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Internet infrastructure and competition in digital markets

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Internet infrastructure and competition in digital markets

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Abstract

Large digital platform companies increasingly integrate vertically by building Internet infrastructure, such as edge computing facilities, content delivery networks, or submarine cables. These investments enable new services while changing their bargaining power towards the upstream supplier. I model competing investment incentives in Internet infrastructure for an upstream player (e.g., an Internet Service Provider) and a large downstream platform and its effects on competition with smaller downstream platforms without proprietary infrastructure. Investment incentives increase discontinuously both upstream and downstream when the downstream platform has the larger network. With symmetric investment costs, the downstream platform will invest more than a pure upstream player. I discuss the model implications for net neutrality, network access regulation, and efficient side payments between platform and upstream industry.

JEL Codes: L13, L42, L51, L63, L86

Keywords: platforms, multi-sided markets, competition policy, net neutrality, Internet, telecommunications infrastructure

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1 Introduction

The size of large technology companies, as well as their political and economic power, is a defining feature of the modern economy. Reigning in and regulating “big tech”, a catch-all for diverse companies known by acronyms such as GAFAM or BAT, is on the political agenda in China, the European Union (EU), and the United States (US). Some economists have explained the scale of technology firms through features that generate “winner-takes-all” markets: (indirect) network effects, platform economics, or the use of big data analytics. One less well-researched aspect of big tech market power is the role of big tech’s proprietary Internet infrastructures. This paper seeks to fill this gap by proposing a theory of vertical integration in platform markets to study the effect of proprietary Internet infrastructure on competition in (digital) platform markets.

Both the physical aspect of the Internet - data centers, Internet exchanges, Internet backbone - and the ownership structure of the Internet have undergone drastic changes in the past decade¹ with consequences for competition and innovation. Traditionally, large voice carriers, such as AT&T or MCI/Verizon in the US, have acted as carriers between local networks, including campus or corporate intranets or lower-tier Internet Service Providers (ISP) which handle so-called “last-mile” connections to residential buildings. These carriers offer delivery services of data packages based on principles of net neutrality and best-effort. Smaller ISP typically pay the largest, so-called Tier-1 ISP for access to a global network, while the Tier-1 ISP interconnect with each other free of payment, creating a global network of networks, the Internet.

Consumer-facing, content-producing firms, such as Google, Netflix or Meta, have increasingly complemented this so-called “public Internet” (albeit operated by private companies) with their own investments. The investments made by some of the largest digital companies have created parallel, proprietary infrastructures.² These networks do not fall under net neutrality rules, so in particular, users can pay for higher quality or guaranteed reliability. This is essential for the delivery of innovative, quality- or latency-sensitive applications, including video game streaming, virtual reality (VR) content, but also corporate and security-related applications that require near 100% uptime. Ownership of geographically distributed infrastructure resources is likely to become even more important in the future with the trend towards edge computing and upcoming 5G technology representing a move towards the decentralization of the Internet.

Researchers and competition authorities are becoming increasingly aware of the role played by private Internet infrastructure but there is little knowledge about its implications. The EU’s Digital Markets Act (DMA) recognizes that large platforms can steer

¹<https://classic.qz.com/map-of-the-internet/>

²The most spectacular examples include ocean-crossing submarine cables, such as JUPITER, connecting the United States, Japan, and the Philippines, owned by a consortium including Amazon Web Services, Meta, NTT, PCCW, PLDT, and Softbank Corp (<https://www.submarinecablemap.com/submarine-cable/jupiter>). A transatlantic example, Havfrue/AEC-2 connects the United States, Ireland, Denmark and Norway and is owned by Aqua Comms, Bulk, Meta, and Google (<https://www.submarinecablemap.com/submarine-cable/havfrueaec-2>). Both cables became ready for service in 2020.

and block access to certain infrastructures and calls for openness and free choice in its pursuit of “fairness” and “contestability” in digital markets.³ The German competition authority in its report on “Competition 4.0” singles out content delivery networks (CDN) as one piece of Internet infrastructure which has been increasingly used by content firms.⁴ However, neither text draws conclusions for the application of competition policy based on economics principles. There is also uncertainty in how to weight this infrastructure in the analysis of market power by technology firms. This is relevant for authorities deciding whether to allow, for example, a firm such as Meta to acquire competitors such as WhatsApp, Instagram, or Giphy. Trade-offs arise between increased efficiency in serving the customers of the owners and users of private infrastructure and enabling competition policy objectives such as maintaining contestable markets.

