_I^2 D_E^2 \gamma} < 0$. The intuition is as follows. The data can be used to differentiate products because better targeted ads based on more available data attract more consumers. Thus, consumer information that is used to generate better targeted ads increases product differentiation, which softens price competition.

Given the interior solution assumption on s, the four thresholds are ranked as $\bar{C}_I < \bar{\bar{C}}_I < \bar{C}_E < \bar{\bar{C}}_E$. Based on the ranking on C, the platform makes a data pricing decision. Given the equilibrium decision of each seller, the platform's profits under different levels of C are

$$\begin{cases} \pi_p^{BB} = 2\bar{C}_I \tau^c & \text{if} \quad C \le \bar{C}_I, \quad \text{(Buy, Buy)} \\ \pi_p^{NB} = \bar{\bar{C}}_E \tau^c & \text{if} \quad C \le \bar{\bar{C}}_E, \quad \text{(Not buy, Buy),} \end{cases}$$

because it wants to set as high a price as possible. By comparing different profit levels, the platform sets the optimal C.[21] From the profit comparison, there exists a τ_{NV} such that if $\tau^c < \tau_{NV}$, the platform sets $C^* = \bar{C}_I$, meaning that both sellers buy data, which means (B, B). Similarly, if $\tau^c > \tau_{NV}$, the platform sets $C^* = \bar{\bar{C}}_E$, meaning that only seller E buys data, whereas seller I does not, which means (N, B). The result is summarized in Proposition 2.2. Note that I restrict my attention to $\frac{1}{2} < s < 1$, since $s > 1$ always leads to a data acquisition equilibrium in which the entrant is the only data holder, which is not interesting.

Proposition 2.2. *If less data become available due to greater privacy concerns ($\tau^c < \tau_{NV}$), the platform sets a lower price, meaning that both sellers buy data, which means (B, B). However,*

[21] In Section 2.7, I consider the case in which the platform engages in data price discrimination.

if more data are available ($\tau^c > \tau_{NV}$), the platform sets a higher price, meaning that seller E buys data, whereas seller I does not, which means (N, B).

Intuitively, if more data become available, E is able to overcome its disadvantage in targeting skills, thereby having higher willingness to pay for additional data. Therefore, $\tau^c > \tau_{NV}$ leads to the exclusive data selling arrangement with E.[22]

2.3.2 Implications

Proposition 2.2 states that if consumers are more privacy-sensitive (less data availability, $\tau^c < \tau_{NV}$), both sellers buy data, while only seller E buys if more data become available ($\tau^c > \tau_{NV}$). Intuitively, if only a small amount of data is available, the data are not sufficient for E to overcome its targeting disadvantage. So, if I buys the same small set of data, it can dominate the market easily. Thus, seller E always suffers from a lower market share if seller I also buys data while it can enjoy higher market revenue if it is the only data holder.[23] However, the effect on profits is ambiguous because the seller needs to pay a much higher price to the platform to secure a data monopoly. By comparing π_E^{BB} to π_E^{NB}, where the superscripts denote data acquisition status, one can find another threshold on τ_i, denoted as τ'_{NV}, that determines whether one of the profit levels is greater than the other. If $\tau^c > \frac{-\gamma-4\gamma s+\sqrt{(\gamma+(4\gamma-6)s)^2-8(\gamma-2)(-\gamma+(2\gamma-3)s+1)+6s}}{2(\gamma-2)} \equiv \tau'_{NV}$, $\pi_E^{BB} > \pi_E^{NB}$, and the reverse holds under $\tau^c < \tau'_{NV}$. As in Figure 2.3, τ'_{NV} can be larger than τ_{NV}, which leads to counterintuitive consequences. If $\tau^c < \tau'_{NV}$, (N, B) makes E better off, but this usually does not arise in equilibrium because I also always wants to buy data for a small range of τ^c. Since E's best response to I's buying decision is also to buy, E selects (B, B). Analogously, if $\tau^c > \tau'_{NV}$, (B, B) leads to a higher profit for E because the platform extracts too much rent given (N, B). However, for this range of τ^c, I always refuses to buy data, thereby leading to (N, B) in

[22] As Montes et al. (2016) note, this exclusive data-selling strategy accords with a reality in which different firms are unlikely to obtain data on the same consumers despite doing business in the same industry.

[23] Note that seller I becomes indifferent between buying and not buying data because the platform extracts the surplus from buying data by charging the data price C.

equilibrium. Therefore, the optimal choice for E might lead to a suboptimal result in terms of profit. Corollary 2.1 summarizes this finding.

Corollary 2.1. *For the entrant E, the exclusive use of data, (N, B), leads to greater market share and higher revenue than data sharing, (B, B). However, (N, B) leads to lower profit than (B, B) in most cases, except for $\tau_{NV} < \tau^c < \tau'_{NV}$.*

This result suggests that consumers' privacy concerns and the resulting decrease in available data disproportionately harm the entrant in terms of market share and revenue. Figure 2.3 demonstrates the results in the no vertical integration game: except for the shaded area, the optimal decision for E results in the suboptimal outcome in terms of profit.[24]

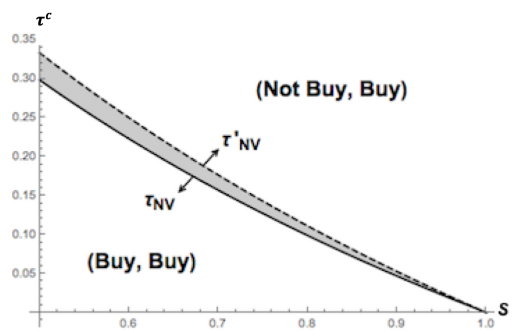

Figure 2.3 Equilibrium under No Vertical Integration if $\gamma = 1.8$

2.4 Vertical Integration Case

In this section, I analyze the effect of vertical integration between the platform and one of the sellers. Regarding the timing, after each consumer decides whether to disclose information, the platform first makes a vertical integration deal with one of the sellers. After the vertical integration deal is made, the unaffiliated seller decides whether to purchase data from the platform. The affiliated seller always uses data for targeted ads. Next, the sellers simultaneously set their prices, and then the consumers decide.

[24] If $\tau'_{NV} < \tau_{NV}$ holds, a similar argument can be applied. Except for $\tau'_{NV} < \tau^c < \tau_{NV}$, the optimal decision for E results in the suboptimal outcome in terms of profit.

2.4.1 Equilibrium

By backward induction, each seller's price and market share are the same as before. Given this setting, I examine the result when the platform makes a deal with one of the sellers. First, I assume that the platform merges with seller I, which has better targeting technology. Because seller I always uses data, seller E buys data if $C \leq \bar{C}_E$ but does not if $C > \bar{C}_E$. The profit for the integrated firm can be written as follows.

$$\pi_{VI} = \begin{cases} P_I(\Delta_{BB})X_I(\Delta_{BB}) + \bar{C}_E\tau^c \equiv \pi_{VI,S} & \text{if the integrated firm sells data to } E \\ P_I(\Delta_{BN})X_I(\Delta_{BN}) \equiv \pi_{VI,F} & \text{otherwise (foreclose),} \end{cases} \tag{2.9}$$

where the first two letters in the subscript *VI* denote *Vertical Integration with I* and the last letter indicates data foreclosure or selling status. By comparing $\pi_{VI,S}$ to $\pi_{VI,F}$, the integrated firm decides whether to sell data to the unaffiliated firm.

$$\pi_{VI,S} - \pi_{VI,F} = -\frac{2(\tau^c-1)\tau^c\left(\gamma\left(s\tau^c + s + (\tau^c)^2 + \tau^c - 2\right) - 2\tau^c + 2\right)}{9\gamma s(\tau^c+1)^2}. \tag{2.10}$$

Thus, if $\tau^c < \frac{\sqrt{\gamma^2((s-2)s+9)-4\gamma(s+3)+4}-\gamma(1+s)+2}{2\gamma} \equiv \bar{\tau}'$, $\pi_{VI,S} < \pi_{VI,F}$: as τ^c increases, it is more likely to sell data to the rival. For the incumbent, the marginal benefit of obtaining more data is much smaller due to his initial advantage in targeting technology. Thus, if the amount of data is above a certain threshold, the market dominance effect becomes smaller than the data-selling revenue effect. Accordingly, the integrated firm earns greater profits from selling data.

Now, I examine the result when the platform merges with seller E. By the above logic, the profits for the integrated firm and the difference between the two profit levels are as follows.

$$\pi_{VE} = \begin{cases} P_E(\Delta_{BB})X_E(\Delta_{BB}) + \bar{C}_I\tau^c \equiv \pi_{VE,S} & \text{if the integrated firm sells data to } I \\ P_E(\Delta_{NB})X_E(\Delta_{NB}) \equiv \pi_{VE,F} & \text{otherwise (foreclose).} \end{cases} \tag{2.11}$$

$$\pi_{VE,S} - \pi_{VE,F} = -\frac{2(\tau^c - 1)\tau^c \left(-\gamma((s+2)\tau^c + s - 2) + (\tau^c)^2 + \tau^c - 2\right)}{9\gamma^2 s(\tau^c + 1)^2}. \tag{2.12}$$

Thus, if $\tau^c > \frac{1}{2}\left(-\sqrt{\gamma^2(s+2)^2 + 2\gamma(s-6) + 9} + \gamma(s+2) - 1\right) \equiv \underline{\tau}$, the integrated firm forecloses data access. In contrast to the former case, if the platform is integrated with seller E, it is more likely to foreclose data access as τ^c increases because if τ^c is sufficiently large, seller E is able to overcome his targeting disadvantage and can more easily dominate the market. Therefore, the integrated firm sells data only if τ^c is small; the data-selling revenue effect is greater than the market dominance effect of data foreclosure. Note that the right-hand side of the inequality decreases in s, which means that if s increases, it is more profitable to foreclose data access because the combination of data monopolization and a higher s provides a greater advantage to the integrated firm.

To determine which seller offers sufficient incentive to induce the platform to integrate, I compare the profits from integration with I to those from integration with E. Since $\underline{\tau} < \bar{\tau}'$, there are three possible cases: I-Foreclose or E-Sell for $\tau^c < \underline{\tau}$, I-Foreclose or E-Foreclose for $\underline{\tau} < \tau^c < \bar{\tau}'$, and I-Sell or E-Foreclose for $\tau^c > \bar{\tau}'$.[25] First, if $\tau^c < \underline{\tau}$ (less data availability), the ISP integrates with I and forecloses E from data access. Second, if $\underline{\tau} < \tau^c < \bar{\tau}'$ (moderate data availability), there is another threshold on τ_i, denoted as τ_V, such that $\tau^c > \frac{\sqrt{\gamma^2((s-2)s+9)+2\gamma(s-9)+9}+\gamma(-(s+1))+1}{2(\gamma-1)} \equiv \tau_V$ leads to vertical integration with E and data foreclosure. If $\tau^c < \tau_V$, the platform and I integrate and foreclose data access. Finally, if $\tau^c > \bar{\tau}'$ (more data availability), the platform and E integrate and foreclose data access for I in equilibrium. As a result, there are two possible cases with a vertical integration equilibrium: (a) integration with I if $\tau^c < \tau_V$ and (b) integration with E if $\tau^c > \tau_V$. There is no data-selling equilibrium in any case, and data foreclosure always emerges in the vertical integration game.

Furthermore, I must verify whether the platform and each seller have an incentive to vertically integrate with one another by comparing the joint profits of the platform and each seller under no vertical integration to the profits of the integrated firm. First, if the platform and

[25] For example, I-Foreclose means that the ISP integrates with I and forecloses E from data access. Similarly, E-Sell means that the ISP and E integrate and sell data to I.

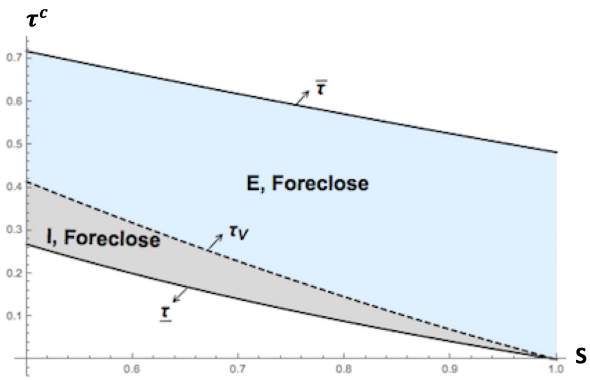

Figure 2.4 Vertical Integration Equilibrium on (s, τ^c) space when $\gamma = 2$

I are integrated, they always want to be integrated if (B, B) is the no vertical integration equilibrium. However, for the case of (N, B), vertical integration is more profitable only if $\tau^c < \frac{\sqrt{4\gamma\left(\gamma(3\gamma-5)(3\gamma+1)+\gamma(\gamma-1)^2 s^2-(\gamma(2(\gamma-3)\gamma+3)+1)s+6\right)+9}+2\gamma(s-\gamma(s+1))+1}{4(\gamma-1)\gamma-2} \equiv \bar{\tau}$: if τ^c is sufficiently large, the platform can extract much higher revenue from E by charging a higher price for the data. Similarly, the platform and E have an incentive to be integrated if $\tau^c > \underline{\tau}$. The intuition is similar to that above: if τ^c is small, the platform is better off from selling data to both sellers at a lower price. Therefore, if $\underline{\tau} < \tau^c < \bar{\tau}$ holds, vertical integration can always occur. As in Figure 2.4, vertical integration can emerge in the shaded area, and the merger partner is determined by the threshold of τ_V. Proposition 2.3 summarizes these results.

Proposition 2.3. *The platform has an incentive to vertically integrate with seller I if there are more privacy-sensitive consumers and less available personal data ($\tau^c < \tau_V$), whereas integration with E emerges if there are more privacy-insensitive consumers and more available personal data ($\tau^c > \tau_V$). Regardless of which seller is involved, the unaffiliated seller forgoes buying data.*

2.4.2 Implications

Absent vertical integration, seller E always wants to buy data to overcome its initial disadvantage in targeting skills, while I buys data only when τ^c is small. Because vertical integration always leads to data foreclosure, it is more likely to adversely affect the entrant, E, which always needs data access. To determine how this affects sellers, especially seller E, I compare sellers' profits with and without vertical integration. First, if the platform and seller E are integrated, the unaffiliated seller, I, becomes indifferent to the existence of vertical integration. Absent vertical integration, seller I has the same profit level whether buying or not buying data because the platform extracts all additional revenue by setting the price of data. Since the vertical integration equilibrium is (N, B), which is the same as in one case of no vertical integration, there is no difference in I's profits due to the merger between the platform and E.

If the platform and I are integrated, the unaffiliated seller E always suffers from lower profits due to the integration and resulting data foreclosure: $\min\{\pi_E^{BB}, \pi_E^{NB}\} > \pi_{VI,F}^E$ where $\pi_{VI,F}^E$ denotes E's profit under vertical integration with I. Thus, due to data foreclosure, seller E generally suffers from lower profits under vertical integration because it has a smaller market share when the platform integrates with I than it does in any case under no vertical integration, which leads to either (B, B) or (N, B). Proposition 2.4 summarizes this implication.

Proposition 2.4. *When the platform is vertically integrated with seller I, seller E suffers from a smaller market share, thereby obtaining lower profits due to data foreclosure. When the platform is vertically integrated with E, seller I faces no difference in profit, regardless of the presence of vertical integration.*

This result raises a very important antitrust implication regarding data-driven vertical integration. Although vertical integration always forecloses data access regardless of the seller with which the deal is made, the entrant seller is more likely to be harmed. As consumer information is vital for a small seller or a market entrant with weaker targeting skills, vertical integration with a seller with better targeting skills is likely to have an anti-competitive effect because it prevents the unaffiliated entrant from using data to overcome its initial disadvantage. Moreover, given that greater privacy concerns and the resulting decrease in available personal data lead to integration with seller I, consumers' privacy concerns might disproportionately harm seller E.

2.5 Welfare Analysis

Based on the equilibrium results derived thus far, I examine welfare consequences in this section. First, the total social welfare function is the sum of consumer surplus and sellers' profits, including the platform's profits as follows.

$$SW = CS + \mathbb{1}_{\{NV\}}(\pi_p + \pi_I + \pi_E) + \mathbb{1}_{\{V\}}(\pi_K^I + \pi_K^E), \tag{2.13}$$

where $CS = CS_p + CS_K$, and the subscript $K \in \{VI, VE\}$; *VI* (*VE*) denote the surplus from vertical integration with seller I (E), respectively. CS_p denotes the surplus from using the platform's services. π_{VI}^I (π_{VE}^E) is the profit for the integrated firm, and π_{VI}^E (π_{VE}^I) is that for the non-integrated firm. The indicator functions, $\mathbb{1}_{\{NV\}}$ and $\mathbb{1}_{\{V\}}$, are one if under the no vertical integration and vertical integration games, respectively. The profits for firms under the no vertical integration and vertical integration models are all given in the paper. Consumer surplus can be obtained in the following way.

$$\begin{aligned} CS = &\int_0^{\tau^c} \left(v(\tau^c) - \frac{\psi(x)}{r}\right) dF(x) + \tau^c \left[\int_0^{\theta_{\mathcal{D}}^c} \Big(V + \theta s_I - P_I\Big) d\theta + \int_{\theta_{\mathcal{D}}^c}^1 \Big(V + \theta s_E - P_E\Big) d\theta\right] \\ &+ (1-\tau^c)\left[\int_0^{\theta_{\mathcal{ND}}^c} \Big(V + \theta s_I - P_I - \frac{1}{\gamma D_I}\Big) d\theta + \int_{\theta_{\mathcal{ND}}^c}^1 \Big(V + \theta s_E - P_E - \frac{1}{D_E}\Big) d\theta\right]. \end{aligned} \tag{2.14}$$

For simplicity, I make parametric assumptions as $\tau_i \sim U[0,1]$, $\psi(\tau_i) = \lambda \tau_i^2$ where $\lambda > 2$, $r = 1$, and $v(\tau^c) = 1 + \tau^c$; in addition, $V = 2$. The main focus here is to determine how data-driven vertical integration affects consumer surplus and total social welfare, so I focus only on the parametric space in which vertical integration can always occur, i.e., $\underline{\tau} < \tau^c < \bar{\tau}$. First, I examine how consumer surplus from sellers is affected by vertical integration. Figure 2.5 shows data acquisition equilibria under a different parametric space. As shown in Section 2.3.1, $\tau^c = \frac{\sqrt{4\lambda+1}+1}{2\lambda}$ in this example, which means that consumer surplus is a function of λ, which is the marginal privacy nuisance cost. Given that $\tau^c > \tau_V$ leads to integration with E in equilibrium, there exists a threshold on marginal privacy nuisance cost λ, say $\bar{\lambda}$, below which

$\tau^c > \tau_V$.[26] As in Figure 2.6, the consumer surplus under (B, N), which arises from vertical integration with I, is always lower than that under (N, B), which arises from vertical integration with E, if $s > \bar{s}$. Thus, if s is sufficiently large, the consumer surplus under integration with E is always greater than that under vertical integration with I. The comparison between different social welfare levels generates a qualitatively similar result.[27] In other words, the integration with the incumbent is welfare-reducing if s is sufficiently large.[28]

Proposition 2.5. *Data-driven vertical integration with the incumbent makes a consumer worse off than either no vertical integration or vertical integration with the entrant if the entrant's product quality is sufficiently higher than the incumbent's.*

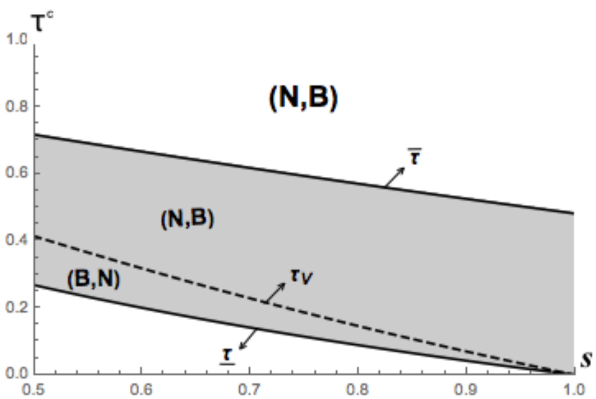

Figure 2.5 (s, τ^c) space when $\gamma = 2$

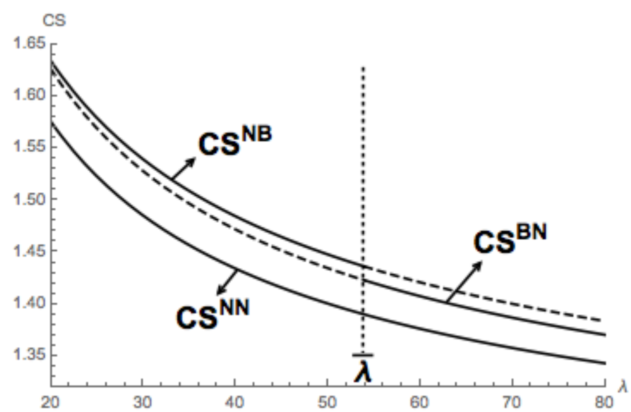

Figure 2.6 CS Comparison if $s > \bar{s}$ and $\gamma = 2$

The welfare analysis result implies that consumers' privacy concern, which determines the aggregate amount of information availability, not only harms the entrant in a disproportionate

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[26] $\bar{\lambda} = \dfrac{(\gamma-1)\left(3\sqrt{\gamma^2((s-2)s+9)+2\gamma(s-9)+9}+\gamma(s+7)-7\right)}{2(\gamma(s-2)+2)^2}$, which can be derived from $\tau_V = \tau^c = \dfrac{\sqrt{4\lambda+1}+1}{2\lambda}$.

[27] Note that the threshold that leads to Proposition 2.5 is $s > \bar{s} \equiv \dfrac{(4\lambda+15\sqrt{4\lambda+1}+1)\left(\gamma^2-1\right)}{4\lambda\gamma(5\gamma-4)}$. The only difference is the threshold $\bar{s}$, which guarantees $SW^{NB} > SW^{BN}$: $s > \bar{s}^{SW} \equiv \dfrac{(20\lambda+3\sqrt{4\lambda+1}+5)\left(\gamma^2-1\right)}{4\lambda\gamma(7\gamma-2)}$ guarantees that $SW^{NB} > SW^{BN}$.

