Direct Interconnection and Investment Incentives for Content Diversity[*†]

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February 7, 2020

Abstract

This paper analyzes the effects of the regulation of direct interconnection agreements on the Internet backbone industry. The model assumes that when the internet service provider (ISP) has a vertical affiliation with a content provider (CP), the ISP directly interconnects the affiliated CP's traffic to its network while taking a direct interconnection fee from the unaffiliated CP. If a direct interconnection deal is not made between the ISP and unaffiliated CP, the unaffiliated CP's traffic is indirectly interconnected to the ISP's network via a third party transit provider, which offers a slower network quality than a direct interconnection. Focusing on the case in which both CPs make an investment for more exclusive and diverse content, I find that the affiliated CP invests more in content when the rival indirectly interconnects. Additionally, there is a condition under which the ISP does not want to offer direct interconnection to the unaffiliated CP. However, consumers are not always worse off from this interconnection foreclosure. Thus, the regulation of paid direct interconnection is not necessarily welfare enhancing.

Keywords Direct Interconnection, Net Neutrality, Two-sided Market, Investment Incentives, Internet Service Provider
JEL Code L22, L42, D4

*I would like to thank Jay Pil Choi, Thomas Jeitschko, John Wilson, and Aleksandr Yankelevich; the participants of the Red Cedar Conference at Michigan State University, the Fall 2016 Midwest Economic Theory Conference, and the Eastern Economic Association 2017 Conference; and other anonymous referees for their valuable discussions and comments.

†An earlier version of this paper has been circulated under the title "Paid Peering and Investment Incentives for Network Capacity and Content Diversity."

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1 Introduction

This paper analyzes recent debates on the so-called "strong" net neutrality in the state of California, which has attempted to regulate interconnection deals on the Internet,[1] by focusing on the effects of paid direct interconnection deals on the market and on consumers. Especially, I investigate how asymmetry in the content market with respect to a vertical affiliation with the ISP plays an important role. The Internet is literally a system of interconnected networks. By design, a stable interconnection of networks is essential for the Internet to function properly. This interconnection is a very complex and dynamic process because it needs to deal with traffic from millions of Internet users located all around the globe and using different Internet service providers (ISPs) or backbone providers. For efficient interconnection, ISPs make specific interconnection agreements with other ISPs, backbone providers, or content providers (CPs), guaranteeing the stable delivery of Internet traffic. In the interconnection between ISPs and CPs, CPs such as Google or Netflix deliver content to consumers via their ISP in two ways: direct or indirect interconnection. The first option allows CPs to deliver traffic to the ISPs' network directly, which means that a direct monetary transfer between ISPs and CPs is made. CPs enter into such direct interconnection agreements either through third party content delivery networks (CDNs) or their own CDNs—some large CPs, including Amazon, Google, and Netflix, have developed their own global CDNs. Once directly interconnected, CPs' traffic is directly delivered to ISPs' networks and, ultimately, to customers, without any redundant hops in between. Under indirect interconnection, CPs first deliver their traffic to third-party transit providers, which then interconnect between CPs and ISPs. Thus, indirect interconnection does not involve a direct monetary transfer between CPs and ISPs.

Interconnection agreements have been free from government regulation because they are made using economic sense: it is the norm for anyone who benefits from a service to pay for it. If traffic delivery is one-way (as it is in indirect interconnection with transit providers), CPs that benefit from the service need to pay the transit providers. However, direct interconnection is a two-way peering interaction because both CPs and ISPs send and receive traffic. Thus, if the amount of traffic in each direction is similar, both parties engage in "Settlement-free peering" in which no direct monetary transfer is made. If there is any imbalance between sent and

[1]Refer to https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB822 for details.

received traffic, the party with more traffic needs to compensate the other, which is called paid direct interconnection. Given that the agreements here seem to work using the efficient market mechanism, even net neutrality regulation (which was repealed by the Federal Communications Commission (FCC) in December 2017) did not regulate any interconnection-related business practices, including paid direct interconnection.

However, there have been recent disputes over direct interconnection agreements. In 2014, after experiencing video quality degradation over ISPs' networks, Netflix made direct interconnection deals with several major ISPs, including Comcast, to pay certain fees for improved service. From the ISPs' perspective, the payment made by Netflix is reasonable because the volume of traffic coming from it is much more than the reverse. Nevertheless, some argue that such paid direct interconnection poses a potential anticompetitive threat: because most CPs have less bargaining power than major ISPs, they are more likely to pay the fee even if this direct interconnection can benefit all other customers who do not subscribe to the content but use the ISPs' Internet service. Furthermore, if ISPs use the paid direct interconnection to discriminate against certain CPs in favor of their own affiliated CPs, it can nullify the effect of net neutrality. In this sense, Netflix's CEO, Reed Hastings, addressed the need for strong net neutrality that prevents ISPs from asking for additional interconnection tolls.[2]

The lack of competition in the last-mile ISP market exacerbates the situation. In the context described above, if the ISP directly interconnects its affiliated CPs to achieve better network quality while taking a fee for the same service from the unaffiliated CPs, it may discourage the unaffiliated CPs from investing in content quality. For small or relatively new CPs, in particular, the tradeoff can be much larger, implying that the higher cost for paid direct interconnection leads to less innovation in the content-providing market in the form of less diverse content or higher barriers to entry. Netflix mentions this point in its formal "Petition to Deny" against the proposed Comcast-Time Warner merger: unstable network delivery quality and the associated extra costs would stifle the online video distributor's increasing investments in original content, which means less innovation in the content delivery market.[3]

Even after the FCC's revocation of net neutrality, paid direct interconnection has attracted

[2] Refer to https://media.netflix.com/en/company-blog/internet-tolls-and-the-case-for-strong-net-neutrality for details. Michael Mooney, general counsel at Level 3 Communications, also made a similar argument: https://gigaom.com/2014/03/18/level-3-gets-the-problems-of-peering-fights-so-right-and-then-so-wrong/.

[3] Refer to https://ecfsapi.fcc.gov/file/7521825167.pdf for details.

attention from the public in conjunction with local movements toward reviving net neutrality. As mentioned in the beginning of the article, California signed into law S.B. 822 in response to the revocation of net neutrality. The bill aims for stronger net neutrality that regulates paid direct interconnections if ISPs attempt to discriminate against one CP versus another by charging an interconnection fee. It is uncertain how the debates over the state-level net neutrality will end,[4] but it should be noted that the law considers (paid) direct interconnection as an important issue. Consequently, any area of paid direct interconnection that has been neglected by economic analysis should be investigated so that relevant issues can be fairly evaluated.