I expand a standard model of competition for a competitive bottleneck by a vertical dimension. An upstream player owning only infrastructure invests in infrastructure and bargains with downstream firms over access to the infrastructure which allows platforms to reach consumers. Downstream, a large content platform and a fringe platform compete for consumers and collect advertisement revenues in a competitive bottleneck setup. The content platform can increase the size of the market it can address with a costly investment in private infrastructure and acts as a monopolist towards this segment of the market. I focus on the investment incentives of the upstream player and the downstream content platform, as well as their effect on bargaining upstream and downstream. Our setup allows us to discuss net neutrality, network access regulation, and capacity constraints of the fringe platform that can explain the side payments that have been observed between content firms such as Netflix and carriers.

The investment by the large content firm impacts its outside option. This has a crucial impact on the result of bargaining between it and the upstream player. The optimal choice of investment for both players is discontinuous and dependent on who owns the larger network. Surprisingly, if the network of the downstream firm is larger, both players have higher investment incentives. I present conjectures regarding net neutrality, network access for the fringe platform, and capacity constraints and side payments. The model is also relevant for other industries in which technology firms integrate vertically and face shifting bargaining power with suppliers, such as automotive.

³The DMA discusses network access in recitals 14 and 51 of the preamble. Article 6(1)(e) proposes an unspecified obligation for “gatekeeper” firms not to restrict choice of Internet access providers. However, it is not clear how the DMA will treat proprietary networks operated by gatekeepers. References are to the draft version of December 15, 2020, <https://eur-lex.europa.eu/legal-content/de/TXT/?qid=1608116887159&uri=COM%3A2020%3A842%3AFIN>.

⁴Bundeskartellamt (2016) Working Paper: Market power and platforms https://www.bundeskartellamt.de/SharedDocs/Publikation/DE/Berichte/Think-Tank-Bericht.pdf?__blob=publicationFile&v=2 [in German]. The authors mention that on-demand server and network services allow small scale entry, while many large firms invest additionally in CDN to reduce response times. The report does not contain conclusions for the competitive assessment of these CDN.

2 Literature

The current paper relates closely to the emerging literature on the economics of Internet infrastructure (Greenstein, 2020). Wilson, Xiao, and Orazem (2021) analyze the investment decisions of Internet service providers (ISP) and find long-term effects of investment delays on infrastructure quality. Greenstein and Fang (2020) find that data centers are being built primarily close to where customers are located, rather than in locations with favorable (land- and energy-) cost structure. Chaturvedi, Dutta, and Kanjilal (2021) investigate ISP pricing, in the presence of complementarities with content providers. Net neutrality, the principle of non-discrimination of data by carriers, sets this relationship apart from other vertical relationships. Even though net neutrality is controversial and not uniformly enforced, it poses economic questions and trade-offs as described by Greenstein, Peitz, and Valletti (2016). Current net neutrality regulation is uneven, focusing on ISP while leaving open bypass opportunities and loopholes for cloud services and content providers (Stocker, Smaragdakis, and W. Lehr, 2020). This paper contributes to this literature by exploring the implications of vertical integration by downstream content platforms on competition between platform companies. I analyze how Internet infrastructure as an essential input to content services impacts platform competition in a two-sided market framework.