[28] Note that the consumer surplus level under (N, N), which is the no data selling regime that never arises in equilibrium, attains the lowest level.

way but may also adversely affect consumers themselves. If there is a high privacy concern, so that only limited information becomes available, the platform and the incumbent are likely to integrate and foreclose the entrant from data access. Data foreclosure obviously harms the entrant in terms of lower market share and profit, as I have shown in Proposition 2.4. Moreover, the welfare result shows that data foreclosure ultimately makes consumers worse off although they make individually rational information disclosure decisions.[29]

2.6 Empirical Evidence and Policy Implications

So far, I have shown that privacy concerns and the resulting decrease in available information not only harm the entrant but also make consumers worse off. In that sense, any policy that encourages consumers' voluntary information disclosure is socially desirable. If the platform clarifies how user data are used and the potential benefit of disclosing information, more consumers will be able to understand the benefit and make a better decision: a more transparent and easy-to-read data usage policy will allow more consumers to discern any potential benefit, which will increase the immediate benefit $v(\tau^c)$ in the utility of the platform.

In addition, if the data collector can decrease users' privacy nuisance cost, it would also help to increase the amount of information available. From the utility specification in (2.1), which assumes that consumers' concern for privacy is asymmetric with respect to firm reputation, one way to reduce the nuisance cost is to increase the data collector's reputation. In reality, as I show in this section, a consumer has an asymmetric privacy concern with respect to the data collector's reputation: consumers are more likely to agree to app developers' data usage policy if the developers are relatively well-known rather than unknown. Therefore, if the platform's reputation as a data collector plays a significant role in increasing information disclosure, any policy that helps the platform build its reputation would be socially desirable.

In this section, I focus on policies that decrease privacy nuisance cost, especially reputation-

[29] Even if there is no vertical integration, a decreased amount of information results in the incumbent buying data as well, which makes the entrant worse off.

based remedies. To determine whether, in reality, consumers care about privacy when choosing a product and to explore how likely it is that a consumer's willingness to provide information is trust-based (related to the data collector's reputation), I analyze the mobile application ecosystem, using Kummer and Schulte (2017) as a key reference. Specifically, I used *Python* to scrape the necessary data from the Google Play Store, which is the official application (app) store for the Android operating system. Since users browse and download apps directly from this website, it provides all necessary app-specific information, such as price, category, and app size. Moreover, the Google Play Store provides information on which permissions each app requests, and thus, users can see those permissions before downloading apps. There are a number of different groups for each permission, such as Device and App History, Identity, Contacts, and Location. For example, *Google Photos* asks users for access to three pieces of information about Identity, three about Contacts, two about Location, and 27 different pieces of information about other groups. Thus, users can see the details regarding these permissions and decide whether to download an app.

More specifically, as privacy concerns are closely related to a user's trust in data collectors, this effect might be stronger for small app providers that lack a market reputation, while app providers that have an excellent reputation would not experience any negative effects from unnecessary permissions. Therefore, the focus here is to examine whether there is any asymmetric effect of privacy concerns with respect to a firm's size or reputation, even after controlling for app-specific characteristics and other relevant factors that affect app demand.

2.6.1 Data and Summary Statistics

I gathered the data from the end of October 2016 to the middle of January 2017 on a weekly basis, yielding a total sample size of 10,737.

First, a measure of app demand and the number of privacy-related permissions that each app requests are necessary to analyze the asymmetric effect of privacy concerns on consumer demand. For app demand, I use the number of reviews for each app as a proxy demand measure

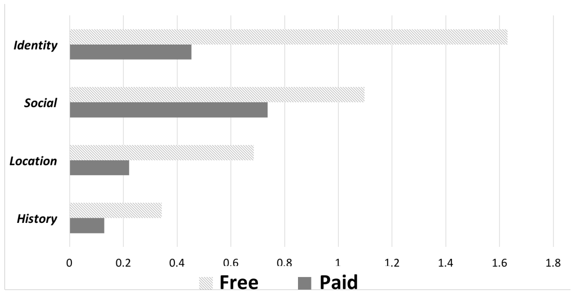

Figure 2.7 The most frequent permissions on average

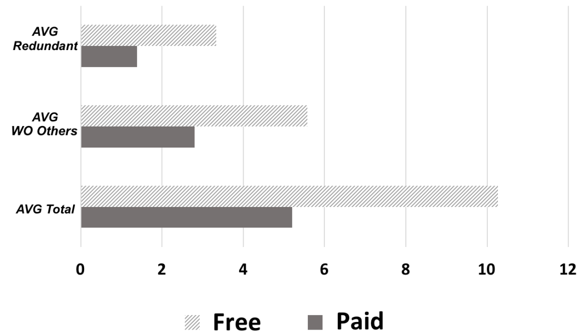

Figure 2.8 The number of privacy-sensitive permissions

because it represents at least the lower bound of demand, as some portion of customers who download each app write a review.[30] Regarding the number of permissions, Google provides 17 categories of permission groups, such as Device & App History, Identity, Contacts, and Location, from which each app developer can choose. Each app developer then might have several different permissions for each category. Among the 17 categories, "Other" represents manufacturer- or app-specific custom settings that include permissions that are relatively insignificant to privacy. Figure 2.7 shows that "Identity (Identity and Contact)", "Location", "Social (SMS and Phone)", and "Device & App History" are the most frequent critical permission groups requested by apps on average.[31]

Furthermore, as Kummer and Schulte (2017) mention in their paper, the data show that there are some unnecessary permissions that do not affect app function. These redundant permissions might be used for monetizing purposes and therefore might increase consumer reluctance to download the app due to privacy concerns.[32] Moreover, as shown in Figure 2.8, free apps request more permissions than paid apps on average, which raises the concern that app developers have ulterior motives for providing free apps.

Finally, I use a set of app-specific characteristics as control variables to estimate app demand.

[30] Kummer and Schulte (2017) also partly use the number of reviews as a demand measure.

[31] According to Sarma et al. (2012) and Olmstead and Atkinson (2015), those four permission groups are part of privacy-sensitive permissions or related to access to user information.

[32] See Kummer and Schulte (2017) for a more detailed description of redundant permissions. For example, although a GPS/navigation app needs to access location information to function properly, information on a user's web browsing history would not be necessary.

Table 2.1 Summary statistics

Variable	Mean	Std. Dev.	N
ln_reviews	10.741	2.938	10,737
ln_App_Age	6.568	1.123	10,737
D_Price	0.421	0.494	10,737
Avg_rating	4.301	0.357	10,737
Top_Dev	0.518	0.5	10,737
Number_of_screenshots	13.179	6.447	10,737
Num_of_apps_per_dev	4.024	6.131	10,737
Per_Inapppurchase	0.391	0.491	10,737
Per_DeviceandApphistory	0.253	0.568	10,737
Per_Identity	0.562	0.793	10,737
Per_Contacts	0.593	0.865	10,737
Per_Calendar	0.084	0.373	10,737
Per_Location	0.495	0.820	10,737
Per_SMS	0.241	0.829	10,737
Per_Phone	0.723	1.017	10,737
Totalpermissions	15.649	10.585	10,737
Dum_Location	0.299	0.458	10,737
Dum_Social	0.570	0.495	10,737
Dum_Identity	0.509	0.5	10,737
Dum_Browsing	0.198	0.399	10,737

These include price, app age since release date, average app rating, app size, a dummy for game apps, the number of screenshots on the app description page, the total number of distinct apps that each developer provides, and a dummy variable for top developer status. The top developer variable takes a value of one if the Google Play Store grants "Top Developer" status to the app. The selected set of variables is summarized in Table 2.1, where $Per\_$ denotes the number of permission-related variables. $Dum\_$ denotes a dummy variable for whether an app requests at least one permission related to Location, Social, Identity, or Browsing History. I use log-transformed variables for the number of reviews (as a demand measure) and for app age.

2.6.2 Empirical Model and Results

I estimate how the privacy-sensitive permissions affect app demand based on a pooled cross-sectional sample. The empirical model is as follows.

$$\begin{aligned} \text{ln\_reviews}_i = \beta_0 + \beta_1 \text{Dum\_privacy}_i + \beta_2\, \text{Top\_Dev}_i + \beta_3\, \text{Dum\_privacy}_i \times \text{Top\_Dev}_i \\ + \delta\, \text{ln\_Price}_i + \boldsymbol{\xi} X_i + \epsilon_i, \end{aligned} \tag{2.15}$$

where i denotes each app, Dum_privacy_i takes one if an app requests at least one permission regarding Identity, Social, Location, or Browsing History, Top_Dev_i is a dummy variable for top developer status, β_3 is the coefficient of interest that identifies the interaction effect of the top developer and privacy-sensitive permissions, and X_i is a set of app-specific characteristics used as control variables. The dependent variable, which is a proxy for app demand, is the log-transformed number of reviews for each app.

Table 2.2 reports the results. The first column does not include any app-specific characteristics as controls, while the remaining columns do include them. The second column does not take into account price endogeneity, whereas column (3) uses BLP type instruments as a remedy for potential price endogeneity.[33] The fourth and fifth columns are based on the Inverse Probability Weighting (IPW) estimation. The problem with the cross-sectional analysis is that the treatment variable, Dum_privacy, could be endogenous and could be correlated with unobservables relegated to the error term: an app may ask for more permissions for better functionality, which might mean high quality. To control for this potential non-random treatment problem, I use the IPW method. I first use a probit model to estimate the probability of having at least one privacy-sensitive permission for each app. Then, I use the predicted probabilities as weights to estimate the effect of privacy-sensitive permissions on the app's demand. All columns include time- and category-specific fixed effects.

As an app requests privacy-sensitive permissions ($Dum\_privacy = 1$), lower demand is observed across all regressions, except for the first column, in which no controls are added. In-

[33] I use standard instruments including the characteristics of competing products. The instruments correct an upward bias of the price coefficient, thereby leading to more negative coefficients.

Table 2.2 Results from the Cross-Sectional Data

VARIABLES	(1) No Controls	(2) Controls	(3) IV	(4) IPW OLS	(5) IPW IV
Dum_privacy_Top_Dev	0.670***	0.560***	0.544***	0.743***	0.580***
	(0.0979)	(0.0798)	(0.122)	(0.0823)	(0.166)
Dum_privacy	0.0547	-0.182***	-0.177***	-0.367***	-0.437***
	(0.0636)	(0.0555)	(0.0622)	(0.0651)	(0.106)
Top_Dev	0.909***	0.422***	0.460**	0.221***	0.708**
	(0.0863)	(0.0713)	(0.213)	(0.0694)	(0.320)
Constant	11.47***	-1.248***	-1.301**	-0.615	-1.278*
	(0.0599)	(0.433)	(0.517)	(0.537)	(0.760)
Controls	No	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Category FE	Yes	Yes	Yes	Yes	Yes
Observations	10,737	10,737	10,737	10,737	10,737
R-squared	0.495	0.692	0.690	0.699	0.299

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

terestingly, this effect is mitigated for apps launched by top developers, which have a stronger market reputation. For example, from the third column, having at least one privacy-sensitive permission for a non-top developer that has a lower reputation relative to top developers corresponds to a decrease in app demand of approximately 17.7%. However, for top developers, the same change is associated with a 36.7% increase in demand.[34] The estimation results show that there is an asymmetric reputation effect from privacy concerns with respect to a firm's status in the market. This empirical evidence corroborates the assumptions that are imposed throughout the paper and supports a policy remedy that I suggest below.

As mentioned earlier, any remedy that makes more people willing to disclose information or be more privacy-insensitive, leading to integration with the entrant in equilibrium, is socially optimal. A privacy certification program represents one such remedy given the empirical evidence, which shows that a data collector's reputation significantly reduces consumers' privacy concerns and ultimately increases their willingness to disclose personal information. If a credible institution grants a certificate indicating that firms comply with government-enacted

[34] See Table B.1 for the full results from the cross-sectional data in Appendix. For the robustness check, I use the pure cross-sectional data and the sample with twin apps only—as in Kummer and Schulte (2017)—and check the qualitatively same sign. The results are reported in Tables B.2 and B.3 in Appendix.

privacy rules, marginally privacy-sensitive consumers who refuse to provide information due to possible data abuse might switch and decide to disclose personal information. Although there are a few private firms, such as *TRUSTe*, that serve a similar function, their certifications indicate only self-certification at best. A credible certification program could serve as a global standard that helps participating firms to increase their reputation regarding data usage. As the empirical evidence has shown, privacy is a trust-based matter in that consumers care about who asks for their personal information. Because willingness to disclose information depends on a firm's reputation, this remedy is likely to be effective. This policy suggestion is consistent with the policy implications in some previous literature (e.g. Campbell et al. (2015), Kummer and Schulte (2017)).[35]

2.7 Extensions

2.7.1 Consumers with Foresight

Thus far, I have assumed that a consumer only takes into account immediate benefits when making information disclosure decisions but does not consider any potential future benefits arising from better targeted ads. Though this assumption is reasonable for the case of a social media platform, it is worth showing what happens if consumers have perfect foresight when making decisions: if they are sophisticated enough to recognize that greater personal data availability on the platform will lead to more relevant personalized ads, they might take this potential effect into consideration.[36] To capture this effect, I consider the total net utility that each consumer obtains from using the platform and from purchasing a product. For simplicity, I normalize the immediate benefit from using the platform to zero, which means that each

[35] The Cyber Shield Act of 2017, which is a recently introduced bill, is in the same vein.

[36] Using cable TV operators or Internet service provider(ISPs) as examples of the platform, whether to disclose personal information means opting in or out of targeted ad programs. Even in this example, there can be an immediate benefit from disclosing information other than targeting benefits—e.g., AT&T used to offer a monthly discount in exchange for being allowed to collect personal information. Without such a price discount, the immediate benefits in this example might not be obvious compared to the social media platform examples. Thus, in this case, a consumer is likely to take into account future potential targeting benefits when making an information disclosure decision.

consumer compares the privacy nuisance cost to the potential mismatch cost when making information disclosure decisions.[37] The aggregate utility specification is as follows.

$$u_{ij}^{\text{Foresight}} = V + \theta_i s_j - P_j - \mathbb{1}_{\{i \in \mathcal{ND}\}}\Big(\frac{1}{\gamma_j D_j}\Big) - \mathbb{1}_{\{i \in \mathcal{D}\}}\Big(\frac{\psi(\tau_i)}{r}\Big). \tag{2.16}$$

Working backward, P_j and X_j are the same as previously. $P(i \in \mathcal{D})$, which is determined in the first stage, can be implicitly derived as follows.

$$\begin{aligned} P(i \in \mathcal{D}) = \tau^c &= \theta^c P(i \in \mathcal{D} | i \in \mathcal{L}) + (1 - \theta^c) P(i \in \mathcal{D} | i \in \mathcal{H}) \\ &= \theta^c F\Big(\psi^{-1}\big(\frac{r}{\gamma D_I}\big)\Big) + (1 - \theta^c) F\Big(\psi^{-1}\big(\frac{r}{D_E}\big)\Big), \end{aligned} \tag{2.17}$$

where θ^c, which is a function of τ^c, is given as in Equation (2.6). Because consumers are assumed to be sufficiently sophisticated, the disclosure probability now depends on each seller j's targeting effectiveness, which implies that $P(i \in \mathcal{D})$ can differ depending on the information acquisition equilibrium. By comparing the right-hand side of Equation (2.17), I can rank different τ^c levels depending on each data acquisition equilibrium. Given that D_j can be either one or $1 + \tau^c$, it is easy to show that τ^c_{BB} is the lowest, whereas τ^c_{NN} is the highest, where the subscript denotes the data acquisition equilibrium. In other words, knowing that a seller acquires personal data, a consumer becomes reluctant to disclose information. The relative size of τ^c_{NB} and τ^c_{BN} depends on γ and s. Put simply, $\tau^c_{NB} > \tau^c_{BN}$ is more likely to hold as γ increases given s or as s decreases given γ. That is, anticipating that E is the only data holder, a consumer becomes more willing to disclose personal information as I's targeting technology improves or E's product quality advantage shrinks. Since $X_E = 1 - \theta^c$ decreases as s decreases or γ increases, the effect of E's data-buying decision becomes smaller, which leads to $\tau^c_{NB} > \tau^c_{BN}$. That is, if the total demand for the seller is small, the effect of data acquisition on τ^c is negligible.

[37] The normalization of immediate benefits to zero is harmless, since it does not change the qualitative results.

Proposition 2.6. *If a consumer has perfect foresight, the equilibrium disclosure probability is lowest when both sellers buy personal data, whereas it is highest when neither buys. The relative size of τ^c_{NB} and τ^c_{BN} depends on the size of γ and s.*

Next, to check the robustness of the main findings, I compare consumer surplus levels under numerical examples. I focus on the relative size of the consumer surplus under the asymmetric data acquisition cases where only one seller buys data. I find that as data become more available, consumer surplus increases. For example, if s is sufficiently small and γ is large so that $\tau^c_{BN} < \tau^c_{NB}$ holds, the ranking of consumer surplus levels is $CS^{BN} < CS^{NB}$: I's monopoly of the data makes consumers worse off. Intuitively, if τ^c_{NB} is sufficiently large, E is able to make better targeted ads using a more extensive amount of detailed data, thereby leading to a lower mismatch cost. Though s is small, which implies that a consumer cannot enjoy more utility through product quality, a consumer is overall better off because of the sufficiently low mismatch cost stemming from greater information availability: regarding the increasing consumer surplus, the effect of the low mismatch cost dominates that of a high-quality product.

Though $CS^{BN} < CS^{NB}$ can still hold under this extension, the driving force is different. In the main model, $CS^{BN} < CS^{NB}$ holds if E's product quality advantage is sufficiently great, i.e., $s > \bar{s}$. Here is the intuition. Given that the amount of data that can be used for targeting is fixed, a higher s generates a consumer benefit, as consumers enjoy high-quality products. Also, if E buys data, thereby sending more relevant ads, a consumer can also save through a lower mismatch cost. Therefore, if high-quality product seller E buys data and is thus able to generate better targeted ads, the additional utility outweighs the high price that a consumer will be paying E, thereby leading to greater consumer surplus. However, in the model with sophisticated consumers, a higher s is likely to lead to E having a lesser amount of data available for targeting, i.e., $\tau^c_{BN} > \tau^c_{NB}$. Then, even if a consumer enjoys a high-quality product, he will face a higher mismatch cost from E due to the lack of data, which might result in $CS^{BN} > CS^{NB}$: the additional utility from a high-quality product that also incurs a high mismatch cost is comparably lower than that from a low-quality product accompanied by a lower mismatch cost. The key point here is that if s is not that high, say $s < \bar{\bar{s}}$, we can obtain $CS^{BN} < CS^{NB}$ as in the main model: if s is not that high, τ^c_{NB} will decrease only a little bit, which means that $\tau^c_{BN} < \tau^c_{NB}$ still holds. Under $\tau^c_{BN} < \tau^c_{NB}$, E's exclusive use of data leads to a greater consumer surplus level than in the other case. In other words, for $\bar{s} < s < \bar{\bar{s}}$, a consumer is better off if the platform and E integrate and use data exclusively, which has implications similar to those identified in the main model.[38]

Lastly, comparative statics can be calculated to see how the implicitly determined equilibrium τ^c is affected by exogenous parameters, such as γ and s. By applying the implicit function theorem to Equation (2.17), it is easy to see that $\frac{d\tau^c}{d\gamma} < 0$ while $\frac{d\tau^c}{ds} > 0$ for any τ^c from each data acquisition equilibrium. In other words, more consumers are willing to disclose personal data as I's initial targeting technology becomes less effective or E's product quality improves. The intuition is that as γ becomes close to one, both sellers provide less relevant targeted ads because they lack personal data. Knowing that, a consumer becomes more willing to provide personal information to allow both sellers to send better targeted ads, thereby lowering the mismatch cost. Also, if s increases, the products provided by the two sellers become more differentiated, which leads to soft price competition. In this case, one way for a consumer to save costs is to provide more personal data and incur a lower mismatch cost. Proposition 2.7 summarizes the finding.

Proposition 2.7. *Consumers are more willing to disclose personal data as I's initial targeting technology becomes less effective or E's product quality improves.*

The findings in this subsection provide an important policy implication: if a consumer has perfect foresight and thus takes into consideration any potential benefits from better targeted ads when determining his or her level of information disclosure, any policy that encourages market entrants to upgrade their product quality would encourage consumers to voluntarily

[38] See Appendix for detailed numerical exercise.

provide their personal information, thereby leading to socially optimal market outcomes—integration with E and the (N, B) data acquisition equilibrium, for example.

2.7.2 Endogenous Entry

In this section, I consider a variation of the model by introducing a fixed cost of entry for the entrant. Thus, the entrant is allowed to stay out of the market if the expected profit is lower than the entry cost. The timing of the game is modified accordingly in that the entrant decides whether to enter the market in the very first stage. Denoting the fixed entry cost as FC, the relevant thresholds of FC below which the entrant enters the market can be obtained as follows: $\overline{FC}_{BB} = \pi_E^{BB}$; $\overline{FC}_{NB} = \pi_E^{NB}$; $\overline{FC}_{BN} = \pi_E^{BN}$. In other words, if the fixed cost is higher than the equilibrium profit, the entrant stays out of the market. For simplicity, I focus on a relatively small range of γ, which leads to $\overline{FC}_{BN} < \overline{FC}_{BB} < \overline{FC}_{NB}$.[39] Then, there are four possible cases for the entrant: (1) staying out in any case if $FC > \overline{FC}_{NB}$, (2) staying out under (B, B) or (B, N) but entering under (N, B) if $\overline{FC}_{BB} < FC < \overline{FC}_{NB}$, (3) staying out under (B, N) but entering under (B, B) or (N, B) if $\overline{FC}_{BN} < FC < \overline{FC}_{BB}$, and (4) entering in any case if $FC < \overline{FC}_{BN}$. Focusing on this parametric space, I analyze how the entrant's entry decision affects the market.