To determine the validity of the two conflicting claims mentioned above, I model a two-sided market with one ISP and two competing CPs, $j \in \{1, 2\}$. Consumers and CPs interact via the ISP, i.e., the network. I compare direct and indirect interconnection: direct interconnection guarantees more stable and faster content delivery than indirect interconnection in which the third party transit provider interconnects in the middle. In particular, I focus on how asymmetry in the content market plays an important role. To model the content market asymmetry, I assume that CP_1 is affiliated with the ISP, whereas CP_2 is not, without loss of generality. The affiliated CP_1 always delivers content via direct interconnection without any explicit fee. From the comparison, I investigate under what conditions the ISP wants to directly interconnect the unaffiliated CP and how direct interconnection requiring the unaffiliated CP to pay the relevant cost directly to the ISP affects the pricing and investment incentives of CPs. From the equilibrium results, I provide insights into how different interconnection regimes affect consumer welfare.

I find that CP_1 affiliated with the ISP is more likely to invest in content diversity when the rival does not make a direct interconnection agreement by using its high revenue in an indirect interconnection agreement. However, the unaffiliated CP_2 has more incentive to invest in content diversity through a direct interconnection agreement.

Additionally, the ISP wants to offer a direct interconnection to CP_2 only if the associated cost of direct interconnection is sufficiently low. This finding provides a supportive background for strong net neutrality proponents in that the ISP may exert its leverage power and discriminate some CPs over others in terms of interconnection. In particular, as this paper suggests, if the

[4]The California legislation is being challenged by the U.S. Justice Department.

ISP is affiliated with a specific CP, it favors its own CP by directly interconnecting content while charging very high fees for the unaffiliated CPs. Nevertheless, the welfare analysis finds that consumers are not always worse off because of this interconnection foreclosure. I find that consumer surplus can be enhanced when the unaffiliated CP's traffic is indirectly interconnected to the ISP's network: if the marginal benefit from direct interconnection is sufficiently small, consumers are worse off from direct interconnection agreement.

Although direct interconnection leads to more intense competition in the content market, it is not always the best scenario for consumers. In this sense, policymakers need to be careful when evaluating the effects of regulation on nondiscriminatory interconnection agreements, as in the case of California's strong net neutrality policy (S.B. 822).

The remainder of this paper is organized as follows. In Section 2, I show how my work is related to the literature. In Sections 3 and 4, I introduce the model setup and solve for the equilibrium. I conduct the welfare analysis in Section 5. Finally, I provide some concluding remarks in Section 6.

2 Related Literature

This paper connects to two interrelated bodies of the literature: the literature on net neutrality and the literature on interconnection in two-sided markets. The study 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 study 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 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) relate the impact of net neutrality to market competition and the incentive to invest in network capacity. Gans (2015) differentiates weak from strong net neutrality to show that whether regulations on specific behaviors such as direct payment from consumers to CPs affect the market depends on the type of net neutrality. Aside from the model setup, there is a major difference between my research and the papers listed above: all the papers mentioned above analyze paid priority in the last mile because their main focus is on examining the effects of (now defunct) net neutrality from diverse perspectives. However, my paper focuses on paid direct interconnection agreements made in the backbone industry between an ISP and CPs and examines how the direct access fee in direct interconnection affects investment incentives and social welfare. Furthermore, unlike the papers mentioned above, this paper focuses on the dynamic implications of the paid direct interconnection agreement by examining investment in content diversity. Given the debates on whether paid direct interconnection should be regulated under future (state- or federal-level) net neutrality laws,[5] this paper can help policymakers determine whether any related future regulations should take paid direct interconnections into consideration.

In addition, my paper is closely linked to the interconnection-related literature in the sense that it discusses the peering issue mainly in terms of being the backbone of the Internet market.[6] First, Armstrong (1998) discusses how access fees, i.e., interconnection fees, can be set in networks and discusses 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 costs affect the final retail market. Gilo and Spiegel (2004) identify a competitive transit environment that can alleviate potential anticompetitive market behaviors regarding interconnection fees that are too high. Mendelson and Shneorson (2003) consider consumers' delay costs and show how the existence of a delay cost affects the competitive structure of the backbone industry and the final market structure. Goetz (2019) focuses on bargaining between ISPs and CPs over interconnection and empirically shows that as the ISP's size in terms of the number of subscribers becomes larger, CPs lose more bargaining power, which discourages CPs from paying for better network quality through direct interconnection. A model assumption on bargaining between the ISP and CP over the interconnection in my paper is partly motivated by the empirical findings in this paper.

There are several papers that show how different interconnection agreements affect the market and consumers. Koning and Yankelevich (2017) state that if ISP services are independent,

[5]California's S.B. 822 reflects this movement.

[6]Some studies (Laffont et al. (2001), Economides (2005), Carter and Wright (1999), Crémer et al. (2000), Baake and Wichmann (1999)) focus only on pricing and competition issues in the backbone industry and do not investigate the effect of market outcomes on the Internet backbone industry for the last mile market.

settlement-free interconnection can be optimal. Jahn and Prüfer (2008) also analyze the strategic use of interconnection. These scholars show that the paid direct interconnection regime can harm consumers. Friden (2014) analyzes how the interconnection disputes between the ISP and upstream CPs, especially congestion-sensitive CPs, can be resolved through their strategic interactions in the market without harming end-users; thus, premature government intervention can lead to inefficient consequences although policy interventions are justified in other cases. In this sense, Frieden (2014) makes several suggestions to regulators such as requesting ISPs to transparently disclose the details about interconnection negotiations. In another paper, Frieden (2015) 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 (2015) discusses 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. These scholars show that paid direct interconnection can be mutually beneficial to both ISPs and CPs under certain circumstances. Clark et al. (2011) show that paid direct interconnection is required to maintain necessary investment in network infrastructure, although there are anticompetitive concerns arising from it. Although the papers listed above also consider the effect of interconnection fees on the relevant markets, they do not relate these effects to diverse investment incentives such as investment in content diversity: in this regard, my paper discloses how interconnection agreements, particularly paid direct interconnection, potentially pose anticompetitive threats to some CPs through adversely affecting content diversity investments. From this perspective, Little and Wright (2000) discuss an implication that is similar to the one discussed in my paper in that they find that settlement-free peering leads to underinvestment in network capacity. However, again, their papers do not identify any conflicts of interest, for example, in terms of content diversity investments made by asymmetric CPs. My paper focuses on the dynamic implications of the paid direct interconnection regime rather than its static consequences.