This paper innovates the modeling of two-sided markets with regards to investment incentives and vertical relationships. So far, both the managerial literature on platform innovation and economic models have emphasized innovation in terms of quality or product features (Lin, S. Li, and Whinston, 2011; Scholten, 2011; Boudreau, 2010; Zenny, 2016; Jung et al., 2019). Bourreau and Verdier (2014) study investment in marginal cost reductions by symmetric firms, and focus on the role of spillover effects. B. G. Li, McAndrews, and Wang (2020) study the adoption speed of a cost-saving technology in payment cards while Choi et al. (2019) analyze technology with an ambiguous effect on market sides. Our setting differs from papers that call agreements with one market side “vertical” (Lee, 2013; Carroni, Madio, and Shekhar, 2018; D’Annunzio, 2017). The notion of vertical relations in these papers is based on a prosaic understanding that one side provides an input to the platform’s service (e.g., a content producer to a video streaming platform). In our model, the vertical element is represented by an upstream player who is not a platform member, but a separate entity. The key difference with the rest of the literature is that the upstream industry provides an input - “connectivity” - that is a perfect complement to the downstream provision of platform services. The platform services downstream are a simple example of competition for a competitive bottleneck (with single-homing consumers) with per-user charges (to advertisers) as outlined in Armstrong (2006).

Researchers in digital economics and computer science have started to document a trend towards private and proprietary networks which has drastically changed the ecosystem of the Internet in the recent past. This paper is a first approach from an economic theory angle to analyze the effects of this drastic shift in ownership structure. Stocker, Knieps, and Dietzel (2021) document extensively the geographic and virtual dimension

of private networks and describe their implications for firm costs, service quality, and innovation. Concurrently, the future of the public “best-effort” Internet and the functional disparities between services that rely on it versus services that are supported by proprietary networks and clouds has caught attention (Lehr et al., 2019; Balakrishnan et al., 2021). By analyzing the previously overlooked competitive effect of a novel aspect of competition in digital markets that is currently used predominantly by the largest digital firms, this paper contributes to the academic debate on regulation and antitrust towards large technology companies (see also Petit, 2020).

Industry background: Competition in digital markets has entered mainstream discussion, with concerns including market power or privacy (Baker, 2019; Zuboff, 2019). In particular, the size and market power of the largest technology firms (“big tech”) has drawn regulatory scrutiny and a barrage of antitrust action both in the EU and the US. The EU’s Digital Markets Act brings additional obligations for large platform companies, including freedom of network access.

Some large content providers, including American and Chinese technology firms that are likely to be identified as “gatekeepers” under the DMA, have pursued vertical integration strategies through the construction of private backbone networks, edge computing facilities, and owned content delivery networks (CDN) that improve their ability to expand and change their digital infrastructure to improve the performance and quality of their services (Arnold et al., 2020; Arnold, 2020; Sermpezis, Nomikos, and Dimitropoulos, 2017; Motamedi et al., 2019).

I summarize all of these very different technologies that broadly relate to the infrastructure side of providing digital services as a single upstream industry but recognize that different platforms have adopted specific strategies related to, for example, proprietary networks (Stocker, Knieps, and Dietzel, 2021) or content delivery network (Stocker, Smaragdakis, W. Lehr, and Bauer, 2017). Depending on the business model, private infrastructure can result in cost decreases because of hardware that is fit for purpose.

More attention has also been shifted to the ability of large platform companies to control innovation on their ecosystems (consider, for example, Apple’s control of apps that appear on its app store). Ecosystems that rely on proprietary networks are important in so far as sophisticated enterprise software is increasingly provided through the cloud services of large platforms, i.e. on their hardware. Final consumers are typically unaware of and indifferent to the choice of hardware or networking solutions through which these services are provided (for example, Microsoft Azure, Amazon Web Services, Google Cloud).

3 Model

Our modeling strategy is to focus on the decisions of the upstream player and a downstream content platform (CP) to invest in bandwidth capacity and the effect on a fringe platform (FP) downstream which does not invest. The FP could correspond to any small scale supplier of internet services, such as e-mail, for which own physical investment is not economical for reasons of scale. For the purpose of the model, I take this difference between a CP willing to invest in network capacity and the FP as given. For the upstream player, increasing capacity is attractive because it increases the size of the market downstream. One could imagine that greater network investment increases the number of consumers with high-speed Internet access, leading to rising demand for digital services both on the extensive margin (new consumers getting into the market) and the intensive margin (existing consumers demanding additional services). For example, higher bandwidth capacity allows new services that are not viable at lower bandwidths, such as Voice over IP, streaming audiovisual content, online gaming and streaming video games. This distinction between the extensive and intensive margin on the demand side is not further investigated in the model. Expanding the market size downstream allows the upstream player to charge higher fees to downstream players.