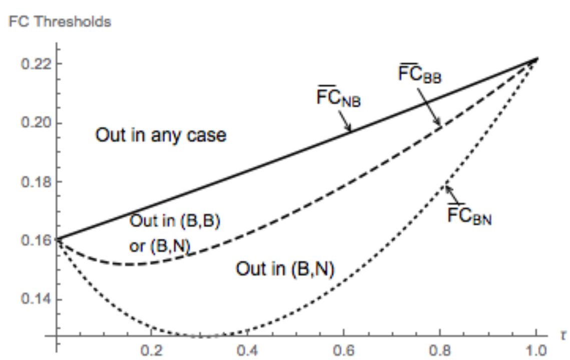

Figure 2.9 Entrant's entry decision depending on the fixed cost thresholds

As in Figure 2.9, (B, N) (or (N, B)) is the most (or least) likely to lead to entry foreclosure

[39] As γ becomes larger, $\overline{FC}_{NB} < \overline{FC}_{BB}$. However, $\overline{FC}_{BN}$ is always the lowest, which implies the same messages as in Proposition 2.8.

whereas (B, B) is somewhat in the middle. That is, vertical integration with the incumbent and the resulting data foreclosure, which means (B, N), is highly likely to lead the entrant to stay out of the market due to lower profit when entering. When both sellers buy data, which means (B, B), the entrant is more likely to enter than in the case of (B, N). Obviously, when the entrant is able to use data exclusively, which means (N, B), it is the most likely to enter the market. Proposition 2.8 summarizes this finding.

Proposition 2.8. *When the entrant faces a fixed cost of entry, it is least likely to enter the market if vertical integration with the incumbent and the consequential data foreclosure emerges in equilibrium.*

To see how entry foreclosure affects the market outcome, I first derive the monopoly market equilibrium. Given that the entrant stays out, the incumbent can monopolize the market. The monopoly market share is determined by $P(\theta > \frac{\mathbb{1}_{\{i \in \mathcal{ND}\}}(\frac{1}{\gamma D_I}) + P_I - V}{s_I})$, which means that $X_{\mathcal{ND}}^{Mono} = 1 - \frac{\frac{1}{\gamma D_I} + P_I - V}{s_I}$ and $X_{\mathcal{D}}^{Mono} = 1 - \frac{P_I - V}{s_I}$ from the utility specification as in (2.2). Given the weighted monopoly market share, the incumbent maximizes its profit by charging the monopoly price at $P_I^{Mono} = \frac{\gamma D_I (s_I + V) + \tau^c - 1}{2\gamma D_I}$, which leads to $X_I^{Mono} = \frac{\gamma D_I (s_I + V) + \tau^c - 1}{2\gamma D_I}$. Specifically, the equilibrium profit levels under buying and not buying data from the platform can be derived as follows.

$$\pi_B^{Mono} = \frac{(\gamma(\tau^c + 1)(s_I + V) + \tau^c - 1)^2}{4\gamma^2(\tau^c + 1)^2} - C^{Mono} \times \tau^c; \quad \pi_N^{Mono} = \frac{(\gamma(s_I + V) + \tau^c - 1)^2}{4\gamma^2}, \tag{2.18}$$

where the subscripts B and N denote Buy and Not buy, respectively. Comparing two profit levels, the platform optimally sets the data price at C^{Mono} which is derived from $\pi_B^{Mono} - \pi_N^{Mono}$, meaning that $\pi_p^{Mono} = C^{Mono} \times \tau^c$. Under the monopoly, π_B^{Mono}, π_N^{Mono}, and π_p^{Mono} are all greater than the corresponding profit levels under all possible data acquisition equilibria without considering entry. However, a consumer obviously becomes worse off under the monopoly.

Proposition 2.9. *If the entrant does not enter the market due to lower profits, the incumbent monopolizes the product market. The monopoly leads to greater profits for the incumbent and the platform in most cases, but the consumer becomes worse off.*

In other words, if the entrant needs to pay the fixed cost of entry, vertical integration with the incumbent, which is most likely to lead to monopoly in the product market, is welfare-reducing.

2.7.3 Data Price Discrimination

So far, I have assumed that the platform charges a unit data price for all sellers. However, since the platform knows that sellers I and E have asymmetric targeting technology, it might be able to engage in data price discrimination: it might want to charge a higher data price for any seller whose willingness to pay is higher. I investigate how the platform's data price discrimination affects the market's competitive structure in this subsection.

Assuming that the platform extracts all rents from sellers in the form of data price C, data price discrimination can emerge only if both sellers buy data. Given that rivals also buy data, I and E want to buy as well if $C < \bar{C}_I$ and $C < \bar{C}_E$, respectively, where $\bar{C}_I < \bar{C}_E$. In other words, E, whose initial targeting technology is worse, has higher willingness to pay for data to overcome the disadvantage. Knowing that, the platform can charge different prices to both sellers: $C = \bar{C}_I$ to I and $C = \bar{C}_E$ to E. Then, the platform's profit is $\pi_p^{PD,BB} = \bar{C}_I + \bar{C}_E$, where the superscript PD denotes price discrimination. By the same logic as in subsection 2.3.1, the platform either chooses to sell data to both sellers with different price levels or to E only by charging $\bar{\bar{C}}_E$. The difference in profits is as follows.

$$\pi_p^{PD,BB} - \pi_p^{NB} = \frac{(1-\tau^c)\tau^c\left(2\gamma\left(s(\tau^c+1)+(\tau^c-1)^2\right)+(\tau^c)^2+\tau^c-2\right)}{9\gamma^2 s(\tau^c+1)^2} \tag{2.19}$$

From Equation (2.19), if $2\gamma\left(s(\tau^c+1)+(\tau^c-1)^2\right)+(\tau^c)^2+\tau^c-2>0$, the platform wants to engage in price discrimination and sell data to both sellers. It is easy to show that the left-hand side is increasing in γ and s, respectively, and its local minimum is attained at $\tau^c = \frac{-2\gamma(s-2)-1}{4\gamma+2}$.

Thus, the minimum value is $\frac{2}{3}$, which can be attained from $\tau^c = \frac{1}{3}$ with $s = \frac{1}{2}$ and $\gamma = 1$. This implies that $2\gamma\left(s(\tau^c+1)+(\tau^c-1)^2\right)+(\tau^c)^2+\tau^c-2 > \frac{2}{3}$, which leads to $\pi_p^{PD,BB} > \pi_p^{NB}$. Consequently, if data price discrimination is allowed, the platform always sells data to both sellers, thereby making the entrant worse off in terms of lower market share and revenue. Moreover, the entrant now faces much lower profit than before due to a higher data price.

Proposition 2.10. *If the platform engages in data price discrimination, (B, B) emerges in data acquisition equilibrium and the platform charges $C = \bar{C}_I$ to I and $C = \bar{C}_E$ to E. Data price discrimination always makes the entrant worse off in terms of profit.*

2.8 Conclusion

In this paper, I analyze how consumers' privacy concerns affect market competition when each seller attracts potential customers by creating targeted ads based on personal information obtained from a platform. In particular, I focus on the relationship between privacy sensitivity and the data-sharing aspects of vertical integration between the platform and the seller. I show that the platform and the incumbent with better initial targeting technology are more likely to vertically integrate as the number of privacy-sensitive consumers increases. The integrated firm always wants to prevent access to the data by the unaffiliated entrant, thereby adversely affecting the entrant in terms of smaller market share and lower profits. Therefore, the entrant that needs consumer data to overcome its initial disadvantage in targeting technology is disproportionately affected by a lack of access to data arising from greater privacy concerns. Moreover, this process eventually leads to lower consumer surplus and lower total social welfare due to the lack of competition arising from data foreclosure.

The extended models also investigate aggravating factors: data price discrimination and an entrant's entry decision due to entry cost make the entrant and consumers worse off. Consequently, individually rational decisions on information disclosure, which depend on each consumer's privacy sensitivity, might not be socially optimal when aggregated.

Therefore, any policy that encourages integration with the entrant would be beneficial. In this sense, any remedy that makes more people willing to disclose information or reduces privacy concerns is socially optimal because it leads to integration with the entrant in equilibrium. One specific remedy I propose in the paper is a privacy certification program. It is worth mentioning that if consumers have perfect foresight and thus take into account future targeting benefits when making information disclosure decisions, policy makers need to consider that the willingness to disclose information then depends on targeting technology and product quality.

There is another policy implication regarding data foreclosure practices in vertical integration. Since consumer data have become key to sellers' business performance, data foreclosure is directly related to the competitive structure. This anti-competitive effect is more apparent in the case of integration with an incumbent. To mitigate this detrimental effect, regulators might force the integrated firm to share customer data with its rivals by asking that the price of data be set within a reasonable range to guarantee the efficient level of data availability.[40]

Broadly speaking, this paper emphasizes that lower privacy concerns lead to greater information availability, which, in turn, reduces barriers to entry to the marketplace. This main implication can be applied to a much broader but analogous competitive setup and supported by similar empirical research: e.g., Petrova et al. (2017) empirically show that more information channels, such as Twitter, benefit new politicians more than incumbents by reducing the gap in political donation opportunities between new and experienced politicians. Although privacy and information availability are potentially important areas to investigate in order to encourage competition, regulators have not yet established any concrete antitrust standards regarding this complex interaction. In that sense, the findings from my model help to understand the relevant issues and propose various policy implications regarding privacy protection and data-driven vertical integration.

[40] For example, U.S. media companies plan to request such a data-sharing-related regulation in response to the AT&T and Time Warner merger.

CHAPTER 3

ZERO-RATING AND VERTICAL CONTENT FORECLOSURE

3.1 Introduction

Internet service providers (ISPs) offer a large variety of subscription plans to consumers, many of these consisting of a periodic fee and overage charges for exceeding a predetermined limit or cap on data consumption. Among mobile wireless ISPs like Verizon Wireless, a typical plan involves a monthly fee H for X GB of data and an overage charge for each additional Y GB of data beyond X GB.[1] Home Internet service providers have also started to limit the service that their monthly subscription fee buys, but the limits are typically much higher than those of mobile wireless providers.[2]

In this manuscript, we study a hybrid pricing strategy that several ISPs have introduced to distinguish their service offers whereby the ISPs do not subject a subset of available content to caps or overage charges. Such content is said to be zero-rated, meaning that its consumption is not counted when tabulating consumers' monthly data consumption toward or beyond the cap. Additionally, ISPs may offer to zero-rate certain content providers' data in exchange for a fee, a practice referred to as sponsored data.

There are numerous examples of zero-rating and sponsored data programs. For example, under Verizon's "Go90" and "FreeBee" sponsored data programs, content providers (CPs) pay Verizon to zero-rate their content.[3] Similar, T-Mobile's "Binge On" allows consumers to watch unlimited HBO, Hulu, Netflix, Sling TV, and other content without eating into their data allowances. To offer the service, T-Mobile reduces video quality to 480p+, but does not collect

[1] Periodically, mobile wireless providers instead offer unlimited service plans, but plans with data caps remain common (FCC 2017c ¶¶50-51).

[2] For example, Comcast, which currently uses data caps, caps usage at a terabyte of Internet data. Comcast claims that more than 99 percent of customers do not use a terabyte of data. See XFINITY. XFINITY Data Usage Center, Frequently Asked Questions. Available at https://dataplan.xfinity.com/faq/.

[3] See Verizon, go90 FAQs. Available at https://www.verizonwireless.com/support/go90-faqs/; Verizon, Free-Bee Data, What is FreeBee DataFigure Available at https://freebee.verizonwireless.com/.

fees from video providers.[4] Comcast's Stream TV service presents an example of zero-rating by an ISP that is vertically integrated into content. Stream TV competes with other streaming services like Amazon Video, Hulu, and Netflix, but does not count toward Comcast's data allowance (see Comcast 2016; Public Knowledge 2016). More generally, any ISP that sets a cap on Internet service but also provides other content using a means beside the Internet (i.e., cable) effectively zero-rates the other content.

On the surface, zero-rating appears to benefit consumers by allowing them to consume certain content without being concerned about overage charges. In principle, this can increase broadband consumption and foster greater innovation and competition among CPs. Nevertheless, zero-rating has spurred a heated debate over its merits among scholars, public interest groups, and industry advocates,[5] and raised regulator concerns as a potentially harmful discriminatory practice. For instance, possibly worried that zero-rating was a violation of net neutrality antidiscrimination principles, the Federal Communications Commission (FCC) in 2016 conditioned its approval of the merger between Charter Communications and Time Warner on an agreement that the parties not impose data caps or usage based pricing and in 2017 released a report (later retracted) putting forward a framework for evaluating mobile zero-rated offerings (see FCC 2016 ¶457, FCC 2017a, b).[6] Taking a sterner approach, in 2016, India prohibited data service providers from offering or charging different prices for data—even if it is free. This had the effect of banning Facebook's Internet.org Free Basics program, which provided a pared-down version of Facebook and weather and job listings.[7] Similarly, regulators in Canada, Chile, Norway, the Netherlands, and Slovenia have made explicit statements against zero-rating

[4] T-Mobile, Binge On. Available at https://www.t-mobile.com/offer/binge-on-streaming-video.html.

[5] Crawford (2015), Drossos (2015), and van Schewick (2015, 2016) argue that zero-rating is an anti-competitive violation of net neutrality, whereas Brake (2016), Eisenach (2015), and Rogerson (2016) view the practice as an efficient competitive ISP response to market conditions.

[6] In its 2015 Open Internet Order, the FCC explicitly banned providers of broadband Internet access service from blocking, impairing or degrading, or charging for prioritization of lawful Internet content. However, the FCC has not banned zero-rating, which enables ISPs to discriminate across CPs via consumer pricing without charging CPs different prices for termination.

[7] See Gowen, A. "India bans Facebook's 'free' Internet for the poor." *The Washington Post.* February 8, 2016. Available at https://www.washingtonpost.com/world/indian-telecom-regulator-bans-facebooks-free-internet-for-the-poor/2016/02/08/561fc6a7-e87d-429d-ab62-7cdec43f60ae_story.html?utm_term=.12778fed9821.

as anti-competitive or contravening national net neutrality regulation (OECD 2015). A primary concern is that zero-rating can give an unfair advantage to zero-rated services, allowing ISPs to favor some content over other. Verizon, for instance, excluded its own video streaming service "go90" from data charges, thereby advantaging the service over rival CPs, who would need to pay a fee to register on Freebee in order to be similarly exempt from data overages.

The debate over zero-rating raises several interesting research questions. On what grounds will ISPs and CPs agree to a zero-rating deal if CPs are asymmetric in the quality of content that they provide? Under what conditions is zero-rating harmful or alternatively beneficial to market competition and social welfare? Finally, how does vertical integration together with zero-rating of affiliated content alter competition from rival CPs and how does vertical integration impact ISP incentives to offer sponsored data options?

In attempt to answer the questions above, we set up a model in which a monopolistic ISP offers consumers a three-part tariff consisting of a hookup fee H, data cap L, and linear data overage charge τ, and where two asymmetric CPs sell content to consumers. CPs are asymmetric in terms of the content quality that they provide. CP content is substitutable to some degree. We characterize and compare the set of equilibria when zero-rating is banned as well as when it is permitted with and without monetary transfers. There are two conflicting effects of zero-rating on the ISP's profit, one operating through the hookup fee, the other through the overage charge. Moreover, for each CP, zero-rating not only directly affects content demand, but also indirectly influences demand by affecting the content price. The aggregate effect of zero-rating on both of ISP's and CPs' profits depends on content quality and the degree of content substitutability.

Suppose first that CPs cannot offer monetary transfers for zero-rating. Then, the ISP zero-rates the lower quality CP to take advantage of a higher overage charge for higher quality content. Also, a zero-rating equilibrium emerges under a sufficiently large level of substitutability. The intuition for this result is as follows. If the ISP zero-rates any content if CP content is highly differentiated (low level of substitutability), the loss to ISP from an overage charge that could be charged on low quality content is relatively large: there are distinct demands for both content regardless of content quality. Consequently, the ISP chooses not to zero-rate to take advantage of consumers' relatively inelastic demand if both CPs' content is relatively independent.

If instead, CPs must pay to be zero-rated — i.e. sponsored data programs—, both CPs end up being zero-rated in equilibrium, which we call as full zero-rating in the paper. If content is sufficiently differentiated, both CPs always pay a positive fee for zero-rating, which increases ISP's incentive to lead to full zero-rating. As both CPs' content becomes more substitutable, however, the low quality CP has no incentive to pay a positive fee for full zero-rating. For this high range of substitutability, ISP rather pays a positive subsidy to the low quality CP to have full zero-rating because the fee obtained from the high quality CP is large enough to offset the subsidy paid to the low quality CP.

In Section 3.5, we permit the ISP platform to integrate with one of the CPs. The ISP has an incentive to vertically integrate with the high quality CP. That is because integration with the high quality CP and zero-rating its content lead to greater additional profit from selling content. Moreover, without a monetary transfer, the integrated firm only wants to zero-rate its affiliated content while it optimally does not zero-rate the rival's content in an attempt to vertically foreclose its rival. However, if there is a monetary transfer, full zero-rating can emerge in equilibrium if content is sufficiently differentiated. Thus, as long as there is a monetary transfer for zero-rating, forming a vertical integration does not exclude full zero-rating. Still, the low quality CP can be worse off from the vertical integration because it deprives him of the chance to be zero-rated if not paying for zero-rating.

Finally, we find that full zero-rating is likely to attain the highest level of social welfare because the sum of CPs' profits under full zero-rating is large enough to offset any possible loss to the ISP from full zero-rating. Thus, zero-rating with monetary transfers (sponsored data plan) is welfare-enhancing relative to zero-rating without monetary transfers because the latter does not induce full zero rating. Also, vertical integration is welfare-enhancing than no integration but this result comes at the expense of the unaffiliated CP which loses market share and profit due to the vertical integration and the consequential no zero-rating offer.

The rest of the paper is organized as follows. In Section 3.2 introduces the relevant literature. Section 3.3 provides the basic model setup. Section 3.4 and 3.5 solve the game for no vertical integration and vertical integration, respectively. In Section 3.6, welfare implications are drawn, and the conclusion follows in Section 3.7.

3.2 Literature

Our model setup leans heavily on the framework of Economides and Hermalin (2015), who analyze a monopoly ISP that can impose download limits on rival CPs. Economides and Hermalin show that these limits can place downward pressure on CP prices, permitting ISPs to profit from an increase in demand.[8] Using a variant of the model of Economides and Hermalin (2015) in which content is *ex ante* substitutable (to account for limits on consumers' time that can be devoted to content) we investigate when an ISP might wish to relax download limits. As in Economides and Hermalin (2015), an overage charge leads to lowering content subscription fees. That is, zero-rating that sets zero overage charge allows the ISP to fine-tune how it wants different CPs to behave by adjusting its pricing to consumers. Note that this allows the ISP to discriminate among different CPs without actually charging the CPs different prices for termination.

To our knowledge, there are presently two other working papers, Jullien and Sand-Zantman (2016) and Somogyi (2017), that use economic models of two-sided markets to analyze zero-rating.[9] Both Jullien and Sand-Zantman (2016) and Somogyi (2017) model an ISP that intermediates traffic between consumers and CPs who receive benefits proportional to consumer traffic, but do not charge a retail price for content. Jullien and Sand-Zantman (2016) show that

[8] Downward pricing pressure occurs through one of two mechanisms. First, if caps are binding, then the more binding, the more consumers will perceive the digital products they acquire from different content providers (CPs) as substitutes. This, in turn will increase the competitive pressures on the CPs, who will respond by lowering their prices. Alternatively, if download limits can be exceeded by paying an overage fee, a positive per-unit fee acts like an excise tax that falls on consumers, but whose incidence is split between consumers and CPs.

[9] Additionally, Koning and Yankelevich (2017) briefly analyze zero-rating using a standard model of vertically integrated firms who supply their rivals.

in the absence of regulation, the ISP can use sponsored data to improve efficiency by facilitating the transmission of information between CPs and consumers. In equilibrium, CPs that derive greater benefits from being on the network will sponsor consumption while other providers will reduce their costs by letting consumers pay for traffic. Nevertheless, this mechanism results in socially suboptimal consumption levels because the ISP charges excessive prices to CPs.

As we do, Somogyi (2017) models zero-rating more explicitly than Jullien and Sand-Zantman (2016), by viewing it as a three-part tariff.[10] Somogyi finds that zero-rating is an optimal ISP strategy when CP revenue per click is relatively large, whereas the ISP subscription fee is relatively small.[11] Specifically, in his model, when it is optimal to do so, the ISP trades off serving a greater number of consumers by zero-rating the CP that can extract a higher amount of revenue per click in order to extract revenue from that CP directly. Zero-rating can improve (worsen) consumer surplus and social welfare if content is relatively attractive (unattractive).

Our model differs from both those of Jullien and Sand-Zantman (2016) and Somogyi (2017) along a number of important dimensions. First, in contrast to Jullien and Sand-Zantman (2016), who view content as non-rival and Somogyi (2017), who views it as perfectly substitutable,[12] we view CPs as offering imperfectly substitutable content. Aside from being realistic—many rival CPs offer both exclusive and duplicative content—this allows us to examine how the level of content differentiation influences the desirability and optimality of zero-rating. Second, following Economides and Hermalin (2015), we suppose that CPs can charge consumers directly. Although we acknowledge that there is a significant amount of content available to consumers for free, this modeling choice permits us to focus on major providers of streaming services and to also account for the important case of cable ISPs who set data caps. Third, we distinguish between zero-rating programs with and without monetary transfers to the ISP, allowing us

[10] Broadly speaking, three-part tariffs differ from two-part tariffs in that the former additionally offer allowances of free units of the service. Working outside the two-sided market setting explored in this manuscript, Ascaria, Lambrecht, and Vilcassim (2012) empirically study how three-part tariffs affect customer service usage, Chao (2013) theoretically investigates why they may be offered by a dominant firm in an oligopoly setting, Bagh and Bhargava (2013) find that they can be preferable to more complex menus of two-part tariffs, and Fibich et al. (2015) show how to derive an optimal three-part tariff under general conditions.

[11] Both the revenue per click and subscription fee are exogenous in the most recent version of the working paper.

[12] More accurately, in Somogyi (2017), the content of CPs who can be zero-rated is perfectly substitutable.

to account for the incremental impact of sponsored data on incentives and welfare. Finally, in our manuscript, we extend our results to a scenario where the ISP can vertically integrate into content provision in order to study how zero-rating could be used as a means of vertical foreclosure.[13]

Aside from being broadly related to the theoretical literature on pricing in multi-sided markets (Armstrong 2006; Rochet and Tirole 2003, 2006; Rysman 2009, Weyl 2010), the analysis in this manuscript is closely related to the study of net neutrality. The static and dynamic impact of violations of net neutrality—simply put, a ban on discrimination at the point where content terminates—has been shown to vary widely according to the framework under analysis (i.e., the means of modeling prioritization, the level of ISP competition, etc.). For example, Economides and Hermalin (2012) show that price discrimination via paid prioritization diminishes welfare if it diminishes content diversity while Choi and Kim (2010) and Cheng, Bandyopadhyay, Guo (2011) show that prioritization could incentivize ISPs to keep network capacity scarce. Conversely, paid prioritization has been shown to lead to higher broadband investment and increased diversity of content (Krämer and Wiewiorra 2012; Bourreau, Kourandi, Valletti 2015).[14]

As we have already pointed out, paid prioritization differs from zero-rating from both a technical/economic perspective and a legal one. The central technical distinction is that paid prioritization permits an ISP to offer different service quality tiers to different CPs, whereas zero-rating operates via the opposite end of the market, by presenting consumers with a clear pricing distinction between different CPs. Besides having the potential to lead to quantitatively different outcomes, this distinction has clearly been scrutinized by regulators who have made different determinations with regard to whether or not zero-rating violates net neutrality.