3 The Model

Consider a market environment with a unit mass continuum of consumers, one ISP, one third-party transit provider, and two CPs $j \in \{1, 2\}$. Both CPs deliver content to consumers via either indirect or direct interconnection. For indirect interconnection, CP(s) pays a certain fixed fee, denoted f_{ID}, to a third-party transit provider, then CPs' content is delivered to the ISP, and ultimately to consumers, by the transit provider. For direct interconnection, the CP (or CPs) pays a fee, denoted f_D, to the ISP. Direct interconnection does not have network hops in the middle, which guarantees better network quality. Without loss of generality, CP_1 is assumed to be affiliated with the ISP, whereas CP_2 is not. The affiliated CP_1 delivers its content via direct interconnection without any charge. The unaffiliated CP_2 decides whether to deliver via indirect or direct interconnection if the ISP offers. CPs compete for consumer subscription revenues in which consumers choose one of the CPs. I also assume that both the Internet and the content market are fully covered.

The model focuses on how the content market is affected by direct or indirect interconnection; therefore, the ISP's profit maximization with respect to the Internet subscription fee for consumers and the transit provider's revenue-generating process are abstracted from the main analysis, so the fee for indirect interconnection, f_{ID}, is exogenously given.

3.1 Consumers

There are unit mass consumers who obtain net utility from content subscriptions. To model consumer preferences over content, I adopt the 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 located at $x = 1$. The utility specification takes into consideration the degree of content exclusivity. I assume that each CP_j initially provides duplicative content, whose amount is normalized to one. Each CP_j may make an additional investment in its original content, which increases the degree of exclusivity λ_j. For example, some content, such as *American Horror Story*, is available on both Netflix and Hulu (as duplicative content of measure one), whereas *Mindhunter* is only available on Netflix (as original content included in λ_j). More investment in content, which increases γ_j, means that CP_j provides more original content to viewers. The utility for a consumer from CP_j is given as follows.

$$u_j = U(1+\lambda_j) + \mu_j - tx - P_j, \tag{1}$$

where $U(1+\lambda_j)$ is the utility from content diversity, μ_j is either $\alpha\mu$ if directly interconnected or μ if indirectly interconnected where $\alpha > 1$, t is the transportation cost, and P_j denotes the subscription fee charged by CP_j. For the full market coverage assumption, U is assumed to be sufficiently large.

3.2 Content Providers

There are two CPs who compete with each other for subscriptions. 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 $C''(\lambda_j) > 0$. That is, more exclusive content incurs a higher cost, and its marginal cost is also increasing: the more original content CPs have, the higher cost CPs need to spend to have one additional unit of original content. The affiliated CP_1 directly interconnects its traffic to the ISP's server without any fee, whereas the unaffiliated CP_2 pays either f_{ID} to transit provider for indirect interconnection or f_D to the ISP for direct interconnection, where the ISP affiliated with CP_1 optimally charges f_D. The profit maximization for CP_j is given by

$$\begin{aligned} &\max_{P_1,\lambda_1} \quad \pi_{1,ISP} = P_1 Q_1(P_1,\lambda_1;P_2,\lambda_2) - C(\lambda_1) + \mathbb{1}_D(f_D - K) - K. \\ &\max_{P_2,\lambda_2} \quad \pi_2 = P_2 Q_2(P_2,\lambda_2;P_1,\lambda_1) - C(\lambda_2) - \mathbb{1}_D f_D - \mathbb{1}_{ID} f_{ID}, \end{aligned} \tag{2}$$

where the subscript $1, ISP$ denotes the CP_1 that is affiliated with the ISP, Q_j represents the sum of the share of consumers who subscribe to CP_j's content, $\mathbb{1}_D$ is one if CP_2's content is directly interconnected or zero otherwise, and $\mathbb{1}_{ID}$ is one if its content is indirectly interconnected or zero otherwise. The affiliated firm considers possible extra revenue captured by the fee f_D arising from directly interconnecting the unaffiliated CP_2's traffic. For each direct interconnection, the ISP incurs a fixed cost of K, which is assumed to be smaller than f_D. The profit functions are assumed to be concave in choice variables.[7] I focus on the following three-stage game.

[7]The profit functions are always concave with respect to P_j because $\frac{\partial^2 \pi_{1,ISP}}{\partial P_1^2} = \frac{\partial^2 \pi_2}{\partial P_2^2} = -\frac{1}{t} < 0$. The concavity for the choice variable of λ is guaranteed if $\frac{U^2}{9} < t$, in the parametric example with $C(\lambda_j) = \frac{\lambda_j^2}{2}$,

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. In addition, the investment has a cost of $C(\lambda_j)$.

2. In stage 2, the ISP affiliated with CP_1 makes a take-it-leave-it direct interconnection offer at a fee of f_D to CP_2. If CP_2 rejects the offer, CP_2 makes an indirect interconnection deal with the transit provider at a fee of f_{ID}.

3. In stage 3, CPs set their subscription fees, P_j. Consumers choose the CP to which they subscribe.

Throughout the paper, a direct interconnection agreement means that the unaffiliated CP_2 is directly interconnected to the ISP's server; therefore, all CPs deliver their content via a high-quality network. As for indirect interconnection agreements, CP_2 is not directly interconnected, so only CP_1's content is delivered via a high-quality network.

3.3 Discussions of Model Assumptions

Before I proceed, I discuss two important model assumptions.

Take-it-or-leave-it Interconnection Offer: In the model, I assume that the ISP has all the bargaining power that allows it to make the take-it-or-leave-it direct interconnection offer to the unaffiliated CP. In reality, although CPs have some bargaining power, the ISP is more likely to have greater bargaining power. As Goetz (2019) empirically shows, facing a larger ISP with a large number of consumers means that CPs lose more negotiating power. If the ISP monopolizes the market, as I assume in the paper, it gains greater bargaining power. However, even if the ISP market is competitive, the ISP is more likely to have an advantage in interconnection agreements if consumers have relatively high switching costs: in most cases, promotional Internet plans prohibit consumers from changing their provider before the contract expires, which locks consumers into the ISP. As long as the ISP has greater bargaining power than CPs, the qualitative results still hold.

Content singlehoming consumers: I assume that a consumer chooses one CP over the other and do not allow content multihoming in the sense that the consumer subscribes to both CPs'

which is assumed to be satisfied.

content. Given that each CP provides a certain amount of original content, some portion of consumers are willing to subscribe to both CPs' service. If I allow such multihoming behavior, it leads to soft competition in the content market. Thus, introducing multihoming in the model to some extent lowers the incentives for the ISP to foreclose the unaffiliated CP from being directly connected. However, given that the ISP does not charge the Internet subscription fee twice for multihoming consumers and there are still singlehoming consumers, the implications from the singlehoming consumer model are robust.

4 Equilibrium

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

4.1 Stage 3

The consumer demand for each CP is determined by the indifferent consumer type, denoted as x^*. If a consumer is located at x^*, he is indifferent between subscribing to CP_1 and subscribing to CP_2. Given that the affiliated CP_1's content is always directly interconnected, which means that the utility from network delivery quality for the affiliated CP_1 is always $\alpha\mu$, the indifferent consumer type x^* satisfies the following equation: $U(1+\lambda_1)+\alpha\mu-tx^*-P_1 = U(1+\lambda_2)+\mu_2-t(1-x^*)-P_2$, therefore, $x^* = \frac{\alpha\mu-\mu_2-(P_1-P_2)+t+U(\lambda_1-\lambda_2)}{2t}$. Given that $Q_1 = x^*$ and $Q_2 = 1-x^*$, each CP_j solves its profit maximization with respect to P_j. The optimal P_j and Q_j are derived as follows. I focus on the interior solution case in which $Q_j > 0$.[8]

$$\begin{aligned} P_1 &= \frac{3t+\alpha\mu-\mu_2+U(\lambda_1-\lambda_2)}{3}; \quad Q_1 = \frac{3t+\alpha\mu-\mu_2+U(\lambda_1-\lambda_2)}{6t}. \\ P_2 &= \frac{3t-\alpha\mu+\mu_2-U(\lambda_1-\lambda_2)}{3}; \quad Q_2 = \frac{3t-\alpha\mu+\mu_2-U(\lambda_1-\lambda_2)}{6t}. \end{aligned} \tag{3}$$

4.2 Stage 2

In this stage, CP_2 accepts the direct interconnection offer made by the ISP affiliated with CP_1 as long as the profit from direct interconnection is greater than that from indirect interconnection.

[8] In the parametric example of $C(\lambda_j) = \frac{\lambda_j^2}{2}$, the sufficient condition for the interior solution is $\frac{2U^2+3(\alpha-1)\mu}{9} < t$, which is assumed throughout the paper.

Assuming that f_{ID} is exogenously given, I find the threshold on f_D, denoted f_D^*, below which CP_2 accepts the direct interconnection offer, as follows: $f_D^* = f_{ID} + \frac{(\alpha-1)\mu[6t-(\alpha-1)\mu-2U(\lambda_1-\lambda_2)]}{18t}$, where the subscripts D and ID denote direct interconnection and indirect interconnection, respectively. Thus, the ISP optimally sets f_D at f_D^*.

4.3 Stage 1

From the profit maximization problem as in Equation (2), the first order condition with respect to λ_j for each CP_j can be derived. First, the optimal $\lambda_{j,D}^*$ in direct interconnection satisfies the following first order condition where the subscript j, D denotes j's variable in the direct interconnection agreement.

$$\frac{U\left[3t-(\alpha-1)\mu+U(\lambda_{1,D}-\lambda_{2,D})\right]}{9t} - C'(\lambda_{1,D}) = 0; \quad \frac{U\left[3t-(\alpha-1)\mu-U(\lambda_{1,D}-\lambda_{2,D})\right]}{9t} - C'(\lambda_{2,D}) = 0. \tag{4}$$

Next, the optimal $\lambda_{j,ID}^*$ in indirect interconnection satisfies the following first order condition, where the subscript j, ID denotes the j variable in the indirect interconnection agreement.

$$\frac{U\left[3t+(\alpha-1)\mu+U(\lambda_{1,ID}-\lambda_{2,ID})\right]}{9t} - C'(\lambda_{1,ID}) = 0; \quad \frac{U\left[3t-(\alpha-1)\mu-U(\lambda_{1,ID}-\lambda_{2,ID})\right]}{9t} - C'(\lambda_{2,ID}) = 0. \tag{5}$$

Comparing Equation (4) to (5), two forces come into a play regarding whether direct or indirect interconnection encourages more investment in original content: the interconnection spillover effect and strategic effect. First, all other things being equal, each CP has more incentive to invest in content diversity if it is in a more advantageous interconnection agreement that yields more profit: the indirect interconnection agreement is more advantageous for the affiliated CP_1 because it maintains its advantage in network quality as a sole provider of high delivery quality, whereas the direct interconnection agreement is better for the unaffiliated CP_2 in that it makes the CP at least provide better network quality. This complementarity between content investment and any additional benefits from a specific interconnection is what I call the interconnection spillover effect. Additionally, due to the two CPs' strategic interactions, there is another effect called the strategic effect. By differentiating the first order condition with respect to the rival's content investment level, it is easy to show that the amounts of content investments made by the two CPs (denoted λ_j where $j \in \{1, 2\}$) are strategic substitutes. This implies that content investments for the two CPs offset one another. Lemma 1 summarizes this finding. The detailed proof is in the Appendix.

Lemma 1. *Whether the direct or indirect interconnection agreement encourages CPs to invest more in content depends on two effects: the interconnection spillover effect and the strategic effect.*

The affiliated CP_1 is more likely to invest in content under the indirect interconnection agreement because of the positive interconnection spillover effect. In direct interconnection, the affiliated CP_1 earns extra revenue from the fee paid by CP_2, but it loses its competitiveness in terms of network quality. However, in indirect interconnection, the affiliated CP_1 takes a greater market share by exploiting its advantage in network quality, which leads to greater revenue from the market. The second effect is greater than the first; therefore, the net interconnection spillover effect from indirect interconnection is positive. Knowing this advantage, the affiliated CP has more incentive to invest in content to attract more consumers because it can additionally recoup the content investment cost through the higher content price made possible by the better network. Nevertheless, this does not necessarily mean that indirect interconnection always leads to more content investment for the affiliated CP because of the strategic interactions with the unaffiliated CP. If the unaffiliated CP_2 invests more in content under direct interconnection ($\lambda_{2,D} > \lambda_{2,ID}$), the affiliated CP always makes more content investment under indirect interconnection ($\lambda_{1,D} < \lambda_{1,ID}$). However, if the unaffiliated CP invests considerably more in content under indirect interconnection ($\lambda_{2,D} < \lambda_{2,ID}$ and the gap is large), the strategic effect dominates the interconnection spillover effect, and therefore, $\lambda_{1,D} > \lambda_{1,ID}$ can emerge.