[13] This is the aspect of zero-rating that Koning and Yankelevich (2017) are also interested in, though in that paper, the authors' do not account for the two-sided nature of the market of interest.

[14] Moreover, a number of authors have explored the welfare "neutrality" of net neutrality (Gans 2015; Gans and Katz 2016; Greenstein, Peitz, and Valletti 2016).

3.3 Model

Assume that there are two content providers (CPs) and one Internet service provider (ISP). As in Economides and Hermalin (2015), the monopolistic ISP has a network bandwidth of B. Given that a consumer has decided to connect to the platform, she chooses the amount of content to purchase from each CP. The content provided by two CPs may be substitutes or independent goods to each other with the degree of content substitutability of γ. Assuming that there is a unit mass of consumer, the utility for each consumer is defined by a variation of typical quadratic utility function and the utility specification in Economides and Hermalin (2015).

$$
\begin{aligned}
u_i =& [\alpha_1 x_1 - \frac{1}{2}\delta(X|B)x_1^2 - \frac{\gamma}{2}x_1 x_2 + \alpha_2 x_2 - \frac{1}{2}\delta(X|B)x_2^2 - \frac{\gamma}{2}x_1 x_2] \\
& - H - \Sigma_{n=1}^{2} p_n x_n - \tau \max\{0, -L + \Sigma_{n=1}^{2} x_n \mathbb{1}_n\},
\end{aligned} \tag{3.1}
$$

where α_n denotes content quality provided by CP_n, x_n is the amount of content provided by CP_n, $\delta(X|B)$ is the level of congestion which is a function of total content purchased(X) given the platform's bandwidth(B), γ is the degree of content substitutability, H is a hookup fee charged by the ISP, p_n is a content n's subscription fee, τ is a per unit overage charge set by the ISP, L is a data cap also set by the ISP, and $\mathbb{1}_n$ is if CP_n is no zero-rated and is 0 if zero-rated.

The ISP chooses a hookup fee H, a data cap L, and an overage charge τ. With this three-part tariff pricing scheme, an overage charge is only applied to any excess usage beyond the cap L. However, if L is set to be zero, which means that there is no free data allowance in a certain monthly plan, the pricing scheme is collapsed to a typical two-part tariff and τ means a per unit data charge rather than an overage charge. On top of that, the ISP needs to decide whether and to which CPs to offer a zero-rating deal.

Each CP here decides whether to accept ISP's zero-rating offer if any. If it accepts the offer, the overage charge τ is exempted for his content. Then, CPs set their optimal content prices by solving profit maximization problems. We assume zero marginal costs for providing content. In the next section, we describe important assumptions which we impose throughout the paper.

3.3.1 Assumptions

For simplicity, we normalize α_2 to one and denote α_1 as α for the rest of paper. Also, we further assume that $1 \leq \alpha \leq 2$ is assumed. The condition implies that the quality of CP_1's content is much higher than that of CP_2's content. By assuming asymmetric CPs, we can see that on what grounds the ISP wants to make a deal with either one of the CPs.

Also, we limit our attention to the case of $L \leq \Sigma_{n=1}^{2} x_n \mathbb{1}_n$ which implies that consumers overuse data beyond a data cap the ISP sets because our main interest is to see the effect of overage charges. Note that if L is equal to zero, this condition is always satisfied with any positive x_n. For simplicity, we assume that $L = 0$ throughout the analysis.

On top of that, there is a restriction on γ which guarantees the interior solutions for both CPs to have positive market shares. For the interior solution assumption, we need an assumption that $\gamma < \tilde{\gamma}$. The thresholds can be derived later after the equilibrium is obtained.

Last, the equilibrium is derived under the assumption of $\delta(X|B) = 1$, which means no congestion. No congestion assumption is reasonable in some senses as for low levels of total content consumption, it might be possible that there is no congestion.[15]

3.4 No vertical integration

In this section, we first analyze the equilibrium under no vertical integration. Various cases which we consider are (1) no zero-rated content, (2) zero-rated content without monetary transfer, and (3) zero-rated with a monetary transfer. In all cases, the ISP's market is assumed to be fully covered, so that the ISP extracts everything from consumers.

The timing of the game is as follows. The ISP first announces its policies regarding to which CP(s) it offers a zero-rating deal and sets a data cap L which is assumed to be zero. Then, it also sets prices which are a hookup fee and an overage charge. After that, CPs decide whether to accept ISP's zero-rating offer if there is an offer and announce per unit content subscription

[15] Economides and Hermalin(2015) also mention this in their paper.

fees. Last, consumers decide how much content to subscribe to each CP. The equilibrium concept is the subgame perfect equilibrium which is derived by backward induction.

3.4.1 No zero-rated content

In this section, let's derive the equilibrium for no zero-rating case by backward induction. At the last stage, consumer decides x_n by solving the utility maximization problem with respect to each x_n. The resulting x_n for each CP_n is as follows.

$$x_1 = \frac{\alpha - p_1 - \gamma(1-p_2) - \tau(1-\gamma)}{1-\gamma^2}; \quad x_2 = \frac{1 - p_2 - \gamma(\alpha - p_1) - \tau(1-\gamma)}{1-\gamma^2}. \tag{3.2}$$

Given this, each CP solves profit maximization problem to obtain the equilibrium prices as follows.

$$p_1 = \frac{\gamma + \alpha(\gamma^2-2) - (\gamma^2+\gamma-2)\tau}{\gamma^2-4}; \quad p_2 = \frac{\gamma\alpha + (\gamma^2-2) - (\gamma^2+\gamma-2)\tau}{\gamma^2-4}. \tag{3.3}$$

This leads to the equilibrium market share for each CP is given by

$$x_1 = \frac{\alpha\left(2-\gamma^2\right) - \gamma + \left(\gamma^2+\gamma-2\right)\tau}{(\gamma^2-4)(\gamma^2-1)}; \quad x_2 = \frac{\left(2-\gamma^2\right) - \gamma\alpha + \left(\gamma^2+\gamma-2\right)\tau}{(\gamma^2-4)(\gamma^2-1)}. \tag{3.4}$$

Given each CP's price and market share, the ISP sets a hookup fee, an overage charge, and a data cap. First, since the ISP's market is fully covered, it sets a hook up fee at the level which can extract all consumer surplus. That means,

$$H = \frac{(\alpha^2+1)\left(3\gamma^2-4\right) + 2\alpha\gamma^3 - 2\tau(\gamma+2)^2(\gamma-1)(\alpha+1) + 2\tau^2(2+\gamma)^2(\gamma-1)}{2\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)}. \tag{3.5}$$

Then, the profit for ISP is given by

$$\pi_{ISP} = \frac{(\alpha^2+1)\left(3\gamma^2-4\right) + 2\alpha\gamma^3 - 2\left(\gamma^2+\gamma-2\right)^2\tau(\alpha+1) + 2(\gamma-1)(\gamma+2)^2(2\gamma-3)\tau^2}{2\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)}. \tag{3.6}$$

The optimal τ can be obtained by solving profit maximization problem with respect to τ. The set of equilibrium can be derived as follows.

$$
\begin{aligned}
\tau &= \frac{(\alpha+1)(1-\gamma)}{6-4\gamma} \\
H &= \frac{(\alpha^2+1)\left(-3\gamma^3+11\gamma^2+3\gamma-13\right)+2\alpha\left(5\gamma^3-5\gamma^2-3\gamma+5\right)}{4(\gamma^2-1)(2\gamma^2+\gamma-6)^2} \\
\pi_{ISP}^{NZ} &= \frac{(\alpha^2+1)\left(7+\gamma-5\gamma^2-\gamma^3\right)-2\alpha(-1+\gamma+\gamma^2+\gamma^3)}{4(\gamma^2-1)(\gamma+2)^2(2\gamma-3)} \\
p_1 &= \frac{\alpha(3\gamma^2-5)-(\gamma^2-2\gamma-1)}{2\left(2\gamma^2+\gamma-6\right)}; \quad p_2 = \frac{(3\gamma^2-5)-\alpha(\gamma^2-2\gamma-1)}{2\left(2\gamma^2+\gamma-6\right)} \\
x_1 &= \frac{\alpha\left(5-3\gamma^2\right)+\left(\gamma^2-2\gamma-1\right)}{2(2+\gamma)(-3+2\gamma)(-1+\gamma^2)}; \quad x_2 = \frac{\left(5-3\gamma^2\right)+\alpha\left(\gamma^2-2\gamma-1\right)}{2(2+\gamma)(-3+2\gamma)(-1+\gamma^2)}.
\end{aligned}
\tag{3.7}
$$

Since $\alpha \geq 1$ is assumed, the demand for content is weighted towards CP_1 from a certain level of γ. As γ increases, which means that content becomes more substitutable, consumers choose only one of the types of content. So, there is a threshold of γ above which p_2 becomes zero, otherwise consumers would not choose CP_2's content at all. It is easy to see that this threshold which guarantees interior solutions under no zero-rating is derived as follows.

$$
x_2 > 0 \Longleftrightarrow \gamma < \frac{\alpha - \sqrt{2\alpha^2 - 8\alpha + 15}}{\alpha - 3} \equiv \tilde{\gamma}_{NZ}, \tag{3.8}
$$

where the subscript NZ denotes no zero-rating. This interior solution condition on γ is assumed to be satisfied throughout the paper.[16]

3.4.2 Zero rated content without monetary transfer

3.4.2.1 Partial zero-rated content

In this section, let's consider the case that the ISP makes a zero-rating deal with one of the CPs but without any monetary transfer for zero-rating. First, consider the case in which the ISP makes a deal with CP_1. Then, the market share for each CP derived from consumer's utility maximization problem is given by

$$
x_1 = \frac{\alpha - p_1 - \gamma(1-p_2) + \gamma\tau}{1-\gamma^2}; \quad x_2 = \frac{1 - p_2 - \gamma(\alpha - p_1) - \tau}{1-\gamma^2}. \tag{3.9}
$$

[16] Assuming that $\alpha = 2$, $\tilde{\gamma}_{NZ} \approx 0.645751$

Also, by solving CP's profit maximization problem, we can obtain the following optimal price.

$$p_1 = \frac{\alpha(\gamma^2-2)+\gamma-\tau\gamma}{\gamma^2-4}; \quad p_2 = \frac{\gamma\alpha+(\gamma^2-2)-\tau(\gamma^2-2)}{\gamma^2-4}. \tag{3.10}$$

The set of equilibrium is given by as follows.[17]

$$\begin{aligned}
\tau &= \frac{2\alpha\gamma(\gamma^2-2)+(4-3\gamma^2+\gamma^4)}{12-9\gamma^2+2\gamma^4}\\
H &= \frac{\alpha^2(-36+59\gamma-28\gamma^4+4\gamma^6)+2\alpha\gamma(-8+18\gamma^2-11\gamma^4+2\gamma^6)+(3\gamma^2-4)(\gamma^2-2)^2}{2(\gamma^2-1)(12-9\gamma^2+2\gamma^4)^2}\\
\pi_{ISP}^{ZR_1} &= \frac{\alpha^2(2\gamma^2-3)+2\alpha\gamma-(\gamma^2-2)^2}{2(\gamma^2-1)(12-9\gamma^2+2\gamma^4)}\\
p_1 &= \frac{(\gamma^2-2)(\alpha(2\gamma^2-3)+\gamma)}{12-9\gamma^2+2\gamma^4}; \quad p_2 = \frac{-\alpha\gamma+(\gamma^2-2)^2}{12-9\gamma^2+2\gamma^4}\\
x_1 &= \frac{(\gamma^2-2)(\alpha(2\gamma^2-3)+\gamma)}{(1-\gamma^2)(12-9\gamma^2+2\gamma^4)}; \quad x_2 = \frac{-\alpha\gamma+(\gamma^2-2)^2}{(1-\gamma^2)(12-9\gamma^2+2\gamma^4)}.
\end{aligned} \tag{3.11}$$

For interior solution, we need the assumption on γ which guarantees positive p_2 and x_2. Let's denote this threshold for zero-rating with CP_1 case as $\tilde{\gamma}_{ZR_1}$. Thus, for $\gamma < \tilde{\gamma}_{ZR_1}$, there are interior solutions.[18]

Similarly, the set of equilibrium when the ISP makes a deal with CP_2 is given by as follows.

[17] As in no zero-rating case, let's fix L at zero, which means full data cap.

[18] Assuming that $\alpha = 2$, $\tilde{\gamma}_{ZR_1} \approx 0.839287$.

$$
\begin{aligned}
\tau &= \frac{2\gamma(\gamma^2-2)+\alpha(4-3\gamma^2+\gamma^4)}{12-9\gamma^2+2\gamma^4} \\
H &= \frac{(-36+59\gamma-28\gamma^4+4\gamma^6)+2\alpha\gamma(-8+18\gamma^2-11\gamma^4+2\gamma^6)+\alpha^2(3\gamma^2-4)(\gamma^2-2)^2}{2(\gamma^2-1)(12-9\gamma^2+2\gamma^4)^2} \\
\pi_{ISP}^{ZR_2} &= \frac{(2\gamma^2-3)+2\alpha\gamma-\alpha^2(\gamma^2-2)^2}{2(\gamma^2-1)(12-9\gamma^2+2\gamma^4)} \\
p_1 &= \frac{-\gamma+\alpha(\gamma^2-2)^2}{12-9\gamma^2+2\gamma^4}; \quad p_2 = \frac{(\gamma^2-2)((2\gamma^2-3)+\alpha\gamma)}{12-9\gamma^2+2\gamma^4} \\
x_1 &= \frac{-\gamma+\alpha(\gamma^2-2)^2}{(1-\gamma^2)(12-9\gamma^2+2\gamma^4)}; \quad x_2 = \frac{(\gamma^2-2)((2\gamma^2-3)+\alpha\gamma)}{(1-\gamma^2)(12-9\gamma^2+2\gamma^4)}.
\end{aligned}
\tag{3.12}
$$

As above, for interior solution, we assume that $\gamma < \tilde{\gamma}_{ZR_2} \equiv \frac{\sqrt{\alpha^2+24}-\alpha}{4}$.[19]

3.4.2.2 Full zero-rated content

In this section, we consider the case of full zero-rating, which means that the ISP zero-rates all content provided by both CPs. Under full zero-rating, the market share for each CP derived from consumer's utility maximization problem is given by

$$
x_1 = \frac{\gamma-\alpha-\gamma p_2+p_1}{\gamma^2-1}; \quad x_2 = \frac{\alpha\gamma-1-\gamma p_1+p_2}{\gamma^2-1}. \tag{3.13}
$$

By solving CP's profit maximization problem, we can obtain the following optimal price.

$$
p_1 = \frac{\alpha\left(\gamma^2-2\right)+\gamma}{\gamma^2-4}; \quad p_2 = \frac{\left(\gamma^2-2\right)+\alpha\gamma}{\gamma^2-4}. \tag{3.14}
$$

By the same logic as in no zero-rating content case, the set of equilibrium is given by as follows.[20]

$$
\begin{aligned}
H = \pi_{ISP}^{FZ} &= \frac{2\alpha\gamma^3+(\alpha^2+1)\left(3\gamma^2-4\right)}{2\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)} \\
p_1 &= \frac{\alpha\left(\gamma^2-2\right)+\gamma}{\gamma^2-4}; \quad p_2 = \frac{\left(\gamma^2-2\right)+\alpha\gamma}{\gamma^2-4} \\
x_1 &= -\frac{\alpha\left(\gamma^2-2\right)+\gamma}{\gamma^4-5\gamma^2+4}; \quad x_2 = -\frac{\left(\gamma^2-2\right)+\alpha\gamma}{\gamma^4-5\gamma^2+4}.
\end{aligned}
\tag{3.15}
$$

[19] Assuming that $\alpha = 2$, $\tilde{\gamma}_{ZR_2} \approx 0.822876$

[20] As in no zero-rating case, let's fix L at zero, which means full data cap.

For interior solution, we assume that $\gamma < \tilde{\gamma}_{FZ} = \frac{\sqrt{\alpha^2+8}-\alpha}{2}$.[21]

3.4.2.3 Equilibrium

To characterize the equilibrium, we first need to see whether the ISP has any incentive to offer zero-rating deals to both CPs, i.e., full zero-rating, by comparing ISP's profit from full zero-rating to that from either no zero-rating or partial zero-rating. After some algebra, it is easy to show that the ISP never wants to fully zero-rate all content from both CPs if there is no monetary transfer for zero-rating. This suggests that either partial zero-rating or no zero-rating emerges in equilibrium.

Now let's see to which CP the ISP offers a zero-rating deal and whether the CP accepts the offer or not. First, in order to see whether CP_1 accepts the zero-rating offer, we need to compare CP_1's profits with and without zero-rating. In other words, the following condition needs to be satisfied for CP_1 to accept the offer.

$$\pi_1^{NZ} = \frac{(\alpha(5-3\gamma^2)+(\gamma^2-2\gamma-1))^2}{4(1-\gamma^2)(2\gamma^2+\gamma-6)^2} \leq \frac{(-2+\gamma^2)^2(\alpha(2\gamma^2-3)+\gamma)^2}{(1-\gamma^2)(12-9\gamma^2+2\gamma^4)^2} = \pi_1^{ZR_1}. \tag{3.16}$$

Although there is no closed form solution to γ which satisfies the above inequality, there is a condition on γ which guarantees that CP_1 obtains greater profit from zero-rating. For example, under the assumption of $\alpha = 2$, Figure 3.1 shows that CP_1 always accepts the offer if the assumption for an interior solution on γ is satisfied. By the similar logic, Figure 3.2 shows that CP_2 always accepts the offer under the interior solution assumption. In other words, CPs have higher incentive to accept ISP's zero-rating offer if their content is independent of each other to some extent.

Given that CPs accept the offer, which means that $\gamma < \tilde{\gamma}_{ZR_2}$, it remains to show to which CP that the ISP offers zero-rating.

[21] Under $\alpha = 2$, $\tilde{\gamma}_{FZ} \approx 0.732051$.

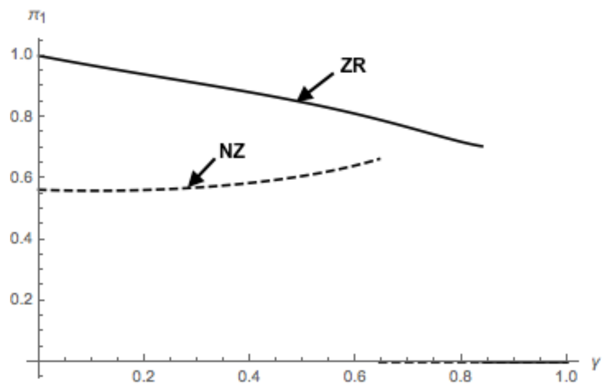

Figure 3.1 CP_1's profits as a function of γ under $\alpha = 2$

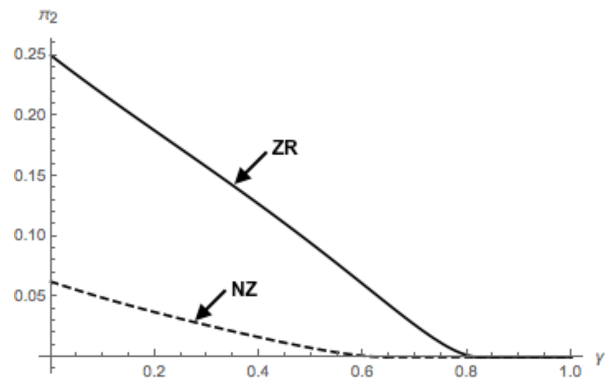

Figure 3.2 CP_2's profits as a function of γ under $\alpha = 2$

$$\pi_{ISP}^{ZR_1} - \pi_{ISP}^{ZR_2} = \frac{(\alpha^2 - 1)(\gamma^2 - 1)}{(24 - 18\gamma^2 + 4\gamma^4)} < 0 \quad \because \alpha \geq 1. \tag{3.17}$$

Thus, if the ISP chooses only one of the CPs for zero-rating without any monetary transfer, he chooses CP_2 regardless of γ.

Last, given that the ISP offers a deal with CP_2 and CP_2 accepts it, i.e., γ is sufficiently small, let's see whether it has an incentive to make the offer in the first place by comparing ISP's profit under no zero-rating to that under zero-rating with CP_2.

$$\begin{aligned}\pi_{ISP}^{ZR_2} - \pi_{ISP}^{NZ} = \frac{1}{4}\Big(&\frac{2\alpha^2\left(\gamma^2-2\right)^2 - 4\alpha\gamma - 4\gamma^2 + 6}{\left(\gamma^2-1\right)\left(2\gamma^4 - 9\gamma^2 + 12\right)} \\ &+ \frac{\alpha^2\left(-(\gamma+5)\gamma^2 + \gamma + 7\right) - 2\alpha\left(\gamma^3 + \gamma^2 + \gamma - 1\right) - \gamma^2(\gamma+5) + \gamma + 7}{(\gamma-1)(\gamma+1)(\gamma+2)^2(2\gamma-3)}\Big).\end{aligned} \tag{3.18}$$

From Equation (3.18), we can see that $\pi_{ISP}^{ZR_2} < \pi_{ISP}^{NZ}$ if γ is sufficiently small whereas $\pi_{ISP}^{ZR_2} > \pi_{ISP}^{NZ}$ if γ is large enough. Thus, the ISP offers a zero-rating deal only when content is sufficiently substitutable. Proposition 3.1 summarizes this finding.[22]

[22]Under the same numerical example of $\alpha = 2$, the relevant thresholds on γ which constitutes Proposition 3.1 are as follows: $\gamma_I = 0.237235$ and $\tilde{\gamma}_{ZR_2} = 0.822876$

Proposition 3.1. *When there is no monetary transfer for zero-rating, the ISP offers zero-rated service to a content provider whose quality of content is lower if content is sufficiently substitutable ($\gamma > \gamma_I$). The low quality CP always wants to accept the offer under the interior solution assumption on γ, $\gamma < \tilde{\gamma}_{ZR_2}$. Thus, zero-rating with low quality CP_2 occurs for $\gamma \in (\gamma_I, \tilde{\gamma}_{ZR_2})$.*

Here is the intuition for this finding. Given that the ISP zero-rates CP_2's content, ISP's total profit is the sum of the hookup fee which depends on total content demand, $x_1 + x_2$, and overage charge from x_1 only. If $\gamma < \gamma_I$, there are distinct demands for both content because it is sufficiently differentiated, which means that even CP_2 whose content is lower quality has relatively large demand. Then, the profit loss to the ISP from overage charge that would be paid by CP_2's subscribers under no zero-rating, τx_2, is large in this range of γ, therefore, the ISP does not offer zero-rating in the first place. Consequently, it chooses not to zero-rate to take advantage of consumers' relatively inelastic demand if both CPs' content is relatively independent.