For the unaffiliated CP_2, there is no interconnection spillover effect because any additional revenue from content investment is likely to be *ex post* expropriable by the ISP because the ISP extracts rents from CP_2 when entering a direct interconnection agreement. Thus, there is no additional revenue from investing in content diversity even with better network quality under direct interconnection for CP_2, which leads to zero interconnection spillover effect. That is, whether CP_2's content investment is larger under direct or indirect interconnection agreement depends only on the strategic effect, how much the affiliated CP_1 invests in each agreement.[9]

[9] Even if I relax the take-it-or-leave-it offer assumption and assume that the unaffiliated CP has positive bargaining power, the qualitative result still holds—as long as the ISP's bargaining power is greater, such that it extracts considerable rents for direct interconnection, the interconnection spillover effect is negligible; therefore,

Overall, due to the strategic substitutability between λ_1 and λ_2, the unaffiliated CP invests less in content diversity under the indirect interconnection agreement due to the positive interconnection spillover effect for the affiliated CP. Consequently, the affiliated CP is incentivized to make more content investment under the indirect interconnection agreement. Proposition 1 summarizes this finding.

Proposition 1. *The affiliated CP makes more content investment in indirect interconnection, whereas the unaffiliated CP does so in direct interconnection.*

Given the optimal $\lambda^*_{j,D}$ and $\lambda^*_{j,ID}$, I find the equilibrium content price, market share, and the fee charged by the affiliated ISP in the direct and indirect interconnection agreements as follows.

$$
\begin{aligned}
&P^*_{1,D} = \frac{3t + U(\lambda^*_{1,D} - \lambda^*_{2,D})}{3}; \quad Q^*_{1,D} = \frac{3t + U(\lambda^*_{1,D} - \lambda^*_{2,D})}{6t}.\\
&P^*_{2,D} = \frac{3t - U(\lambda^*_{1,D} - \lambda^*_{2,D})}{3}; \quad Q^*_{2,D} = \frac{3t - U(\lambda^*_{1,D} - \lambda^*_{2,D})}{6t}.\\
&P^*_{1,ID} = \frac{3t + (\alpha-1)\mu + U(\lambda^*_{1,ID} - \lambda^*_{2,ID})}{3}; \quad Q^*_{1,ID} = \frac{3t + (\alpha-1)\mu + U(\lambda^*_{1,ID} - \lambda^*_{2,ID})}{6t}.\\
&P^*_{2,ID} = \frac{3t - (\alpha-1)\mu - U(\lambda^*_{1,ID} - \lambda^*_{2,ID})}{3}; \quad Q^*_{2,ID} = \frac{3t - (\alpha-1)\mu - U(\lambda^*_{1,ID} - \lambda^*_{2,ID})}{6t}.\\
&f^*_D = f_{ID} + \frac{\left[3t - U(\lambda^*_{1,D} - \lambda^*_{2,D})\right]^2 - \left[3t - (\alpha-1)\mu - U(\lambda^*_{1,ID} - \lambda^*_{2,ID})\right]^2}{18t}.
\end{aligned}
\tag{6}
$$

To obtain the closed-form solution, I assume that $C(\lambda_j) = \frac{\lambda_j^2}{2}$. Under this parametric example, the full equilibrium set can be derived as follows.

$$
\begin{aligned}
&P^*_{1,D} = t; \quad Q^*_{1,D} = \frac{1}{2}; \quad P^*_{2,D} = t; \quad Q^*_{2,D} = \frac{1}{2}.\\
&P^*_{1,ID} = t + \frac{1}{3}(\alpha-1)\mu + \frac{2U^2}{9}; \quad Q^*_{1,ID} = \frac{9t + 3(\alpha-1)\mu + 2U^2}{18t}.\\
&P^*_{2,ID} = t - \frac{1}{3}(\alpha-1)\mu - \frac{2U^2}{9}; \quad Q^*_{2,ID} = \frac{9t - 3(\alpha-1)\mu - 2U^2}{18t}.\\
&f^*_D = f_{ID} - \frac{U^2[3t - (\alpha-1)\mu]^2}{162t^2} - \frac{(9t - U^2)\left[3(\alpha-1)\mu - 9t + 2U^2\right]^2}{18\left(9t - 2U^2\right)^2} + \frac{t}{2}.\\
&\lambda^*_{1,D} = \lambda^*_{2,D} = \frac{U}{3} - \frac{(\alpha-1)\mu U}{9t}.\\
&\lambda^*_{1,ID} = \frac{U\left[3(\alpha-1)\mu + 9t + 2U^2\right]}{27t}; \quad \lambda^*_{2,ID} = \frac{U\left[3(\alpha-1)\mu - 9t + 2U^2\right]}{27t}.
\end{aligned}
\tag{7}
$$

From Equation (7), it is easy to find that $\lambda^*_{1,ID} - \lambda^*_{1,D} = \frac{2U\left[3(\alpha-1)\mu + U^2\right]}{27t} > 0$: the affiliated

the strategic effect dominates.

CP_1 is more willing to invest in content diversity in indirect interconnection. Per Proposition 1, this suggests that the unaffiliated CP_2 lowers its content investment level due to the strategic substitutability. Indeed, when comparing the unaffiliated CP_2's content investment level in direct interconnection to that in indirect interconnection, I find that the unaffiliated CP_2 makes less content investment in indirect interconnection: $\lambda^*_{2,ID} - \lambda^*_{2,D} = \frac{2U\left[3(\alpha-1)\mu+U^2-9t\right]}{27t} < 0$ due to the interior solution assumptions, $U^2 < \frac{9t-3(\alpha-1)\mu}{2}$. In indirect interconnection agreements, the unaffiliated CP_2 is able to attract only a small portion of consumers due to its worse network quality, which leaves less room for investment in content diversity.

Not surprisingly, when two CPs are symmetric in network quality as in direct interconnection, they make the same level of content investment, splitting the market equally. However, in indirect interconnection, the affiliated CP_1 with the advantage in network quality makes more investment in quality, thereby attracting more consumers.

When comparing the total amount of content market investment, the sum of investments for both CPs between two interconnection agreements, I find that whether direct or indirect interconnection leads to more investment in content diversity depends on how large the base utility U is: if $U^2 > \frac{9t-6(\alpha-1)\mu}{2}$, $\lambda^*_{1,ID} + \lambda^*_{2,ID} > \lambda^*_{1,D} + \lambda^*_{2,D}$. Corollary 1 summarizes this finding.

Corollary 1. *The total level of content market investment in indirect interconnection is greater than that in direct interconnection only if the base utility is sufficiently large:* $U^2 > \frac{9t-6(\alpha-1)\mu}{2}$.