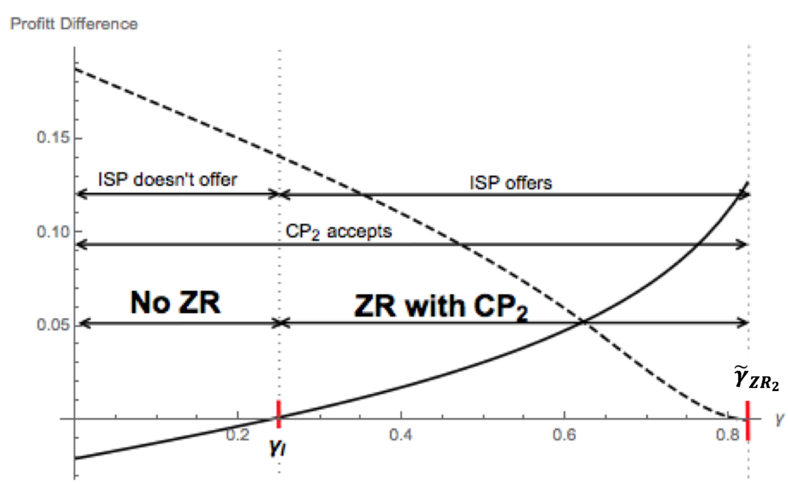

Figure 3.3 Solid line is $\pi_{ISP}^{ZR_2} - \pi_{ISP}^{NZ}$ and dashed line is $\pi_2^{ZR_2} - \pi_2^{NZ}$ when α=2

3.4.3 Zero-rated content with monetary transfer (Sponsored Data)

Here, let's assume that CPs need to pay a fixed fee to be zero-rated. Assume that the ISP makes a take-it-or-leave-it-offer to CPs and γ is small enough for CPs to accept the ISP's offer. Table 3.1 represents each CP's profit.

Table 3.1 CP's Equilibrium Profits

	Accept	Reject
Accept	$\frac{-\left(\alpha\left(\gamma^2-2\right)+\gamma\right)^2}{\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)} - r_1^{FZ}, \frac{-\left(\left(\gamma^2-2\right)+\alpha\gamma\right)^2}{\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)} - r_2^{FZ}$	$\frac{-\left(\gamma^2-2\right)^2\left(\alpha\left(2\gamma^2-3\right)+\gamma\right)^2}{\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)^2} - r_1^{PZ}, -\frac{\left(\alpha\gamma-\left(\gamma^2-2\right)^2\right)^2}{\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)^2}$
Reject	$\frac{-\left(\alpha\left(\gamma^2-2\right)^2-\gamma\right)^2}{\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)^2}, \frac{-\left(\gamma^2-2\right)^2\left(\left(2\gamma^2-3\right)+\alpha\gamma\right)^2}{\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)^2} - r_2^{PZ}$	$\frac{-\left(\alpha\left(3\gamma^2-5\right)+(1-(\gamma-2)\gamma)\right)}{4\left(\gamma^2-1\right)\left(2\gamma^2+\gamma-6\right)^2}, \frac{-\left(\left(5-3\gamma^2\right)+\alpha((\gamma-2)\gamma-1)\right)^2}{4\left(\gamma^2-1\right)\left(2\gamma^2+\gamma-6\right)^2}$

There can be two different levels of equilibrium fees depending on rival's decision: the fee in which the rival also accepts zero-rating offer is different from that in which the rival rejects the offer. The superscripts FZ and PZ denote Full Zero-rating and Partial Zero-rating, respectively.

3.4.3.1 Partial zero-rated content

If the ISP zero-rates only one of the CP's content, the fixed fee r should be small enough as follows.

$$\begin{aligned}
r_1^{PZ} &\leq \pi_1^{ZR_1} - \pi_1^{NZ} = -\frac{\left(\gamma^2-2\right)^2\left(\alpha\left(2\gamma^2-3\right)+\gamma\right)}{\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)^2} + \frac{\left(\alpha\left(3\gamma^2-5\right)+(1-(\gamma-2)\gamma)\right)}{4\left(\gamma^2-1\right)\left(2\gamma^2+\gamma-6\right)^2} \\
r_2^{PZ} &\leq \pi_2^{ZR_2} - \pi_2^{NZ} = -\frac{\left(\gamma^2-2\right)^2\left(\left(2\gamma^2-3\right)+\alpha\gamma\right)}{\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)^2} + \frac{\left(\left(5-3\gamma^2\right)+\alpha((\gamma-2)\gamma-1)\right)}{4\left(\gamma^2-1\right)\left(2\gamma^2+\gamma-6\right)^2}.
\end{aligned} \tag{3.19}$$

Given that the reference point for each CP to decide whether to accept the offer or not is its profit from no zero-rating, we assume that the interior solution on γ for no zero-rating $(\gamma < \tilde{\gamma}_{NZ})$ is satisfied. Assuming that CPs accept the offer, it remains to show to which CP the ISP makes the offer. To check this, let's compare ISP's profit under zero-rating with CP_1 to that under zero-rating with CP_2. For notational convenience, we denote $\widehat{\pi}$ for profits with monetary transfer.

$$\widehat{\pi}_{ISP}^{ZR_1} - \widehat{\pi}_{ISP}^{ZR_2} = -\frac{\left(\alpha^2 - 1\right)(\gamma - 2)(\gamma + 1)(2\gamma + 3)\left(\gamma\left((2\gamma(\gamma + 1) - 15)\gamma^2 + \gamma + 24\right) - 12\right)}{2\left(2\gamma^2 + \gamma - 6\right)\left(2\gamma^4 - 9\gamma^2 + 12\right)^2}. \tag{3.20}$$

We can find that $\widehat{\pi}_{ISP}^{ZR_1} - \widehat{\pi}_{ISP}^{ZR_2}$ is greater than zero if γ is small while the reverse holds otherwise. Thus, as content becomes less substitutable, the ISP has more incentive to make a deal with CP_1. In other words, unlike the case of no monetary transfer for zero-rating, the ISP offers the deal to CP_1 for a certain range of γ but does the same thing to CP_2 for a different level of γ. Therefore, when there is a monetary transfer for zero-rating, we need to compare all of the following; ISP's profit under no zero-rating, ISP's profit under zero-rating with CP_1 and CP_2, respectively. As we can see from Figure 3.4, ISP's profit under no zero-rating is the lowest compared to either partial zero-rating with CP_1 with a monetary transfer or with CP_2. Between the profit under zero-rating with CP_1 and that under CP_2, there exists another threshold on γ, denoted as $\tilde{\gamma}_{PZ}$ such that if $\gamma < \tilde{\gamma}_{PZ}$, the ISP offers a deal to CP_1 but offers to CP_2 if $\gamma > \tilde{\gamma}_{PZ}$. Proposition 3.2 summarizes the findings.[23]

Proposition 3.2. *Assume that there is a monetary transfer between the ISP and CP for zero-rating and the ISP does not offer full zero-rating. There are thresholds on γ, $\tilde{\gamma}_{PZ}$, such that (1) the ISP makes an offer to high quality CP_1 and CP_1 accepts it by paying a positive fee to the ISP for $0 < \gamma < \tilde{\gamma}_{PZ}$, and (2) the ISP has an incentive to make a deal with low quality CP_2 and CP_2 accepts it by paying a positive fee to the ISP for $\tilde{\gamma}_{PZ} < \gamma < \tilde{\gamma}_{NZ}$.*

The intuition behind choosing low quality CP_2 for large γ is similar to why the ISP chooses CP_2 as zero-rating partner without a monetary transfer. If content becomes more substitutable, demand for content shifts toward high quality content, so there will be a greater profit from an overage charge on CP_1. Thus, the ISP optimally chooses CP_2 and does not zero-rate CP_1's content if γ is sufficiently large.

[23] $\tilde{\gamma}_{PZ}$ is the γ satisfying $\widehat{\pi}_{ISP}^{ZR_1} - \widehat{\pi}_{ISP}^{ZR_2} = 0$. Note that $\tilde{\gamma}_{PZ} < \tilde{\gamma}_{NZ}$ is guaranteed under our assumption on α.

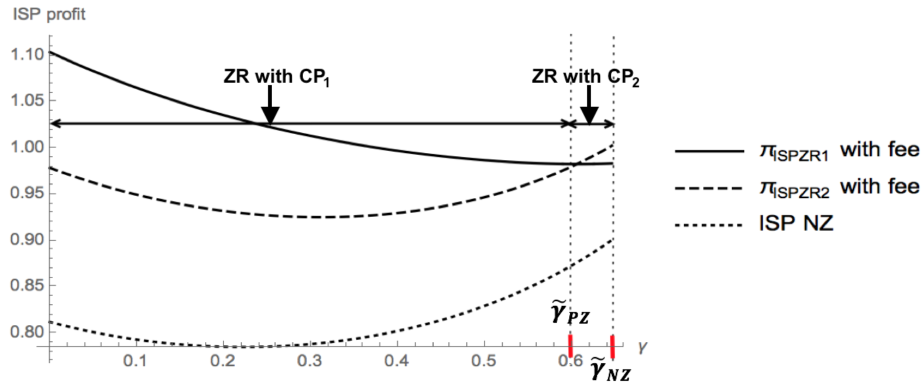

Figure 3.4 Partial Zero-rating Equilibrium if $\alpha = 2$

3.4.3.2 Full zero-rated content

First, assuming that the ISP zero-rates both CPs' content, the fixed fee should be determined as follows.

$$\begin{aligned} r_1^{FZ} &\leq \pi_1^{FZ} - \pi_1^{ZR_2} = \frac{\left(\alpha\left(\gamma^2-2\right)^2-\gamma\right)^2}{\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)^2} - \frac{\left(\alpha\left(\gamma^2-2\right)+\gamma\right)^2}{\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)} \\ r_2^{FZ} &\leq \pi_2^{FZ} - \pi_2^{ZR_1} = \frac{\left(\alpha\gamma-\left(\gamma^2-2\right)^2\right)^2}{\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)^2} - \frac{\left(\left(\gamma^2-2\right)+\alpha\gamma\right)^2}{\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)}. \end{aligned} \tag{3.21}$$

By the similar logic in the partial zero-rating case, we first need to assume that the interior solution assumption on γ is satisfied. The sufficient condition is $\gamma < \min\{\tilde{\gamma}_{ZR_1}, \tilde{\gamma}_{ZR_2}\}$. Under the assumption, it can be shown that r_1^{FZ} is always positive whereas r_2^{FZ} can be negative if γ is sufficiently large. If content is easily substitutable, or less differentiated, more demand shifts toward high quality content, thus, high (low) quality CP charges higher (lower) price for its content. Here, zero-rating softens price competition because it increases product—i.e. content— differentiation. Thus, full zero-rating that symmetrically exempts overage charges on both CPs induces more intense price competition than any asymmetric partial zero-rating such as zero-rating CP_1's content only. This implies that low quality content price falls much more in full zero-rating case (with intense price competition) than in partial zero-rating case (with soft price competition). For sufficiently large substitutability levels, the effect of lower price on boosting demand for low quality content is small. Therefore, lowering content price in full zero-rating leads to lower profit for the low quality CP. Because of that, as content becomes more substitutable, r_2^{FZ} not only decreases but can be negative. For the high quality CP, however, lower content price induces much higher demand, in turn, leads to greater profit, which increases its willingness to pay for full zero-rating. Thus, if both content is sufficiently substitutable, say $\gamma > \gamma_{Subsidy}$,[24] the ISP can extract more rent from CP_1 under full zero-rating because CP_1's willingness to pay for full zero-rating (r_1^{FZ}) is large enough. Since the ISP wants full zero-rating for sufficiently large γ, it rather pays a positive subsidy to CP_2. Lemma 3.1 summarizes the finding. Figure 3.5 demonstrates different fee levels under $\alpha = 2$.

Lemma 3.1. *High quality CP is willing to pay a higher fee for zero-rating if low quality content is zero-rated. However, the low quality CP is willing to pay a higher fee if high quality content is not zero-rated than if it is zero-rated. If content is sufficiently substitutable ($\gamma > \gamma_{Subsidy}$), the ISP needs to pay a positive subsidy to the low quality CP to attain full zero-rating.*

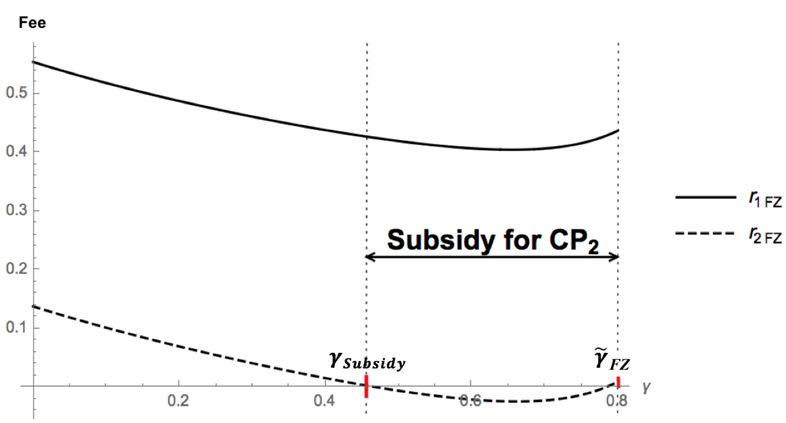

Figure 3.5 Fixed fee comparison

3.4.3.3 Equilibrium

Let's now see how the ISP makes a decision. By comparing $\widehat{\pi}_{ISP}^{FZ}$ to $\widehat{\pi}_{ISP}^{ZR_1}$ and $\widehat{\pi}_{ISP}^{ZR_2}$, it can be shown that $\widehat{\pi}_{ISP}^{FZ}$ is always greater than the other two partial zero-rating cases. Unlike the

[24] $\gamma_{Subsidy} = \frac{1}{2}\left(\sqrt{2\left(\sqrt{\alpha^2-1}+\alpha\right)\alpha+7}-\sqrt{\alpha^2-1}-\alpha\right)$

result from no monetary transfer case, when there is a monetary transfer for zero-rating, the ISP always wants to fully zero-rate as we can see from Figure 3.6. In addition, as in Lemma 3.1, if γ is sufficiently large, the ISP pays a positive subsidy to CP_2 to have full zero-rating. Proposition 3.3 summarizes the equilibrium under zero-rating with monetary transfer.

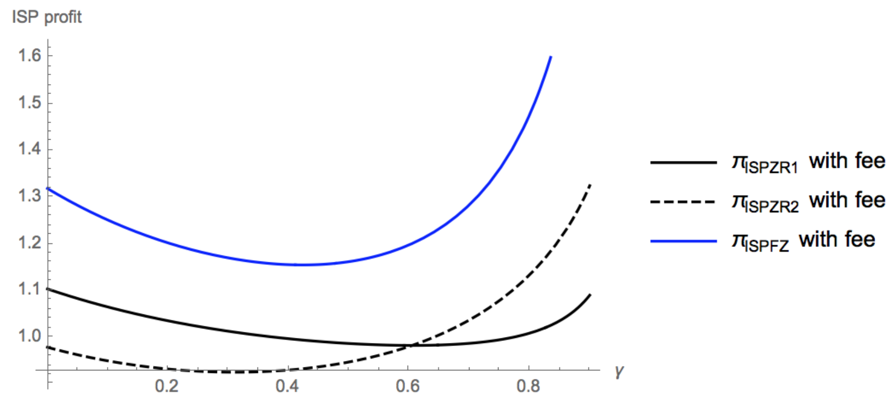

Figure 3.6 ISP profit comparison

Proposition 3.3. *If there is a monetary transfer for zero-rating, the ISP always wants to fully zero-rate all content from both CPs. If content is sufficiently substitutable, the ISP pays a positive subsidy for lower quality CP to attain full zero-rating.*

3.5 Vertical integration

In the previous section, we characterize zero-rating equilibrium with and without monetary transfer between the ISP and CPs. It is worth noting that zero-rating with a positive fee from CPs is one typical example of sponsored data plan in a sense that consumers do not pay any overage charge of consuming zero-rated content but CPs pay instead. As mentioned in the Introduction, we can easily find real case examples of such sponsored data plan. However, in reality, most ISPs zero-rates its affiliated content for free but charges fees to any unaffiliated content. In this section, our focus is to see whether this behavior poses any anti-competitive threat such as vertical content foreclosure.

3.5.1 Zero-rated content without monetary transfer

3.5.1.1 Integrated with CP_1 who provides higher quality of content

Suppose that the ISP and CP_1 are vertically integrated and the vertically integrated firm zero-rates its affiliated content. The timing of the game is as follows. The integrated firm makes a take-it-or-leave-it zero-rating offer to CP_2 and sets the hookup fee and overage charge. Then, CP_2 first decides whether to accept the offer and both of integrated firm and CP_2 set per unit content subscription fee. Last, consumers decide how much content to subscribe to each CP.

First, let's see what happens if CP_2 rejects the offer, which means no zero-rating with CP_2. The set of equilibrium here is as follows.

$$
\begin{aligned}
\tau^R_{VICP_1} &= \frac{\gamma^2\left(\alpha\gamma\left(2\gamma^2-5\right)+7\right)-4}{3\left(\gamma^4+3\gamma^2-4\right)}\\
H^R_{VICP_1} &= \frac{\alpha^2\left(8\gamma^8+52\gamma^6-36\gamma^4-99\gamma^2+108\right)-2\alpha\left(8\gamma^4-11\gamma^2+36\right)\gamma+9\gamma^4+8\gamma^2+16}{18\left(\gamma^4+3\gamma^2-4\right)^2}\\
\pi^R_{VICP_1} &= \frac{\alpha^2\left(4\gamma^6-18\gamma^2+15\right)+2\alpha\gamma\left(5\gamma^2-6\right)-3\gamma^2+4}{6\left(\gamma^2-1\right)^2\left(\gamma^2+4\right)}\\
p^R_{VICP_1} &= \frac{\gamma^3-\alpha\left(\gamma^4-2\gamma^2+2\right)}{\gamma^4+3\gamma^2-4}; \quad p^R_2 = \frac{1}{3}\left(\frac{13\alpha\gamma-8}{\gamma^2+4}-4\alpha\gamma+3\right)\\
x^R_{VICP_1} &= \frac{2\left(\alpha\left(\gamma^4-3\right)+2\gamma\right)}{3\left(\gamma^4+3\gamma^2-4\right)}; \quad x^R_2 = \frac{\alpha\left(4\gamma^2+3\right)\gamma-3\gamma^2-4}{3\left(\gamma^4+3\gamma^2-4\right)}.
\end{aligned}
\tag{3.22}
$$

Note that the subscript $VICP_1$ denotes vertical integrated with CP_1. To have an interior solution ($x^R_2 \geq 0$), we need to restrict our attention to $\gamma < \gamma^R_{VICP_1}$.[25] Let's now see the

[25] When $\alpha = 2$, $\gamma^R_{VICP_1} \approx 0.577$.

equilibrium for zero τ (full zero-rating) for the case in which CP_2 accepts the offer.

$$\begin{aligned}
H^A_{VICP_1} &= \frac{\alpha^2\left(3-2\gamma^2\right)-2\alpha\gamma+1}{2\left(\gamma^4-5\gamma^2+4\right)} \\
\pi^A_{VICP_1} &= \frac{\alpha^2\left(-4\gamma^4+19\gamma^2-20\right)+2\alpha\gamma\left(8-3\gamma^2\right)-\gamma^2-4}{2\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)} \\
p^A_{VICP_1} &= \frac{\alpha\left(\gamma^2-2\right)+\gamma}{\gamma^2-4}; \quad p^A_2 = \frac{\alpha\gamma+\gamma^2-2}{\gamma^2-4} \\
x^A_{VICP_1} &= -\frac{\alpha\left(\gamma^2-2\right)+\gamma}{\gamma^4-5\gamma^2+4}; \quad x^A_2 = \frac{2-\gamma(\alpha+\gamma)}{\gamma^4-5\gamma^2+4}.
\end{aligned} \tag{3.23}$$

To have an interior solution ($x^A_2 \geq 0$), we need to restrict our attention to $\gamma < \gamma^A_{VICP_1}$.[26] To see whether CP_2 accepts or rejects the offer, we need to compare π^A_2 to π^R_2 where the superscript A denotes *Accept* and R denotes *Reject*. We can show that the profit under zero-rating (*Accept*) is always greater than that under no zero-rating (*Reject*) if γ is sufficiently small as in Section 3.4.3.2.

Let's now see the integrated firm makes an offer in the first place. It is easy to see that $\pi^A_{VICP_1} - \pi^R_{VICP_1} = -\frac{\left(\gamma^2\left(\alpha\gamma\left(2\gamma^2-5\right)+7\right)-4\right)^2}{6\left(\gamma^2+4\right)\left(\gamma^4-5\gamma^2+4\right)^2} < 0$ for $\gamma \in (0,1)$. Thus, the integrated firm does not have an incentive to make a zero-rating to CP_2. Therefore, there is no zero-rating with CP_2 when the ISP and CP_1 are vertically integrated even if CP_2 wants to be zero-rated.

3.5.1.2 Integrated with CP_2 who provides lower quality of content

Suppose now that the ISP and CP_2 are vertically integrated and the integrated firm zero-rates its affiliated content and offers zero-rating deal to unaffiliated CP_1. The timing of the game is analogous to Section 3.5.1.1. First, let's characterize the equilibrium in which CP_1 rejects the

[26]When $\alpha = 2$, $\gamma^A_{VICP_1} \approx 0.7321$.

offer.

$$
\begin{aligned}
\tau^R_{VICP_2} &= \frac{7\alpha\gamma^2-4\alpha+2\gamma^5-5\gamma^3}{3\left(\gamma^4+3\gamma^2-4\right)}\\
H^R_{VICP_2} &= \frac{\alpha^2\left(9\gamma^4+8\gamma^2+16\right)-2\alpha\left(8\gamma^4-11\gamma^2+36\right)\gamma+8\gamma^8+52\gamma^6-36\gamma^4-99\gamma^2+108}{18\left(\gamma^4+3\gamma^2-4\right)^2}\\
\pi^R_{VICP_2} &= \frac{-3\left(\alpha^2+6\right)\gamma^2+4\alpha^2+10\alpha\gamma^3-12\alpha\gamma+4\gamma^6+15}{6\left(\gamma^2-1\right)^2\left(\gamma^2+4\right)}\\
p^R_{VICP_2} &= \frac{\gamma^2(\gamma(\alpha-\gamma)+2)-2}{\gamma^4+3\gamma^2-4}; \quad p^R_1 = \frac{13\gamma-8\alpha}{3\left(\gamma^2+4\right)}+\alpha-\frac{4\gamma}{3}\\
x^R_{VICP_2} &= \frac{2\left(2\alpha\gamma+\gamma^4-3\right)}{3\left(\gamma^4+3\gamma^2-4\right)}; \quad x^R_1 = \frac{-3\alpha\gamma^2-4\alpha+4\gamma^3+3\gamma}{3\left(\gamma^4+3\gamma^2-4\right)}.
\end{aligned}
\tag{3.24}
$$

To have an interior solution ($x^R_{VICP_2} \geq 0$), we need to restrict our attention to $\gamma < \gamma^R_{VICP_2}$.[27] Let's now characterize the equilibrium in which CP_1 accepts the offer.

$$
\begin{aligned}
H^A_{VICP_2} &= \frac{\alpha^2-2\alpha\gamma-2\gamma^2+3}{2\gamma^4-10\gamma^2+8}\\
\pi^A_{VICP_2} &= -\frac{\alpha^2\left(\gamma^2+4\right)+2\alpha\left(3\gamma^2-8\right)\gamma+4\gamma^4-19\gamma^2+20}{2\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)}\\
p^A_{VICP_2} &= \frac{\gamma(\alpha+\gamma)-2}{\gamma^2-4}; \quad p^A_1 = \frac{\alpha\left(\gamma^2-2\right)+\gamma}{\gamma^2-4}\\
x^A_{VICP_2} &= \frac{2-\gamma(\alpha+\gamma)}{\gamma^4-5\gamma^2+4}; \quad x^A_1 = -\frac{\alpha\left(\gamma^2-2\right)+\gamma}{\gamma^4-5\gamma^2+4}.
\end{aligned}
\tag{3.25}
$$

To have an interior solution ($x^A_{VICP_2} \geq 0$), we need to restrict our attention to $\gamma < \gamma^A_{VICP_2}$.[28] Comparing π^A_1 to π^R_1 to see whether CP_1 accepts or rejects the offer, we can show that CP_1 always wants to be zero-rated. However, as in the previous section, there is no incentive for the integrated firm to offer zero-rating to unaffiliated CP_1 because $\pi^A_{VICP_2} - \pi^R_{VICP_2} = -\frac{\left(-7\alpha\gamma^2+4\alpha-2\gamma^5+5\gamma^3\right)^2}{6\left(\gamma^2+4\right)\left(\gamma^4-5\gamma^2+4\right)^2} < 0$ for $\gamma \in (0,1)$.

[27] When $\alpha = 2$, $\gamma^R_{VICP_2} \approx 0.692505$.

[28] When $\alpha = 2$, $\gamma^A_{VICP_2} \approx 0.7321$.

3.5.1.3 Equilibrium

We have shown that the integrated firm, regardless of integration partner, does not offer zero-rating to its unaffiliated CP. From the comparison between profits from *Reject* for the integrated firm, we can show that the ISP wants to be vertically integrated with CP_1 whose content is high quality since $\pi^R_{VICP_1} - \pi^R_{VICP_2} = \frac{\left(\alpha^2-1\right)\left(4\left(\gamma^4+\gamma^2\right)-11\right)}{6\left(\gamma^4+3\gamma^2-4\right)} > 0$ for $\gamma \in (0,1)$. This finding completes the equilibrium under vertical integration without monetary transfer as summarized in Proposition 3.4.

Proposition 3.4. *When there is no monetary transfer for zero-rating, the ISP and high quality CP make an integration deal. The integrated firm only wants to zero-rate its affiliated content, but has no incentive to zero-rate unaffiliated low quality content even if the unaffiliated low quality CP wants to be zero-rated.*

On the contrary to no vertical integration game without a fee where the ISP zero-rates CP_2's content (low quality) for intermediate levels of content substitutability, allowing the ISP to vertically integrate leads to a completely opposite situation. Under vertical integration game, the ISP and high quality CP (CP_1) integrate and do not zero-rate CP_2's content. As an integrated firm, the ISP takes into account CP's profit from selling content. Intuitively, high quality CP_1 can earn great profit if zero-rated. Also, if the unaffiliated content is not zero-rated, there is additional profit coming from overage charge as long as content provided by both CPs independent to some extent. Due to this additional profit effects, the ISP wants to integrate with CP_1.[29]

3.5.2 Zero-rated content with monetary transfer (Sponsored Data)

From above, we saw that the integrated firm always wants to foreclose the unaffiliated CP from being zero-rated. However, if there is a fee for zero-rating, the integrated firm might want to

[29] From comparing the joint profits of the ISP and CP_1 under no vertical integration game without a fee to the integrated firm's profit under vertical integration game, it can be shown that there is an incentive to vertically integrate with each other.

fully zero-rate. As in Section 3.4.3, we assume that the ISP makes a take-it-or-leave-it offer to CPs.

3.5.2.1 Integrated with CP_1 who provides higher quality of content

Given that the fee r_2 is determined at $\pi_2^A - \pi_2^R$, the integrated firm's profit from full zero-rating with fee (which means Accept) is always greater than that from no zero-rating (which means Reject) if content is sufficiently independent. That is, $\widehat{\pi}^A_{VICP_1} - \pi^R_{VICP_1} > 0$ under $\gamma < \gamma_{VI}$ where $\widehat{\pi}$ denotes the profit with monetary transfer.[30] Thus, when there is a monetary transfer, full zero-rating occurs in vertical integration equilibrium if $\gamma < \gamma_{VI}$. Also, for $\gamma > \gamma_{VI}$, the integrated firm only wants to zero-rate its own content as in no monetary transfer case.

3.5.2.2 Integrated with CP_2 who provides lower quality of content

We can show that $\widehat{\pi}^A_{VICP_2} - \pi^R_{VICP_2} > 0$ for $\gamma \in (0, 1)$. Thus, if the ISP and CP_2 integrate with each other, it always fully zero-rates all content at a fee.

3.5.2.3 Equilibrium

As long as CP_1's content quality is sufficiently higher than CP_2's, it is easy to show that $\max\{\widehat{\pi}^A_{VICP_1}, \pi^R_{VICP_1}\} > \widehat{\pi}^A_{VICP_2}$. This suggests that no matter whether there is a fee for zero-rating, the ISP and high quality CP makes a vertical integration. However, if the integrated firm can charge a fee for zero-rating, it is willing to zero-rate the unaffiliated CP's content for some range of γ, unlike in the previous finding. Proposition 3.5 summarizes this findings.

Proposition 3.5. *If there is a monetary transfer for zero-rating, the ISP and high quality CP vertically integrate. If content is sufficiently independent ($\gamma < \gamma_{VI}$), the integrated firm wants to zero-rate its unaffiliated CP in exchange for a positive fee. If content is sufficiently substitutable ($\gamma > \gamma_{VI}$), the integrated firm does not offer zero-rating, which may lead to vertical content foreclosure.*

[30] Under $\alpha = 2$, $\gamma_{VI} \approx 0.4775$.

Thus, allowing the integrated firm to charge a fee for zero-rating somewhat alters the result. If content is independent, so that there are distinct demands for both types of content, the integrated firm is able to charge a higher fee for zero-rating. Therefore, it wants to fully zero-rate all content and enjoy additional benefit from higher zero-rating fee paid by the unaffiliated low quality CP. However, if content becomes sufficiently substitutable, the integrated firm does not want to offer zero-rating to its rival because the unaffiliated low quality CP's willingness to pay for zero-rating becomes smaller as γ becomes larger. Also, as in Lemma 3.1, CP_2's fee for zero-rating can be negative if γ is sufficiently large. However, unlike in the no vertical integration game, the integrated firm does not want to pay subsidy to induce full zero-rating: it takes into consideration the positive competitive effect toward affiliated CP from not zero-rating the rival's content, which dominates any positive effects toward the ISP from having full zero-rating. Corollary 3.1 summarizes this finding.

Corollary 3.1. *Vertical integration with high quality content provider makes its rival, low quality content provider, worse off because it does not allow the chance to be zero-rated if not paying for zero-rating.*

3.6 Welfare Analysis

In this section, let's compare welfare levels under different zero-rating regimes. The purpose of this analysis is to see how zero-rating equilibrium under vertical integration can be welfare-enhancing or -reducing compared to that under no vertical integration. Total social welfare is the sum of consumer's surplus, CPs' profits, and ISP's profit. Since the ISP takes all rents from consumers by setting up his optimal hookup fee, consumer's surplus is always zero. Thus, we need to compare CPs' and ISP's profits only.

For the sake of simplicity, we restrict our attention to γ in the middle range. In other words, γ is sufficiently large but smaller enough to guarantee the interior solutions. We first compare total social welfare levels for no monetary transfer cases. Suppose $\gamma_I < \gamma$, which implies that zero-rating with CP_2 is the only equilibrium under no vertical integration game as in Proposition 3.1. Also, Proposition 3.4 states that only affiliated CP_1's content is zero-rated. First, let us compare total social welfare levels under those two scenarios.

$$SW^R_{VICP_1} - SW_{ZR_2} = \underbrace{[\pi^R_{VICP_1} - \pi^{ZR_2}_{ISP} - \pi^{ZR_2}_1]}_{(+)} + \underbrace{[\pi^R_2 - \pi^{ZR_2}_2]}_{(-)} > 0 \tag{3.26}$$

As above, total surplus from vertical integration case attains greater level than that from no integration case when there is no monetary transfer. However, this welfare-enhancing result comes at the expense of the unaffiliated CP_2 which loses its market share and profit due to the integration and no zero-rating offer. We now compare total social welfare levels for monetary transfer cases. From Proposition 3.3, we check that full zero-rating emerges in equilibrium under no vertical integration. Under vertical integration, either full zero-rating or no zero-rating for the unaffiliated CP_2's content emerges as in Proposition 3.5. By the same logic as above, we can find that vertical integration is weakly welfare-enhancing. First, if the integrated firm does not zero-rate the unaffiliated content, the profit increasing effect for the integrated firm dominates the profit decreasing effect for the unaffiliated CP_2. If the integrated firm zero-rates CP_2's content, total social welfare with and without vertical integration are the same. Still, the unaffiliated CP_2 becomes worse off due to vertical integration because it does not receive any positive subsidy for zero-rating as in no vertical integration case. Proposition 3.6 summarizes the finding.

Proposition 3.6. *Vertical integration with high quality content provider is welfare-enhancing than no vertical integration case because profit increasing effect for the integrated firm is large enough. However, the unaffiliated content provider suffers from lower market share and profit under the integration.*

Lastly, it is worth examining whether sponsored data plan is welfare-enhancing. For no vertical integration case, allowing monetary transfers for zero-rating which leads to full zero-rating case attains greater social welfare level. For vertical integration case, sponsored data plan is welfare-enhancing as long as it induces full zero-rating in the equilibrium, i.e., if $\gamma < \gamma_{VI}$. Proposition 3.7 summarizes this finding.

Proposition 3.7. *Sponsored data plan which may lead to full-zero rating equilibrium is welfare-enhancing than no monetary transfer for zero-rating.*

3.7 Conclusion

In this paper, we have shown what makes the ISP want to zero-rate CP's content and how different zero-rating equilibrium affects total social welfare. If there is no monetary transfer for zero-rating, the ISP wants to offer the deal to lower quality CP. However, if there is a fee, full zero-rating equilibrium emerges. Similarly, assuming that the ISP and one of the CPs are vertically integrated, the integrated firm wants to foreclose the unaffiliated CP from being zero-rated if there is no fee. If the integrated firm can receive a fee for zero-rating, it wants to zero-rate its rival's content. From the welfare analysis, we have shown that vertical integration is the most socially desirable but at the expense of the unaffiliated content provider which loses its market share and profit due to the integration and no zero-rating offer. Also, full zero-rating is welfare-enhancing in most cases. Therefore, in order to enhance total social welfare, we might need a policy that encourages a monetary transfer for zero-rating which leads to full zero-rating.

We have not looked into how zero-rating affects the competitive structure in the ISP market. In this regard, it would be interesting for future research to see how zero-rating can be used as a late entrant strategy by providing marketing collaboration to newer ISP entrants.[31]

[31] For example, hoping to boost subscribership, in 2011, urban centered fledgling mobile wireless service provider MetroPCS partnered with Rhapsody to offer a zero-rated music streaming service. Similarly, in 2015, Cell-C, South Africa's third largest mobile wireless service provider, began to offer zero-rated access to Facebook's Intrenet.org app.

APPENDIX

APPENDIX A

PROOFS IN CHAPTER 1

Proof of Proposition 1.1. Given the conditional equilibrium profits for the ISP and the CPs from stage 4, I need to derive the subgame equilibrium in stage 3. First, let me start with the subgame where CP_1 chose high quality in stage 2. (H,H) is chosen instead of (H,L) if

$$
\begin{aligned}
& \pi_{ISP}^{HH} + \pi_2^{HH} > \pi_{ISP}^{HL} + \pi_2^{HL} \\
\iff \quad & U + \alpha\mu + f_1 + f_2 - 2K + \frac{(V(\bar{\lambda} + \lambda_2) + \mu)^2}{4t} - f_2 > U + \mu + f_1 - K + \frac{(V(\bar{\lambda} + \lambda_2))^2}{4t} \\
\iff \quad & K < \mu(\alpha - 1) + \frac{\mu(2V(\bar{\lambda} + \lambda_2) + \mu)}{4t} \equiv \widetilde{K}
\end{aligned}
\tag{A.1}
$$

Similarly, in the subgame where CP_1 choses low quality in stage 2, (L,H) is chosen instead of (L,L) if

$$
\begin{aligned}
\pi_{ISP}^{LH} + \pi_2^{LH} > \pi_{ISP}^{LL} + \pi_2^{LL} \iff \quad & U + \mu + f_2 - K + \frac{(V(\bar{\lambda} + \lambda_2) + \mu)^2}{4t} - f_2 > U + \frac{(V(\bar{\lambda} + \lambda_2))^2}{4t} \\
\iff \quad & K < \mu + \frac{\mu(2V(\bar{\lambda} + \lambda_2) + \mu)}{4t} \equiv \widehat{K}
\end{aligned}
\tag{A.2}
$$

Given two thresholds $\widetilde{K}$ and $\widehat{K}$, I consider four different regions in stage 2: $K > \max\{\widetilde{K}, \widehat{K}\}$, $\widetilde{K} < K < \widehat{K}$, $\widehat{K} < K < \widetilde{K}$ and $K < \min\{\widetilde{K}, \widehat{K}\}$. For the first case when $K > \max\{\widetilde{K}, \widehat{K}\}$, I need to compare the joint profits of the ISP and CP_1 under (H,L) and (L,L). It is easy to show that the profits under (L,L) are always higher than the profits under (H,L) in this region. Likewise, for $K < \min\{\widetilde{K}, \widehat{K}\}$, where (H,H) and (L,H) are compared, the profits under (H,H) are always higher than the profits under (L,H). As for $\widetilde{K} < K < \widehat{K}$, where (H,L) and (L,H) are compared, I can see that the joint profits under each quality specification are the same. Finally, for $\widehat{K} < K < \widetilde{K}$, where (H,H) and (L,L) are compared, I can find another threshold $\bar{K}$

as follows.

$$
\begin{aligned}
& \pi_{ISP}^{HH}+\pi_1^{HH} > \pi_{ISP}^{LL}+\pi_1^{LL} \\
\iff\ & U+\alpha\mu+f_1+f_2-2K+\frac{(V(\bar{\lambda}+\lambda_1)+\mu)^2}{4t}-f_1 > U+\frac{(V(\bar{\lambda}+\lambda_1))^2}{4t} \\
\iff\ & K < \frac{\alpha\mu}{2}+\frac{\mu(2V(\bar{\lambda}+\lambda_1)+\mu)}{4t} \equiv \bar{K}
\end{aligned}
\tag{A.3}
$$

Thus, in the region of $\widehat{K} < K < \widetilde{K}$, if $K < \bar{K}$, (H,H) is chosen; otherwise, (L,L) emerges. □

Proof of Proposition 1.2. Given the conditional equilibrium derived in stage 4 under non-paid peering regime case, ISP solely decides whether to and how much to invest in network quality. The ISP chooses (H,H) if $\pi_{ISP}^{HH} > \pi_{ISP}^{HL}$ and $\pi_{ISP}^{HH} > \pi_{ISP}^{LL}$. That is,

$$
\begin{aligned}
\pi_{ISP}^{HH} > \pi_{ISP}^{HL} \iff\ & U+\alpha\mu-2K > U+\mu-K \iff K < \mu(\alpha-1) \equiv \widetilde{\widetilde{K}} \\
\pi_{ISP}^{HH} > \pi_{ISP}^{LL} \iff\ & U+\alpha\mu-2K > U \iff K < \frac{\alpha\mu}{2} \equiv \bar{\bar{K}}
\end{aligned}
\tag{A.4}
$$

Thus, if $K < \min\{\widetilde{\widetilde{K}}, \bar{\bar{K}}\}$, (H,H) will emerge. In a similar way, I can obtain the conditions for (H,L) (or (L,H)) and (L,L) will emerge. □

Proof of Proposition 1.3. First, I define two sets A and B as follows.

A $:= \{\alpha \mid \alpha\in\mathbb{R},\ \alpha>1\}$, B $:= \{K \mid K\in\mathbb{R},\ K>0\}$

Then, the Cartesian product A × B $:= \{(\alpha,K) \mid \alpha\in A$ and $K\in B\}$ represents all possible pairs of α and K that form any quality specification. I now move on to the (H,H) specification under each regime. For the paid peering regime, I know that (H,H) emerges if $K < \tilde{K}$ for $\alpha < 2$ and $K < \bar{K}$ for $\alpha > 2$. Also, I find that $\tilde{K} = 0$ when $\alpha = 1$ and $\tilde{K}$ is increasing in α. Then, I can define another Cartesian product $A_1 \times B_1$ representing all possible pairs for (H,H) under paid peering, where A_1 and B_1 are defined as follows.

$A_1 := \{\alpha \mid \alpha\in\mathbb{R},\ \alpha>1\}$,

$B_1 := \{K \mid K\in\mathbb{R},\ K<\mu(\alpha-1)+\frac{\mu(2V(\bar{\lambda}+\lambda_2)+\mu)}{4t}$ for $\alpha<2$ and $K<\frac{\alpha\mu}{2}+\frac{\mu(V(2\bar{\lambda}+\lambda_1+\lambda_2)+\mu)}{4t}$ for $\alpha>2\}$

For the non-paid peering case, I can define $A_2 \times B_2$ representing all possible pairs for (H,H) under non-paid peering by defining the relevant sets in a similar way as follows.

$A_2 := \{\alpha \,|\, \alpha \in \mathbb{R},\, \alpha > 1\}$,

$B_2 := \{K \,|\, K \in \mathbb{R},\, K < \mu(\alpha - 1) \text{ for } \alpha < 2 \text{ and } K < \frac{\alpha\mu}{2} \text{ for } \alpha > 2\}$

I know that $A_2 = A_1 = A$ and $B_2 \subset B_1 \subset B$. Since $(A_1 \times B_1) = \{(\alpha, K) \,|\, \alpha \in A_1,\, K \in B_1\}$ and $(A_2 \times B_2)\ \{(\alpha, K) \,|\, \alpha \in A_2,\, K \in B_2\}$, I can show that $(A_2 \times B_2) \subset (A_1 \times B_1)$, i.e., $(A_2 \times B_2)$ is a proper subset of $(A_1 \times B_1)$. Therefore, I can conclude that (H,H) is more likely to emerge under paid peering than under non-paid peering. □

Proof of Proposition 1.4. By the first order conditions given in (1.10) and (1.13), there is no difference in (L,L) for each regime, meaning that the equilibrium λ_L in each regime is the same. However, as for (H,H) or (H,L), the results vary by regime. In either (H,H) or (H,L), CP_1's marginal benefits of investing in λ under each regime are as follows.

$$MB_{PP}^{(H,H)} = MB_{PP}^{(H,L)} = \frac{V(V(\bar{\lambda} + \lambda_1))}{2t} < MB_{NPP}^{(H,H)} = MB_{NPP}^{(H,L)} = \frac{V(V(\bar{\lambda} + \lambda_1) + \mu)}{2t} \tag{A.5}$$

Given that $C(\lambda)$ is increasing and convex in λ, i.e., $C'(\lambda) > 0$ and $C''(\lambda) > 0$, (A.5) implies that $\lambda_{NPP} \geq \lambda_{PP}$ given $\mu > 0$. □

Proof of Proposition 1.5. The threshold $\bar{\mu}$ can be derived from $CS_{HH} = \widehat{CS}_{HL}$ where $\widehat{CS}_{HL}$ denotes consumer surplus level from asymmetric quality specification under non-paid peering regime. The rest of the proof is in the main body. □

Proof of Corollary 1.1. After some algebra, it is easy to derive that

$\frac{\partial \bar{\mu}}{\partial \bar{\lambda}} = V\left(\frac{V(\bar{\lambda}+\lambda_L)}{\sqrt{V^2\left(\bar{\lambda}^2+2\bar{\lambda}\lambda_L+2\widehat{\lambda}_H^2-4\widehat{\lambda}_H\lambda_L+3\lambda_L^2\right)}} - 1\right)$,

$\frac{\partial \bar{\mu}}{\partial \lambda_L} = V\left(\frac{V(\bar{\lambda}-2\widehat{\lambda}_H+3\lambda_L)}{\sqrt{V^2\left(\bar{\lambda}^2+2\bar{\lambda}\lambda_L+2\widehat{\lambda}_H^2-4\widehat{\lambda}_H\lambda_L+3\lambda_L^2\right)}} - 2\right)$, and

$\frac{\partial \bar{\mu}}{\partial \widehat{\lambda}_H} = \frac{2V^2(\widehat{\lambda}_H-\lambda_L)}{\sqrt{V^2\left(\bar{\lambda}^2+2\bar{\lambda}\lambda_L+2\widehat{\lambda}_H^2-4\widehat{\lambda}_H\lambda_L+3\lambda_L^2\right)}} + V$. Given assumptions on parameters, the signs of each comparative statics can be derived as in Corollary. □

Proof of Lemma 1.1 and Lemma 1.2. These lemmas are analyzed in the body of the paper.