The intuition behind Corollary 1 is as follows. Both CPs' equilibrium prices and market shares, shown in Equation (3), are independent of the base utility U when they make the same amount of content investment as in direct interconnection. If λ_1 and λ_2 are asymmetric as in indirect interconnection, P_j and Q_j change as U changes. Given $\lambda_{1,ID} > \lambda_{2,ID}$, per Proposition 1, CP_1's revenue increases but CP_2's decreases as U increases. However, the revenue increasing effect of a larger U for the affiliated CP_1 is greater than the opposite effect for the unaffiliated CP_2. This suggests that the marginal benefit of more content investment for CP_1 increases in U whereas the reverse holds for CP_2. Furthermore, if U is sufficiently large, the positive effect of U for CP_1 dominates the negative effect for CP_2; therefore, $\lambda_{1,ID}$ increases substantially, while $\lambda_{2,ID}$ decreases by a relatively negligible amount. Thus, as long as U is large enough, indirect interconnection leads to more content investment in the market.

Next, I compare both the equilibrium price and market share of CPs between two interconnection agreements. The content provided by both CPs is differentiated into two dimensions: network quality and content diversity. In indirect interconnection, the affiliated CP_1 has advantages in both dimensions because it delivers content via high network quality and provides more original content. Accordingly, it dominates the market even at a higher content price. In terms of the revenue from the content market, the unaffiliated CP_2 loses a lot in indirect interconnection, whereas the affiliated CP_1 gains. Proposition 2 summarizes this finding.

Proposition 2. *The affiliated CP dominates the market in indirect interconnection agreement because it is better than the unaffiliated CP in two dimensions: network quality and content diversity.*

Another interesting question is whether CP_1 has an incentive to offer direct interconnection to the unaffiliated CP_2 in the first place. To see this, I compare the affiliated CP_1's profit in a direct interconnection agreement to that in an indirect interconnection agreement. From the comparison, I find the threshold on the cost for each direct interconnection, denoted $\bar{K}$, below which the affiliated CP_1 wants to offer direct interconnection to the unaffiliated CP_2. As in Figure 1, CP_1 becomes less willing to offer direct interconnection as K increases. Proposition 3 summarizes this finding.

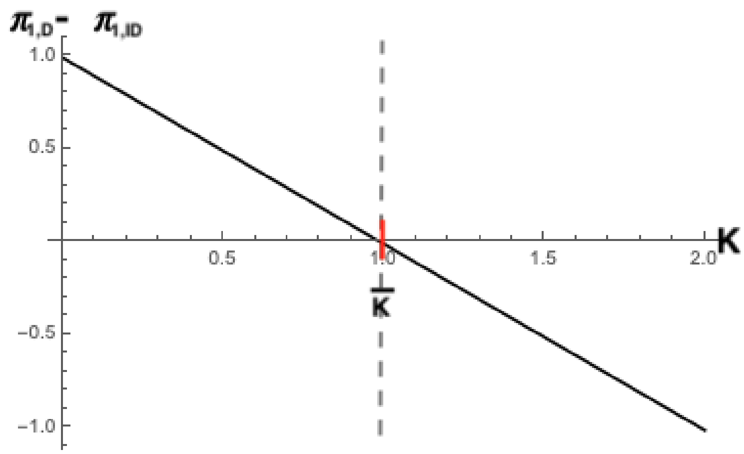

Figure 1: Threshold K at which $\pi_{1,D} = \pi_{1,ID}$ assuming $f_D = 1.2$, $t = 1$, $U = 1.5$, $\mu = 1$, and $\alpha = 1.5$

Proposition 3. *There exists a threshold on the cost of each direct interconnection, denoted $\bar{K}$, below which the affiliated CP wants to offer direct interconnection to the unaffiliated CP, and does not otherwise.*

Intuitively, as K increases, CP_1 demands a higher direct interconnection fee from CP_2. However, CP_2's maximum willingness to pay is determined at which its indirect interconnection fee, which is fixed, plus any profit gains from direct interconnection. Thus, there exists a threshold of K above which CP_1 no longer wants to offer direct interconnection because the associated cost is higher than any extra benefit from CP_2.

For the threshold $\bar{K}$, it is worth examining how changes in parameters affect the size of the threshold. From comparative statics results, I first find that if α increases, which implies that the benefit for direct interconnection becomes greater, CP_1 becomes less willing to offer direct interconnection. This finding implies that the threshold $\bar{K}$ decreases as α increases because higher α allows CPs to extract more rent from consumers by charging higher content prices. If the affiliated CP_1 maintains its advantageous position by not interconnecting the rival's content directly, its revenue increasing effect becomes greater. Thus, the affiliated CP_1 does not want to be symmetric with the rival in terms of network quality as α increases. Additionally, as the basic network quality from indirect interconnection, denoted μ, increases, $\bar{K}$ decreases as well. As μ increases, the unaffiliated CP_2 becomes less willing to pay for direct interconnection. A lower fee for direct interconnection discourages the ISP from offering direct interconnection. Proposition 4 summarizes the results.

Proposition 4. *The ISP is less incentivized to offer direct interconnection as the marginal benefit from higher network delivery quality α increases or as the basic network quality μ increases.*

Thus, as the marginal benefit from higher network delivery quality increases or the basic network quality increases, the ISP is more likely to continue to use indirect interconnection and maintain its affiliated CP's advantageous position in the market. Per Proposition 2, this poses anticompetitive threats because indirect interconnection bolsters the affiliated CP's dominant position. Specifically, this finding provides a supportive background for strong net neutrality proponents in that the ISP may exert its leverage power and discriminate in favor of CPs over others in terms of interconnection. In particular, as this paper suggests, if the ISP is affiliated with a specific CP, it favors its own CP by directly interconnecting content while charging very high fees for the unaffiliated CPs. Nevertheless, the welfare analysis reveals that consumers are not always worse off because of this interconnection foreclosure, as I will show in Section 5.

5 Welfare Analysis

In this section, I calculate consumer surplus.[10] Consumer surplus stems from video content services, which is given by

$$CS = \int_0^{x^*} [V(1+\lambda_1) + \alpha\mu - tx - P_1]dx + \int_{x^*}^1 [V(1+\lambda_2) + \mu_2 - t(1-x) - P_2]dx, \quad (8)$$

where $x^* = \frac{\alpha\mu - \mu_2 - (P_1 - P_2) + t + U(\lambda_1 - \lambda_2)}{2t}$ at which a consumer becomes indifferent between CP_1 and CP_2. Given the equilibria derived in Section 4, I compare the consumer surplus level in direct interconnection to that in indirect interconnection under the same parametric example of $C(\lambda_j) = \frac{\lambda_j^2}{2}$. The comparison shows that there exists a threshold on α, below which $CS_D < CS_{ID}$ and above which the reverse occurs. In other words, if the marginal benefit from direct interconnection increases, consumers become better off from direct interconnection. If α is sufficiently small, say $\alpha < \bar{\alpha}$ where the threshold $\bar{\alpha}$ is precisely defined in the Appendix, consumer surplus is enhanced in indirect interconnection because any benefit from better network quality is smaller than the cost: if both CPs deliver via direct interconnection, both of them charge higher prices, which reduces consumer surplus. Figure 2 shows the comparison. Proposition 5 summarizes this finding.

Proposition 5. *Consumers are better off from indirect interconnection if the marginal benefit of better network quality is sufficiently small. As the marginal benefit from direct interconnection increases, consumer surplus becomes greater in direct interconnection.*

Proposition 5 leads to very important policy implications. Regarding the debate over strong net neutrality that regulates paid direct interconnection agreements, the welfare comparison in this paper suggests that a symmetric market with a direct interconnection agreement is not necessarily welfare-enhancing in terms of consumer surplus: nondiscriminatory interconnection agreements that directly interconnect any CP's content can lower the consumer surplus if the marginal benefit from better network quality is negligible. If this is the case, consumers are better off from the market with asymmetric network quality—one (the affiliated CP) with direct

[10]Since I abstract the analyses on businesses of the ISP's Internet subscription business and transit provider, consumer surplus and social welfare derived here are derived from partial equilibrium. However, the general equilibrium case in which every agent's interaction is fully analyzed changes the qualitative result only as long as I maintain the full market coverage assumption.

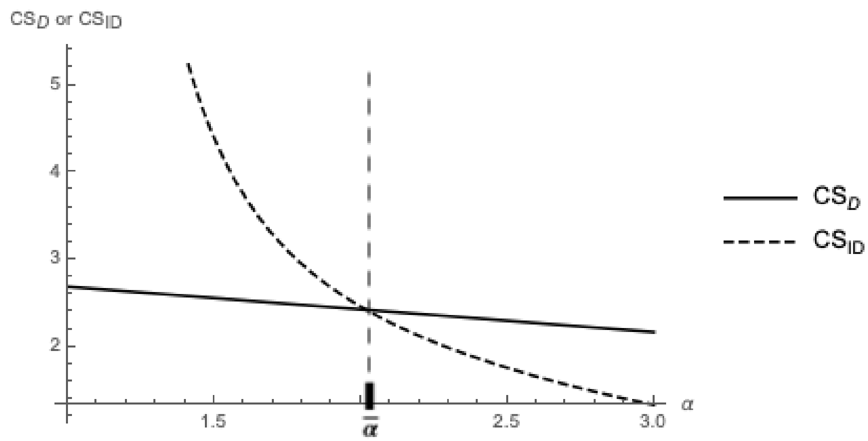

Figure 2: Consumer surplus comparison

interconnection and another (the unaffiliated CP) with indirect interconnection.

In this regard, there can be a specific case that necessitates policy interventions: when the marginal benefit from better network quality, denoted α, is small such that the ISP is more likely to offer a direct interconnection deal per Proposition 4, but the direct interconnection induced by a small α is welfare-reducing (because $\alpha < \bar{\alpha}$ per Proposition 5). That is, if a sufficiently small α not only induces the ISP to have the unaffiliated CP be directly connected but falls below a certain threshold, $\bar{\alpha}$, the market optimum is not socially desirable. In this case, either encouraging indirect interconnection or imposing a regulation that prohibits CPs from charging higher prices after direct interconnection makes consumers better off, instead of requiring unconditional direct interconnection. Similarly, if α is large enough, such that the ISP is more willing to continue to use indirect interconnection but consumer surplus under indirect interconnection is lower than in the other case, the market-driven equilibrium is not optimal from a consumer perspective: a similar policy intervention is necessary to make consumers better off.

Thus, these findings suggest that regulators should be wary of restricting discriminatory interconnection agreements as part of strong net neutrality—any relevant policy remedies should consider how much more marginal benefit a consumer obtains by having the unaffiliated CP directly interconnected in conjunction with any cost that a consumer faces in that case.

6 Conclusion

This paper analyzes the effects of a direct interconnection agreement on content providing market competition and consumers, focusing on the incentives to invest in content diversity. Using a theoretical model in which a monopolistic ISP is vertically affiliated with only one CP and the affiliated CP is always directly interconnected without any fee, I show that a direct interconnection agreement encourages the unaffiliated CP to invest more in content diversity compared to the indirect interconnection, whereas it discourages the affiliated CP from doing so, although the direct interconnection guarantees that both CP deliver traffic via better network quality. Thus, the affiliated CP dominates the content market in the indirect interconnection case in which it has advantages in delivery network quality as well as content diversity. Due to the market dominating effect, the ISP does not always want to offer direct interconnection to the unaffiliated CP, even for a fee. This suggests that if the ISP is affiliated with one CP, it may exert its leverage power and favor its own CP over unaffiliated CPs. However, the indirect interconnection that harms the unaffiliated CP in terms of market share does not necessarily make consumers worse off. As long as the marginal benefit from the direct interconnection agreement is sufficiently small, the indirect interconnection is welfare-enhancing. Note that this welfare implication might be weakened if the model considers a long-run dynamic competition. If the unaffiliated CP that is excluded from direct interconnection remains out of the market, consumer welfare may decline accordingly, although these considerations are beyond the scope of this paper. Nevertheless, as long as the content market is competitive with potential product differentiation, horizontally via content diversity and vertically via network quality as in this paper, the qualitative results hold.

Relative to the literature on the economic impacts of net neutrality, there are few studies on the effects of "strong" net neutrality policy, which includes direct interconnection agreements. Even studies on the effect of direct interconnection (or net neutrality in general) do not take into consideration how such regulations affect content market investment specifically. In this sense, this paper, which considers the dynamic effects of direct interconnection on network quality and content market investment, helps policymakers determine whether such strong regulation is necessary and helpful for consumers.

Appendix - Proofs of the Propositions.