Proof of Proposition 1.6. First, total social welfare for each quality specification under each regime can be expressed as follows. Again, I normalize $\lambda_L = \lambda_H = \widehat{\lambda}_L$ to zero and $\widehat{\lambda}_H$ is denoted as λ.

$$\begin{aligned}
\widehat{SW}_{HH} =&(U+\alpha\mu-2K)+\frac{(V(\bar{\lambda}+\lambda)+\mu)^2}{2t}-2C(\lambda)+\widehat{CS}_{HH}\\
SW_{HH} =&(U+\alpha\mu-2K)+\frac{(V\bar{\lambda}+\mu)^2}{2t}+CS_{HH}\\
\widehat{SW}_{HL} =&(U+\mu-K)\quad+\frac{(V(\bar{\lambda}+\lambda)+\mu)^2}{4t}-C(\lambda)+\frac{(V\bar{\lambda})^2}{4t}+\widehat{CS}_{HL}\\
SW_{HL} =&(U+\mu-K)+\frac{(V\bar{\lambda}+\mu)^2}{4t}+\frac{(V\bar{\lambda})^2}{4t}+CS_{HL}\\
SW_{LL} =&\widehat{SW}_{LL}=U+\frac{(V\bar{\lambda})^2}{2t}+CS_{LL}
\end{aligned} \tag{A.6}$$

Given the assumption that costs K and $C(\lambda)$ are lower than revenues for the ISP and CPs, respectively, it is easy to show that $\widehat{SW}_{HH}$ is the highest, whereas $\widehat{SW}_{LL} = SW_{LL}$ is the lowest. It is obvious that SW_{HL} is the lowest of the other three of social welfare functions. As for SW_{HH} and $\widehat{SW}_{HL}$,

$$\begin{aligned}
\widehat{SW}_{HL}-SW_{HH}=&\underbrace{(\mu(1-\alpha)+K)}_{\text{(-) by assumption}}+\underbrace{(\frac{(V\bar{\lambda}+\mu)(2V-V\bar{\lambda}-\mu)+\lambda^2}{4t}-C(\lambda))}_{\text{(?) sum of CP profits}}\\
&+\qquad\underbrace{\widehat{CS}_{HL}-CS_{HH}}_{\text{(?) difference in consumer surplus}}
\end{aligned} \tag{A.7}$$

Therefore, the overall effects of network and content investments on total social welfare are ambiguous. □

APPENDIX B

PROOFS AND OMITTED DETAILS IN CHAPTER 2

Discussion on initial targeting technology. As mentioned earlier, the assumption of asymmetric initial targeting skill, $\gamma \equiv \gamma_I > \gamma_E \equiv 1$, can be justified by I's existing customer data and previous experience. Given that I has established stronger data analytic skills using such previous experience, I can outperform E if both are given the same amount of data: the overall targeting effectiveness takes a multiplicative form, $\gamma_j D_j$. Though this assumption is crucial to the model, the main implications are quite robust to different specifications. To check the robustness, here I modify the model in two ways: (1) additive separability of γ_j and D_j and (2) a symmetric targeting technology case. First, one might question whether such pre-existing data do not affect the marginal benefit of additional data acquisition but just provide a fixed amount of other data. In the latter case, in Equation (2.2), the overall targeting effectiveness, which is $\gamma_j D_j$, should have an additive separable form, such as $\gamma_j + D_j$. The main results from the main model still hold under this modification. In other words, there exists a threshold on τ^c, say τ_V^{AS}, where the superscript AS denotes additive separability, such that if $\tau^c < \tau_V^{AS}$, ($\tau^c > \tau_V^{AS}$) leads to the integration with I (E) and data foreclosure. The welfare comparison still implies that the integration with I and the consequential data foreclosure arising from greater privacy concerns is welfare-reducing. The detailed proof is omitted.

Second, if the model is changed to the symmetric setup with $\gamma = 1$, it becomes a typical vertical differentiation model. By solving the model in the same way, it is easy to see that the platform always prefers vertical integration with a high-quality seller and the foreclosure of data access for a low-quality seller. Thus, the symmetric model generates results that do not depend on privacy concerns and are thus not of interest in this paper.

The Case of $\mathbf{s_I > s_E}$. The main model analyzes the case of $s_E > s_I$, which means that E as a specialist can provide a higher-quality product than I as a generalist. This specification closely resembles the setup in Campbell et al. (2015). However, it is worth checking the robustness of the main results to the opposite case.

By a similar logic to that used in the main analysis, the indifference condition is $\theta'^{c}_{\mathcal{ND}} = \frac{P_I - P_E + (\frac{1}{\gamma D_I} - \frac{1}{D_E})}{s_I - s_E}$ for $i \in \mathcal{ND}$ and $\theta'^{c}_{\mathcal{D}} = \frac{P_I - P_E}{s_I - s_E}$ for $i \in \mathcal{D}$. The weighted indifference condition can be rewritten in a simple way as follows.

$$\theta'^{c} = \frac{P_I - P_E + (1-\tau^c)\Delta'}{s'}, \tag{B.1}$$

where $\Delta' = (\frac{1}{\gamma D_I} - \frac{1}{D_E})$ and $s' = s_I - s_E$. The market share for each seller is given by $X_I = 1 - \theta'^{c}$ and $X_E = \theta'^{c}$ under $s_I > s_E$. In this case, the ranking of data price C is $\bar{C}_E < \bar{\bar{C}}_E < \bar{C}_I < \bar{\bar{C}}_I$. This leads to the platform either setting a lower price at $C = \bar{C}_E$ to obtain both sellers or setting a higher price $C = \bar{\bar{C}}_I$ to obtain only seller I. As in Proposition 2.2, there exists a threshold on τ^c denoted as $\tau'_{NV} \equiv \frac{\sqrt{4(\gamma-1)\gamma\left(9\gamma(\gamma+1)+4(\gamma-1)\gamma s^2-4\gamma(\gamma+4)s+2s\right)+9}-2\gamma(\gamma+2(\gamma-1)s-2)+1}{4\gamma(\gamma+1)-2}$ below which the platform sets a higher price, which means (B,N) in equilibrium, and above which the platform sets a lower price, which leads to (B,B). In addition, the platform and I want to vertically integrate and foreclose the unaffiliated entrant from data access in equilibrium without any conditions. Thus, (B,N) is the only data acquisition equilibrium under vertical integration. Consumer surplus under no vertical integration, which involves (B,B), reaches a higher level than that under vertical integration, which means (B,N). If E stays out of the market due to data foreclosure, a monopoly makes consumers worse off, as analyzed in Section 2.7.2. This suggests that the main implications for the negative impact of privacy concerns on market competition and consumers still hold.

Proof of Proposition 2.1. Given that the distribution function F is continuous from the closed unit interval [0,1], there exists a fixed point, τ_c, by the fixed point theorem. □

Proof of Proposition 2.2. The corresponding threshold on τ^c is derived from $2\bar{C}_I\tau^c = \pi_p^{BB} = \pi_p^{NB} = \bar{\bar{C}}_E\tau^c$, which leads to $\tau_{NV} = \frac{\sqrt{9\left(\gamma^2-2\right)^2+16(\gamma-1)^2\gamma^2 s^2-8(\gamma((\gamma-9)\gamma+6)+2)\gamma s}-\gamma(\gamma+4(\gamma-1)s+4)+2}{2(\gamma-2)\gamma-4}$. The corresponding product price, P_j, and each seller's market share, X_j, can be derived by substituting the equilibrium data acquisition status into Equations (2.7). □

Proof of Corollary 2.1. The proof is in the paper.

Proof of Proposition 2.3. Most steps in the proof are described in the paper.

Proof of Proposition 2.4. First, I compare E's profit under (B, B) in the no vertical integration case to that under the vertical integration with I case—which means (B, N)—. Then, $\pi_E^{BB} - \pi_{VI,F}^E = \frac{(1-\tau^c)\tau^c\left(\left(\gamma^2-1\right)\left((\tau^c)^2+\tau^c-2\right)+2\gamma(2\gamma-1)s(\tau^c+1)\right)}{9\gamma^2 s(\tau^c+1)^2}$. To show that this is always positive, all I need to show is that $\left((\tau^c)^2 + \tau^c - 2\right) + \frac{2\gamma(2\gamma-1)s(\tau^c+1)}{\left(\gamma^2-1\right)} > 0$. The second term is always positive under the assumptions of $\gamma > 1$ and $s \in [0.5, 1]$, but the first term is always negative for $\tau^c \in [0, 1]$. The second positive term attains a minimum of $4(1 + \tau^c)$ at $s = \frac{1}{2}$ and $\gamma \to \infty$, which implies that the equation attains a minimum of $(\tau^c)^2 + \tau^c - 2 + 4(1 + \tau^c) = (\tau^c)^2 + 5\tau^c + 2$, which is always positive given τ^c. Likewise, the comparison between (N, B) in the no vertical integration case and in the vertical integration case is as follows. $\pi_E^{NB} - \pi_{VI,F}^E = \frac{(1-\tau^c)\tau^c(2\gamma(\tau^c+1)(2s+\tau^c-1)+(1-\tau^c)(\tau^c+2))}{9\gamma^2 s(\tau^c+1)^2}$, which is always positive. □

Proof of Proposition 2.5. For simplicity, I normalize s_I to zero, which implies that $s = s_E$. The difference between the consumer surplus under (N, B) and that under (B, N) is as follows.

$$CS^{NB} - CS^{BN} = \frac{-\lambda\left(\sqrt{4\lambda+1}+12\right)\left(\gamma^2-1\right) + \left(11\sqrt{4\lambda+1}-3\right)\left(\gamma^2-1\right) + \lambda\left(\sqrt{4\lambda+1}-3\right)\gamma(5\gamma-4)s}{18\lambda^2\gamma^2 s} \tag{B.2}$$

Given λ and γ, it is easy to show that $CS^{NB} > CS^{BN}$ if s is larger than a certain threshold. The threshold denoted as $\bar{s}$ can be obtained from $CS^{NB} - CS^{BN} = 0$, which is $\bar{s} = \frac{\left(4\lambda+15\sqrt{4\lambda+1}+1\right)\left(\gamma^2-1\right)}{4\lambda\gamma(5\gamma-4)}$. □

Proof of Proposition 2.6. The right-hand side of Equation (2.17) given each data acquisition case is as follows.

$$RHS_{BB} = \theta_{BB}^c F\left(\psi^{-1}\left(\tfrac{r}{\gamma(1+\tau^c)}\right)\right) + (1-\theta_{BB}^c)F\left(\psi^{-1}\left(\tfrac{r}{(1+\tau^c)}\right)\right)$$
$$RHS_{NB} = \theta_{NB}^c F\left(\psi^{-1}\left(\tfrac{r}{\gamma}\right)\right) + (1-\theta_{NB}^c)F\left(\psi^{-1}\left(\tfrac{r}{(1+\tau^c)}\right)\right)$$
$$RHS_{BN} = \theta_{BN}^c F\left(\psi^{-1}\left(\tfrac{r}{\gamma(1+\tau^c)}\right)\right) + (1-\theta_{BN}^c)F\left(\psi^{-1}(r)\right)$$

$RHS_{NN} = \theta^c_{NN} F\Big(\psi^{-1}(\frac{r}{\gamma})\Big) + (1-\theta^c_{NN}) F\Big(\psi^{-1}(r)\Big).$

The equilibrium τ^c under each data acquisition case is the fixed point satisfying Equation (2.17). First, I show that the RHS under the four data acquisition cases can be ranked. Given that $\gamma > 1$ and $s > 1/2$, $\theta^c_{NB} < \theta^c_{BB} < \theta^c_{NN} < \theta^c_{BN}$. As long as $F\Big(\psi^{-1}(r)\Big) - F\Big(\psi^{-1}(\frac{r}{1+\tau^c})\Big)$ is sufficiently large, it is easy to show that $RHS_{BB} < RHS_{NN}$ because F is non-decreasing and ψ^{-1} is increasing. It remains to be shown that $RHS_{BB} < \min\{RHS_{NB}, RHS_{BN}\}$ and $RHS_{NN} > \max\{RHS_{NB}, RHS_{BN}\}$. As for RHS_{NB} and RHS_{BB}, it is enough to show that $\theta^c_{NB} F\Big(\psi^{-1}(\frac{r}{\gamma})\Big) > \theta^c_{BB} F\Big(\psi^{-1}(\frac{r}{\gamma(1+\tau^c)})\Big)$. Given that γ and $F\Big(\psi^{-1}(\frac{r}{\gamma})\Big) - F\Big(\psi^{-1}(\frac{r}{\gamma(1+\tau^c)})\Big)$ are sufficiently large, the condition always holds. Using similar logic, $RHS_{BN} > RHS_{BB}$, $RHS_{NB} < RHS_{NN}$, and $RHS_{BN} < RHS_{NN}$ can be shown: in any case, the assumption that the effect of information acquisition on the willingness to disclose data is greater than the same effect on market share is sufficient in this regard. This implies that RHS_{BB} is the lowest, while RHS_{NN} is the highest for all ranges of γ and s. The relative size of RHS_{BN} and RHS_{NB} depends on the size of γ and s, respectively.

Finally, I prove that the fixed point for each case uniquely exists and that the fixed point that hits the lower RHS is smaller than another fixed point that hits the higher RHS by using the same logic used by Nayeem and Yankelevich (2017). Let $G_k : [0,1] \to \mathbb{R}$ be defined by $G_k \equiv \tau^c - RHS_k$, where $k = \{BB, BN, NB, NN\}$. Note that $0 < RHS_k(0)$ and $1 > RHS_k(1)$, which leads to $G_k(0) < 0 < G_k(1)$. Let me first show that $\tau^c_{BB} < \tau^c_{NN}$. By the Intermediate Value Theorem, there exists at least one $\tau^c_{BB} \in (0,1)$ such that $G_{BB}(\tau^c_{BB}) = 0$. I now prove by contradiction that there exists a unique such τ^c_{BB}. Suppose τ^c_{BB} and τ'^c_{BB} exist such that $0 < \tau^c_{BB} < \tau'^c_{BB} < 1$ and $G_{BB}(\tau^c_{BB}) = G_{BB}(\tau'^c_{BB}) = 0$. By Rolle's Theorem, there exists $\tau^c_0 \in (\tau^c_{BB}, \tau'^c_{BB})$ such that $G'_{BB}(\tau^c_0) = 0$. By the Mean Value Theorem, there exists $\tau^c_* \in (0, \tau^c_{BB})$ such that $G'_{BB}(\tau^c_*) = -G_{BB}(0)/\tau^c_{BB} > 0 = G'_{BB}(\tau^c_0)$. However, G'_{BB} is nondecreasing, hence the contradiction. Using similar logic, I can show that τ^c_{BB} and τ^c_{NN} are unique. It remains to be shown that $\tau^c_{BB} < \tau^c_{NN}$ for $RHS_{BB} < RHS_{NN}$. Given that $RHS_{BB} < RHS_{NN}$, $\tau^c_{BB} = RHS_{BB}(\tau^c_{BB}) < RHS_{NN}(\tau^c_{BB})$ and $\tau^c_{NN} = RHS_{NN}(\tau^c_{NN})$.

This implies that $G_{NN}(\tau^c_{BB}) < 0 = G_{NN}(\tau^c_{NN})$. By the Mean Value Theorem, there exists $\tau'^c_{NN} \in (0, \tau^c_{NN})$ such that $G'_{NN}(\tau'^c_{NN}) = -G_{NN}(0)/\tau'^c_{NN} > 0$. By the convexity of G_{NN}, $G'_{NN}(\tau^c) \geq G'_{NN}(\tau'^c_{NN})$ for $\forall \tau^c \in (\tau'^c_{NN}, 1)$. Thus, G_{NN} is increasing on $[\tau'^c_{NN}, 1]$. Moreover, $G_{NN}(\tau^c) \geq 0$ for $\forall \tau^c \in [\tau^c_{NN}, 1]$. Since $G_{NN}(\tau^c_{BB}) < 0$, $\tau^c_{BB} < \tau^c_{NN}$. The remaining cases can be proved in the same way. □

Numerical Exercise for Robustness Check in Section 2.7.1. From the utility specification as in Equation (2.16), consumer surplus can be obtained in the following way.

$$\begin{aligned} CS^{\text{Foresight}} =& \int_0^{\theta^c_{\mathcal{D}}} \int_0^{\tau^c} \left(V + \theta s_I - P_I - \frac{\psi(x)}{r}\right) dF(x)d\theta + \int_{\theta^c_{\mathcal{D}}}^1 \int_0^{\tau^c} \left(V + \theta s_E - P_E - \frac{\psi(x)}{r}\right) dF(x)d\theta \\ &+ \int_0^{\theta^c_{\mathcal{ND}}} \int_{\tau^c}^1 \left(V + \theta s_I - P_I - \frac{1}{\gamma D_I}\right) dF(x)d\theta + \int_{\theta^c_{\mathcal{ND}}}^1 \int_{\tau^c}^1 \left(V + \theta s_E - P_E - \frac{1}{D_E}\right) dF(x)d\theta. \end{aligned} \tag{B.3}$$

I make parametric and numerical assumptions: F is a uniform distribution ($\tau_i \sim U[0,1]$), $V = 2$, $\psi(\tau_i) = \lambda\tau_i$, and $r = 1$. For simplicity, I compare two cases where (1) $\tau^c_{BN} < \tau^c_{NB}$ under $s = \frac{1}{2}$, $\gamma = 2$, and 22) $\tau^c_{BN} > \tau^c_{NB}$ under $s = 1$, $\gamma = \frac{3}{2}$. The comparison is shown in the tables below.

(1) $s = \frac{1}{2}$, $\gamma = 2$ ($\tau^c_{BN} < \tau^c_{NB}$)

		(B,N)	(N,B)
$\lambda = 4$	τ^c	0.38	0.39
	CS	1.78	1.80
$\lambda = 5$	τ^c	0.33	0.35
	CS	1.75	1.78
$\lambda = 6$	τ^c	0.31	0.32
	CS	1.74	1.76
$\lambda = 10$	τ^c	0.24	0.25
	CS	1.69	1.71

(2) $s = 1$, $\gamma = \frac{3}{2}$ ($\tau^c_{BN} > \tau^c_{NB}$)

		(B,N)	(N,B)
$\lambda = 4$	τ^c	0.43	0.41
	CS	1.69	1.68
$\lambda = 5$	τ^c	0.39	0.37
	CS	1.67	1.65
$\lambda = 6$	τ^c	0.35	0.34
	CS	1.65	1.63
$\lambda = 10$	τ^c	0.27	0.26
	CS	1.59	1.58

Proof of Proposition 2.7. Since the solution to τ^c for each data acquisition case can be implicitly determined, I apply the implicit function theorem to calculate comparative statics. First, from Equation (2.17), let $G = \tau^c - \theta^c F\Big(\psi^{-1}\big(\frac{r}{\gamma D_I}\big)\Big) + (1-\theta^c)F\Big(\psi^{-1}\big(\frac{r}{D_E}\big)\Big)$. To see the effect of γ on the equilibrium τ^c, I need to show the sign of $\frac{d\tau^c}{d\gamma} = -\big(\frac{\partial G}{\partial \gamma}\big)/\big(\frac{\partial G}{\partial \tau^c}\big)$. Similarly, for the effect of s on τ^c, I need to calculate $\frac{d\tau^c}{ds} = -\big(\frac{\partial G}{\partial s}\big)/\big(\frac{\partial G}{\partial \tau^c}\big)$. After some algebra, it can be shown that $\frac{d\tau^c}{ds} > 0$ and $\frac{d\tau^c}{d\gamma} < 0$ if $\gamma > \max\{1+\tau^c, \frac{2}{(1+\tau^c)^2}\}$. The detailed proof is omitted. $\square$

Proof of Proposition 2.8. By the proof of Proposition 2.4, $\overline{FC}_{BN} < \min\{\overline{FC}_{BB}, \overline{FC}_{NB}\}$. $\square$

Proof of Proposition 2.9. For simplicity, I assume $V = 2$. First, I compare the incumbent's monopoly profits under buying or not buying data to those under the main model in which the entrant does not stay out of the market. Since $\pi_I^{BN} > \pi_I^{BB}$, it is enough to show that $\pi_B^{Mono} = \pi_N^{Mono} > \pi_I^{BN}$: $\pi_B^{Mono} = \pi_N^{Mono}$ because the platform extracts the rents in the form of the data price. Since $\pi_I^{Mono} - \pi_I^{BN} = \frac{9s(\tau+1)^2((2+s_I)\gamma+\tau-1)^2-4(\gamma(\tau+1)(s-\tau+1)+\tau-1)^2}{36\gamma^2 s(\tau+1)^2}$, all I need to show is that the numerator is positive. If its minimum is positive, the proof is complete. Given that the numerator is increasing in both of γ and s, the minimum is $\frac{1}{2}(\tau^c(\tau^c(\tau^c(\tau^c + 44) + 44) + 40) + 7)$ at $\gamma = 1$ and $s = \frac{1}{2}$, which is always positive.