Proof of Lemma 1. First, let $\zeta^D(\lambda_1) \equiv \frac{U\left[3t-(\alpha-1)\mu+U(\lambda_1-\lambda_{2,D})\right]}{9t} - C'(\lambda_1)$, $\zeta^D(\lambda_2) \equiv \frac{U\left[3t-(\alpha-1)\mu-U(\lambda_{1,D}-\lambda_2)\right]}{9t} - C'(\lambda_2)$, $\zeta^{ID}(\lambda_1) \equiv \frac{U\left[3t+(\alpha-1)\mu+U(\lambda_1-\lambda_{2,ID})\right]}{9t} - C'(\lambda_1)$, and $\zeta^{ID}(\lambda_2) \equiv \frac{U\left[3t-(\alpha-1)\mu-U(\lambda_{1,ID}-\lambda_2)\right]}{9t} - C'(\lambda_2)$. It can be shown that

$$\begin{aligned}
\zeta^{ID}(\lambda_1) &= \zeta^D(\lambda_1) + \underbrace{\frac{2U}{9t}\mu(\alpha-1)}_{\text{Interconnection spillover effect }(+)} + \underbrace{\frac{U^2}{9t}(\lambda_{2,D}-\lambda_{2,ID})}_{\text{Strategic effect }(?)}. \\
\zeta^{ID}(\lambda_2) &= \zeta^D(\lambda_2) + \underbrace{\frac{U^2}{9t}(\lambda_{1,D}-\lambda_{1,ID})}_{\text{Strategic effect }(?)}.
\end{aligned} \tag{9}$$

By the conditions in (4) and (5), $\zeta^D(\lambda^*_{j,D}) = 0$ and $\zeta^{ID}(\lambda^*_{j,ID}) = 0$. Then, $\zeta^{ID}(\lambda^*_{1,D}) = \cancelto{0}{\zeta^D(\lambda^*_{1,D})} + \frac{2U}{9t}\mu(\alpha+1) + \frac{U^2}{9t}(\lambda_{2,D}-\lambda_{2,ID}) > \zeta^{ID}(\lambda^*_{1,ID}) = 0$ if either strategic effect is negative or it is positive but with a small effect compared to interconnection spillover effect. Similarly, $\zeta^{ID}(\lambda^*_{2,D}) = \cancelto{0}{\zeta^D(\lambda^*_{2,D})} + \frac{U^2}{9t}(\lambda_{1,D}-\lambda_{1,ID}) < \zeta^{ID}(\lambda^*_{2,ID}) = 0$ if the strategic effect is negative. If the inequality holds, by the concavity of profit functions, $\zeta(\lambda)$ is non-increasing; therefore, $\lambda^*_{1,D} < \lambda^*_{1,ID}$ and $\lambda^*_{2,D} > \lambda^*_{2,ID}$.

Additionally, given that $\frac{\partial\zeta(\lambda_j)}{\partial\lambda_{-j}} < 0$ where $j \neq -j$, i.e., λ_1 and λ_2 are strategic substitutes, positive interconnection spillover effect for the affiliated CP_1 leads to $\lambda^*_{2,ID} < \lambda^*_{2,D}$. This suggests that the strategic effect for the affiliated CP is positive, which implies that $\lambda^*_{1,D} < \lambda^*_{1,ID}$. □

Proof of Proposition 1. The proof is in the paper and in the proof of Lemma 1. □

Proof of Corollary 1. It can be easily shown that $\lambda^*_{1,ID}+\lambda^*_{2,ID}-(\lambda^*_{1,D}+\lambda^*_{2,D}) = \frac{2U\left[6(\alpha-1)\mu-9t+2U^2\right]}{27t}$, which is positive if $U^2 > \frac{9t-6(\alpha-1)\mu}{2}$ and negative otherwise. □

Proof of Proposition 2. It is obvious from Equation (7). □

Proof of Proposition 3. The profit comparison for CP_1 with and without direct interconnection is shown as follows.

$$\pi_{1,D} - \pi_{1,ID} = f_{ID} + \frac{-729Kt^2 - 81(\alpha-1)^2\mu^2 t + 6(\alpha-1)\mu U^2\left(2U^2-9t\right) + 4U^4\left(U^2-9t\right)}{729t^2}. \tag{10}$$

From Equation (10), I find the threshold, denoted $\bar{K}$, as follows.

$$\bar{K} = f_{ID} + \frac{-81(\alpha-1)^2\mu^2 t + 6(\alpha-1)\mu U^2\left(2U^2-9t\right) + 4U^4\left(U^2-9t\right)}{729t^2}. \tag{11}$$

Given $\bar{K}$, it is easy to show that $\pi_{1,D} < \pi_{1,ID}$ if $\bar{K} < K$ and vice versa. □

Proof of Proposition 4. The threshold on K is given as in Equation (11). The comparative statics with respect to α and μ are given as follows.

$$\begin{aligned} \frac{\partial \bar{K}}{\partial \alpha} &= \frac{2\mu\left\{2U^4 - 9t\left[3(\alpha-1)\mu + U^2\right]\right\}}{243t^2}. \\ \frac{\partial \bar{K}}{\partial \mu} &= \frac{2(\alpha-1)\left\{2U^4 - 9t\left[3(\alpha-1)\mu + U^2\right]\right\}}{243t^2}. \end{aligned} \tag{12}$$

It is sufficient to show that the maximum value of $\eta(t) \equiv 2U^4 - 9t\left[3(\alpha-1)\mu + U^2\right]$ is negative to show $\frac{\partial \bar{K}}{\partial \alpha} < 0$ and $\frac{\partial \bar{K}}{\partial \mu} < 0$. To obtain the maximum of $2U^4 - 9t\left[3(\alpha-1)\mu + U^2\right]$, I first replace t with the lowest possible value of t, which is $\underline{t} \equiv \frac{2U^2+3(\alpha-1)\mu}{9}$: from the interior solution assumption, I assume that $\frac{2U^2+3(\alpha-1)\mu}{9} < t$. Then, $\eta(\underline{t}) = -9(\alpha-1)\mu\left[(\alpha-1)\mu + U^2\right]$, which is negative. □

Proof of Proposition 5. First, consumer surplus levels with and without direct interconnection are derived as follows.

$$\begin{aligned} CS_D &= \alpha\mu - \frac{(\alpha-1)\mu U^2}{9t} - \frac{5t}{4} + \frac{U^2}{3} + U; \\ CS_{ID} &= \frac{9(\alpha-1)^2\mu^2 - 405t^2 + 162t(\alpha\mu + \mu + 2U) + 28U^4 + 48(\alpha-1)\mu U^2}{324t}. \end{aligned} \tag{13}$$

From Equation (13), the difference between two levels is obtained as follows.

$$CS_{ID} - CS_D = \frac{9(\alpha-1)^2\mu^2 - 54t\left[3(\alpha-1)\mu + 2U^2\right] + 28U^4 + 84(\alpha-1)\mu U^2}{324t}. \tag{14}$$

It is immediate to show that $CS_{ID} > CS_D$ if $\alpha < \frac{3\mu + \sqrt{729t^2 - 648tU^2 + 168U^4} + 27t - 14U^2}{3\mu} \equiv \bar{\alpha}$. □

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