Next, I compare the platform's profits under the monopoly and duopoly cases. For each data acquisition case under a duopoly,
$\pi_p^{Mono} - \pi_p^{BB} = -\frac{(\tau^c-1)\tau^c\left(8(\tau^c-1)(2\gamma-\tau^c-2)+2(10+9s_I)\gamma s(\tau^c+1)+9s\left((\tau^c)^2+\tau^c-2\right)\right)}{36\gamma^2 s(\tau^c+1)^2}$ and $\pi_p^{Mono} - \pi_p^{NB} = \frac{(\tau^c-1)\tau^c\left(4\gamma(\tau^c-1)(\gamma(\tau^c+2)-2(\tau^c+1))+s\left(16\gamma^2(\tau^c+1)-18(2+s_I)\gamma(\tau^c+1)-9\left((\tau^c)^2+\tau^c-2\right)\right)\right)}{36\gamma^2 s(\tau^c+1)^2}$.

To show that $\pi_p^{Mono} - \pi_p^{BB} > 0$, it is enough to show that $8(\tau^c - 1)(2\gamma - \tau^c - 2) + 2(10 + 9s_I)\gamma s(\tau^c + 1) + 9s\left((\tau^c)^2 + \tau^c - 2\right) > 0$. Given that the right-hand side of the equation is increasing in s, the minimum is $\gamma(9s_I(\tau^c + 1) + 26\tau^c - 6) - \frac{7}{2}\left((\tau^c)^2 + \tau^c - 2\right)$ at $s = \frac{1}{2}$. The minimized value is greater than zero if τ^c is larger than approximately 0.1, which implies that $\pi_p^{Mono} - \pi_p^{BB} > 0$ holds in most cases. Using similar logic, I can also show that $\pi_p^{Mono} - \pi_p^{NB} > 0$.

Lastly, consumer surplus under a monopoly is given as follows.

$$
\begin{aligned}
CS^{Mono} = &\int_0^{\tau^c} \left(v(\tau^c) - \frac{\psi(x)}{r} \right) dF(x) + \tau^c \left[\int_{\theta^c_{\mathcal{D}\_Mono}}^1 \Big(V + \theta s_I - P_I \Big) d\theta \right] \\
&+ (1-\tau^c) \left[\int_{\theta^c_{\mathcal{ND}\_Mono}}^1 \Big(V + \theta s_I - P_I - \frac{1}{\gamma D_I} \Big) d\theta \right],
\end{aligned} \tag{B.4}
$$

where $\theta^c_{\mathcal{D}\_Mono} = \frac{14\sqrt{4\lambda+1}+\lambda(18\lambda+29\sqrt{4\lambda+1}-9)+2}{24\lambda^2}$. Under the numerical examples of $V = 2, \gamma = 2, s = \frac{4}{5}$, and $s_I = \frac{1}{2}$ (which means that $s_E = 1.3$), $CS^{Mono}_B = \frac{14\sqrt{4\lambda+1}+\lambda(18\lambda+29\sqrt{4\lambda+1}-9)+2}{24\lambda^2}$ and $CS^{Mono}_N = \frac{23(\sqrt{4\lambda+1}+1)+2\lambda(36\lambda+34\sqrt{4\lambda+1}+57)}{96\lambda^2}$ where the subscripts B and N denote Buy and Not buy data. Given that CS^{BN} is always lower than CS^{NB} or CS^{BB} as in Figure 2.6, it is enough to show that $CS^{Mono}_B < CS^{BN}$ since $CS^{Mono}_N < CS^{Mono}_B$. After some algebra, $CS^{BN} - CS^{Mono}_B = \frac{45\lambda(2\lambda-\sqrt{4\lambda+1}+5)-2(27\sqrt{4\lambda+1}+5)}{144\lambda^2}$, which attains the local minimum of 0.553 at $\lambda \approx 15.64$. Since the minimum value is still positive, any consumer surplus levels under entry are greater than those under a monopoly. The result still holds even under all different sets of parametric space. The detailed steps are omitted and can be provided upon request. □

Proof of Proposition 2.10. The proof is in the paper.

Full Results from the Cross-sectional Data. Table B.1 reports the full results. For a robustness check, I also run the same regression with a pure cross-sectional dataset with 2,058 observations. The result is reported in Table B.2; qualitatively similar results are observed. Lastly, as in Kummer and Schulte (2017), I use the sample with twin apps—with 85 total observations—in which there are two versions of each app, one free and one paid, launched by the same developer with the same app name. The result in Table B.3 shows a similar pattern. The detailed description of additional variables and results is available upon request.

Table B.1 Results from the Cross-Sectional Data

	WO Controls	W Controls	IV	IPW OLS	IPW IV
Dum_privacy_Top_Dev	0.670***	0.560***	0.544***	0.743***	0.580***
	(0.0979)	(0.0798)	(0.122)	(0.0823)	(0.166)
Dum_privacy	0.0547	-0.182***	-0.177***	-0.367***	-0.437***
	(0.0636)	(0.0555)	(0.0622)	(0.0651)	(0.106)
Top_Dev	0.909***	0.422***	0.460**	0.221***	0.708**
	(0.0863)	(0.0713)	(0.213)	(0.0694)	(0.320)
D_Price	-3.828***	-3.941***	-3.634**	-3.918***	0.212
	(0.0611)	(0.0561)	(1.538)	(0.0820)	(2.500)
ln_price	0.0688	0.0237	-0.276	0.0258	-4.115*
	(0.0424)	(0.0372)	(1.503)	(0.0491)	(2.498)
ln_App_Age		1.044***	1.042***	1.016***	0.995***
		(0.0549)	(0.0557)	(0.0662)	(0.0687)
avg_rating		1.387***	1.398***	1.252***	1.378***
		(0.0557)	(0.0787)	(0.0844)	(0.135)
Numberofpics		0.0420***	0.0430***	0.0405***	0.0560***
		(0.00278)	(0.00580)	(0.00339)	(0.0110)
totalpermissions		0.0351***	0.0355***	0.0439***	0.0535***
		(0.00278)	(0.00326)	(0.00374)	(0.00794)
Num_of_apps_per_dev		0.0333***	0.0327***	0.0402***	0.0336***
		(0.00374)	(0.00414)	(0.00542)	(0.00712)
Constant	11.47***	-1.248***	-1.301**	-0.615	-1.278*
	(0.0599)	(0.433)	(0.517)	(0.537)	(0.760)

Table B.2 Results from the Pure Cross-Sectional Data

	WO Controls	W Controls	IV	IPW OLS	IPW IV
Dum_privacy_Top_Dev	0.544**	0.334	-0.0197	0.580***	0.262
	(0.257)	(0.211)	(0.595)	(0.219)	(0.491)
Dum_privacy	-0.377**	-0.476***	-0.559	-0.688***	-0.469
	(0.161)	(0.137)	(0.400)	(0.150)	(0.305)
Top_Dev	1.100***	0.647***	1.415**	0.372*	1.002*
	(0.228)	(0.192)	(0.673)	(0.204)	(0.595)
D_Price	-3.915***	-3.899***	4.400	-3.873***	1.549
	(0.145)	(0.141)	(4.800)	(0.160)	(4.003)
ln_price	0.119	-0.0139	-8.868*	0.0467	-5.941
	(0.105)	(0.0867)	(5.121)	(0.104)	(4.326)
ln_App_Age		1.054***	0.943***	1.021***	0.840***
		(0.116)	(0.171)	(0.145)	(0.281)
avg_rating		1.238***	1.857***	1.135***	1.729***
		(0.116)	(0.455)	(0.205)	(0.529)
Numberofpics		0.0489***	0.0571***	0.0399***	0.0428***
		(0.00690)	(0.0196)	(0.00845)	(0.0166)
totalpermissions		0.0432***	0.0641***	0.0527***	0.0583***
		(0.00618)	(0.0182)	(0.00709)	(0.0138)
Num_of_apps_per_dev		0.0317***	0.0162	0.0389***	0.0271
		(0.0108)	(0.0206)	(0.0128)	(0.0192)
Constant	11.01***	-1.092	-4.070*	-0.210	-2.309
	(0.157)	(0.877)	(2.352)	(1.356)	(2.359)

Table B.3 Results from the Twin App Data

	WO Controls	W Controls	IV	IPW OLS	IPW IV
Dum_privacy_Top_Dev	1.088	3.255***	3.025***	3.678***	3.443***
	(0.965)	(1.180)	(1.008)	(1.140)	(1.111)
Dum_privacy	0.0403	-1.472*	-1.967**	-1.879**	-2.564***
	(0.796)	(0.840)	(0.813)	(0.830)	(0.848)
Top_Dev	-0.123	-2.183*	-1.931**	-2.593**	-2.381**
	(0.741)	(1.083)	(0.892)	(1.033)	(0.940)
D_Price	-5.103***	-4.195***	-6.746***	-4.092***	-7.288***
	(0.625)	(0.623)	(1.773)	(0.620)	(2.267)
ln_price	0.267	0.189	2.730*	0.190	3.704
	(0.521)	(0.385)	(1.635)	(0.372)	(2.350)
ln_App_Age		0.801**	1.102***	0.731**	1.279***
		(0.381)	(0.340)	(0.329)	(0.473)
avg_rating		1.662**	1.621**	1.858***	1.887**
		(0.657)	(0.731)	(0.623)	(0.952)
Numberofpics		0.0445	0.0259	0.0349	-0.0102
		(0.0526)	(0.0487)	(0.0488)	(0.0588)
totalpermissions		0.0852***	0.109***	0.0929***	0.127***
		(0.0263)	(0.0265)	(0.0259)	(0.0330)
Num_of_apps_per_dev		0.213**	0.128	0.229**	0.125
		(0.0901)	(0.0979)	(0.0903)	(0.115)
Constant	13.21***	2.103	1.730	1.833	0.0760
	(0.653)	(3.210)	(3.421)	(3.136)	(4.429)

APPENDIX C

PROOFS IN CHAPTER 3

Proof of Proposition 3.1. As shown in the paper, we need to first show whether each CP has an incentive to accept any zero-rating offer when there is no fee. The profit difference for each CP can be obtained as follows.

$$\pi_1^{ZR_1} - \pi_1^{NZ} = \frac{\frac{\left(\alpha\left(5-3\gamma^2\right)+(\gamma-2)\gamma-1\right)^2}{\left(2\gamma^2+\gamma-6\right)^2} - \frac{4\left(\gamma^2-2\right)^2\left(\alpha\left(2\gamma^2-3\right)+\gamma\right)^2}{\left(2\gamma^4-9\gamma^2+12\right)^2}}{4\left(\gamma^2-1\right)}$$

$$\pi_2^{ZR_2} - \pi_2^{NZ} = \frac{\frac{\left(-\alpha(\gamma-2)\gamma+\alpha+3\gamma^2-5\right)^2}{\left(2\gamma^2+\gamma-6\right)^2} - \frac{4\left(\gamma^2-2\right)^2(\gamma(\alpha+2\gamma)-3)^2}{\left(2\gamma^4-9\gamma^2+12\right)^2}}{4\left(\gamma^2-1\right)}$$

Both equations above are positive for $1 \leq \alpha \leq 2$ and $0 < \gamma < \gamma_{NZ}$, which implies that each CP wants to be zero-rated. Next, As in Equation (3.17), $\pi_{ISP}^{ZR_1} - \pi_{ISP}^{ZR_2} = \frac{(\alpha^2-1)(\gamma^2-1)}{(24-18\gamma^2+4\gamma^4)} < 0 \quad \because \alpha \geq 1$. Thus, if the ISP chooses low quality CP_2 as a zero-rating partner here. Last, we need to check whether the ISP has any deviation incentive. We compare $\pi_{ISP}^{ZR_2}$ to π_{ISP}^{NZ} and π_{ISP}^{FZ}. First,

$$\pi_{ISP}^{ZR_2} - \pi_{ISP}^{FZ} = -\frac{\left(\alpha\left(\gamma^4-3\gamma^2+4\right)+2\gamma\left(\gamma^2-2\right)\right)^2}{2(\gamma-1)(\gamma+1)\left(\gamma^2-4\right)^2\left(2\gamma^4-9\gamma^2+12\right)},$$

which is always positive. Second,

$$\pi_{ISP}^{ZR_2} - \pi_{ISP}^{NZ} = \frac{1}{4}\Big(\frac{2\alpha^2\left(\gamma^2-2\right)^2-4\alpha\gamma-4\gamma^2+6}{\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)} + \frac{\alpha^2\left(-(\gamma+5)\gamma^2+\gamma+7\right)-2\alpha\left(\gamma^3+\gamma^2+\gamma-1\right)-\gamma^2(\gamma+5)+\gamma+7}{(\gamma-1)(\gamma+1)(\gamma+2)^2(2\gamma-3)}\Big).$$

From Equation (3.18), we can see that $\pi_{ISP}^{ZR_2} < \pi_{ISP}^{NZ}$ if γ is sufficiently small whereas $\pi_{ISP}^{ZR_2} > \pi_{ISP}^{NZ}$ if γ is large enough. The threshold, which is denoted as γ_I, can be implicitly obtained as the solution satisfying $\pi_{ISP}^{ZR_2} - \pi_{ISP}^{NZ} = 0$. □

Proof of Proposition 3.2. First, Equation (3.19) shows the equilibrium fee for each CP. Next, as in Equation (3.20), $\widehat{\pi}_{ISP}^{ZR_1} - \widehat{\pi}_{ISP}^{ZR_2}$ is greater than zero if $\gamma < \tilde{\gamma}_{PZ}$ where $\tilde{\gamma}_{PZ}$ is the γ

satisfying $\widehat{\pi}_{ISP}^{ZR_1} - \widehat{\pi}_{ISP}^{ZR_2} = 0$. It remains to show $\tilde{\gamma}_{PZ} < \tilde{\gamma}_{NZ}$ under our assumptions on α and γ. Note that $\tilde{\gamma}_{NZ}$ is the solution satisfying $x_2^{NZ} = \frac{\alpha\left(\gamma^2-2\gamma-1\right)-3\gamma^2+5}{2\left(2\gamma^4+\gamma^3-8\gamma^2-\gamma+6\right)} = 0$. By comparing the left-hand side of Equation (3.20) to that of x_2^{NZ}, it is easy to see that the fixed point on γ satisfying $\widehat{\pi}_{ISP}^{ZR_1} - \widehat{\pi}_{ISP}^{ZR_2} = 0$ is smaller than that satisfying $x_2^{NZ} = 0$, which implies that $\tilde{\gamma}_{PZ} < \tilde{\gamma}_{NZ}$. $\square$

Proof of Lemma 3.1. First, r_1^{FZ} and r_2^{FZ} can be obtained as in Equation (3.21). After some algebra, it is obvious that r_1^{FZ} is always positive. For r_2^{FZ}, it can be shown that if $\gamma < \gamma_{Subsidy} = \frac{1}{2}\left(-\sqrt{\alpha^2-1} + \sqrt{2\alpha\left(\sqrt{\alpha^2-1}+\alpha\right)+7} - \alpha\right)$, $r_2^{FZ} > 0$. That is, if $\gamma > \gamma_{Subsidy}$, $r_2^{FZ} < 0$, which implies a positive subsidy to CP_2 for zero-rating. The threshold $\gamma_{Subsidy}$ can be obtained as the solution γ satisfying $r_2^{FZ} = \frac{\frac{\left(\left(\gamma^2-2\right)^2-\alpha\gamma\right)^2}{\left(2\gamma^4-9\gamma^2+12\right)^2} - \frac{(\gamma(\alpha+\gamma)-2)^2}{\left(\gamma^2-4\right)^2}}{\gamma^2-1} = 0$. $\square$

Proof of Proposition 3.4. First, we check whether each CP has an incentive to accept any zero-rating offer from the integrated firm. Assuming that the ISP and CP_1 are integrated, the unaffiliated CP_2 has an incentive to accept the offer because

$\pi_2^A - \pi_2^R = \frac{\frac{\left(-\alpha\left(4\gamma^2+3\right)\gamma+3\gamma^2+4\right)^2}{\left(\gamma^2+4\right)^2} - \frac{9(\gamma(\alpha+\gamma)-2)^2}{\left(\gamma^2-4\right)^2}}{9\left(\gamma^2-1\right)} > 0$ for $1 \leq \alpha \leq 2$. Similarly, for the case in which the ISP and CP_2 integrate with each other, the unaffiliated CP_1 also wants to be zero-rated because $\pi_1^A - \pi_1^R = \frac{\left(\alpha\left(\gamma^2-2\right)+\gamma\right)^2}{\left(\gamma^4-5\gamma^2+4\right)^2} + \frac{\left(3\alpha\gamma^2+4\alpha-4\gamma^3-3\gamma\right)^2}{9\left(\gamma^2-1\right)\left(\gamma^2+4\right)^2} > 0$. Given that any CP accepts the offer, it remains to show with which CP the ISP wants to make an integration. As in the paper, $\pi_{VICP_n}^A - \pi_{VICP_n}^R < 0$ for any CP n. On top of that, $\pi_{VICP_1}^R - \pi_{VICP_2}^R = \frac{\left(\alpha^2-1\right)\left(4\left(\gamma^4+\gamma^2\right)-11\right)}{6\left(\gamma^4+3\gamma^2-4\right)} > 0$. $\square$

Proof of Proposition 3.5. Most steps are in the paper. Obviously, γ_I is the solution satisfying $\widehat{\pi}_{VICP_1}^A - \pi_{VICP_1}^R = 0$ where

$$\widehat{\pi}_{VICP_1}^A - \pi_{VICP_1}^R = \frac{\left(\alpha\left(10\gamma^6-89\gamma^4+28\gamma^2+96\right)\gamma-24\gamma^6+11\gamma^4+80\gamma^2-112\right)\left(\gamma^2\left(\alpha\gamma\left(2\gamma^2-5\right)+7\right)-4\right)}{18\left(\gamma^6-\gamma^4-16\gamma^2+16\right)^2}. \square$$

Proof of Proposition 3.6. First, assuming that $\gamma > \gamma_I$, we need to compare total social welfare level under the case of zero-rating CP_2's content only (in no vertical integration game without monetary transfer) to that of zero-rating CP_1's content only (in vertical integration game without monetary transfer). Total social welfare level for each case can be derived as follows.

$$\begin{aligned}
SW^R_{VICP_1} =& \frac{1}{18\left(\gamma^4+3\gamma^2-4\right)^2}\Big(3\left(\gamma^2+4\right)\left(\alpha^2\left(4\gamma^6-18\gamma^2+15\right)+2\alpha\gamma\left(5\gamma^2-6\right)-3\gamma^2+4\right) \\
& -2\left(\gamma^2-1\right)\left(-\alpha\left(4\gamma^2+3\right)\gamma+3\gamma^2+4\right)^2\Big) \\
SW_{ZR_2} =& \frac{-1}{2\left(\gamma^2-1\right)\left(2\gamma^4-9\gamma^2+12\right)^2}\Big(\alpha^2\left(\gamma^2-2\right)^2\left(4\gamma^4-15\gamma^2+20\right) \\
& +2\alpha\left(4\gamma^6-26\gamma^4+57\gamma^2-44\right)\gamma+8\gamma^8-60\gamma^6+170\gamma^4-217\gamma^2+108\Big)
\end{aligned}$$

When there are monetary transfers for zero-rating, we need to compare the case of full zero-rating (in no vertical integration game) to that of full zero rating or zero-rating CP_1's content only (in vertical integration game).

$$\begin{aligned}
SW^A_{VICP_1} - SW_{FZ} =& -\frac{\left(\alpha\left(\gamma^2-2\right)+\gamma\right)^2}{\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)} \\
SW^R_{VICP_1} - SW_{FZ} =& \frac{1}{18\left(\gamma^4+3\gamma^2-4\right)^2}\Big(3\left(\gamma^2+4\right)(\alpha^2\left(4\gamma^6-18\gamma^2+15\right)+2\alpha\gamma\left(5\gamma^2-6\right)-3\gamma^2+4) \\
& -2\left(\gamma^2-1\right)\left(-\alpha\left(4\gamma^2+3\right)\gamma+3\gamma^2+4\right)^2\Big) \\
& +\frac{9\left(2\left(\alpha^2+1\right)\gamma^4-9\left(\alpha^2+1\right)\gamma^2+12\left(\alpha^2+1\right)+6\alpha\gamma^3-16\alpha\gamma\right)}{\left(\gamma^2-4\right)^2\left(\gamma^2-1\right)}
\end{aligned}$$

After some algebra, it can be shown that $SW^R_{VICP_1} > SW_{ZR_2}$, $SW^R_{VICP_1} > SW_{FZ}$, and $SW^A_{VICP_1} > SW_{FZ}$. $\square$

Proof of Proposition 3.7. When there is no monetary transfer, either zero-rating with CP_2 (in no vertical integration game) or zero-rating with CP_1 (in vertical integration game) emerges in equilibrium. When there is monetary transfer, we can observe full zero-rating equilibrium both of the games with and without vertical integration. In order to see whether sponsored data plan (monetary transfer) is welfare-enhancing or not, we need to compare the welfare level under full zero-rating case to any welfare level under partial zero-rating case.

In no vertical integration, we focus on the equilibrium of zero-rating with CP_2 only under no monetary transfer case and that of full zero-rating under monetary transfer case. In vertical integration, we need to compare the welfare level of zero-rating with CP_1 only under no monetary transfer case to that of full zero-rating under monetary transfer case (i.e. $\gamma < \gamma_{VI}$).

$$SW_{FZ} - SW_{ZR_2} = -\frac{\left(4\gamma^4 - 21\gamma^2 + 28\right)\left(\alpha\left(\gamma^4 - 3\gamma^2 + 4\right) + 2\gamma\left(\gamma^2 - 2\right)\right)^2}{2\left(\gamma^2 - 4\right)^2\left(\gamma^2 - 1\right)\left(2\gamma^4 - 9\gamma^2 + 12\right)^2}$$

$$\begin{aligned} SW^A_{VICP_1} - SW^R_{VICP_1} = &\frac{1}{18\left(\gamma^6 - \gamma^4 - 16\gamma^2 + 16\right)^2}\Big((\alpha\left(10\gamma^6 - 89\gamma^4 + 28\gamma^2 + 96\right)\gamma \\ &- 24\gamma^6 + 11\gamma^4 + 80\gamma^2 - 112)\left(\gamma^2\left(\alpha\gamma\left(2\gamma^2 - 5\right) + 7\right) - 4\right)\Big) \end{aligned}$$

The first equation is always positive while the second one is positive for $\gamma < \gamma_{VI}$. Given that the condition, $\gamma < \gamma_{VI}$, guarantees full zero-rating equilibrium in vertical integration game, we can say that full zero-rating attains the highest social welfare level. Also, given that full zero-rating equilibrium only emerges when there are monetary transfers, we can alternatively state that sponsored data leads to welfare-enhancing results. □

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