Simultaneously with the upstream player, the CP invests in capacity. Its incentive to do so is two-fold. First, its investment adds to total network capacity, resulting in a larger downstream market size, in the same fashion as the upstream player. Second, by increasing its own network, the CP can partly bypass the upstream player. For a given total capacity, if the platform owns a larger network, it will pay less in upstream fees to the upstream player if its share of the total bandwidth is higher. This is represented by Nash bargaining where a greater own network by the CP corresponds to a better outside option. Third, platform investment improves its position versus the FP as the CP acts as a monopolist over a part of the demand. More precisely, the CP is a monopolist over the range of demand created by its own investment while competing neck-to-neck with the FP over services that the FP can provide on the ISP's network.

3.1 Setup

I consider a game with full information between an Internet service provider (ISP), a large downstream CP and a FP. The game proceeds in three stages: At $t = 1$, the ISP and CP simultaneously invest in a private network of size X_i , $i = CP, ISP$ at some increasing and convex cost $k_i(X_i)$. At $t = 2$, CP and FP negotiate non-rival access to network of the ISP. I model the negotiation as Nash bargaining with bargaining weights $\delta_j \in (0, 1)$, $j = CP, FP$ and outside options as described below. I define δ_j as the fraction of the surplus captured by the ISP when bargaining with platform j and T_j the transfer paid by platform j to the ISP. At $t = 3$, the CP and FP simultaneously set prices to consumers and advertisers in the downstream market.

Downstream, the platforms serve two market sides: consumers and advertisers. From the point of view of advertisers, the platforms are undifferentiated so advertisers only care about the consumer-side demand that they can reach. There is a unit mass of

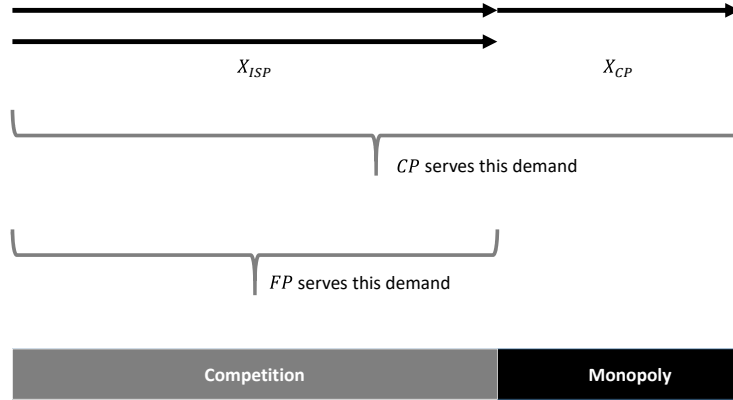


Figure 1: Demand and competitive conditions implied by upstream and downstream investment

small advertisers with a willingness-to-pay of R for showing their ads to a unit mass of consumers. In equilibrium, platforms will generate revenues on the advertiser side proportionate to the consumer-side demand that they serve.⁵ Conditional on negotiating access to the ISP’s network, the CP can utilize both its own network X_{CP} and the ISP’s network X_{ISP} . In the base model, the FP can only use the ISP’s network. I consider agreements between the CP and FP about access to X_{CP} (e.g., hosting a service on the CP’s cloud ecosystem) in an extension.

When both platforms have access to X_{ISP} and $X_{CP} > 0$, the CP serves a mass of consumers equal to its own investment as a monopolist. Over the market that both platforms address, the CP and FP compete à la Bertrand where demand is equally split in case of equal prices. This is summarized in Figure 1. As the CP faces no competition on the right-most segment of demand, it can charge a separate price here. Consumers value each unit of demand at v . The platform’s cost of serving consumers and advertisers is 0. Platform i charges consumer prices $P_i^k \in \mathbb{R}_+$ on sections $k = c(ompetition), m(onopoly)$, resulting in demand functions:

$$Q_i^c = \begin{cases} X_{ISP}, & \text{if } P_i^c < P_{-i}^c \\ 1/2X_{ISP}, & \text{if } P_i^c = P_{-i}^c \\ 0, & \text{if } P_i^c > \min(P_{-i}^c, v) \end{cases} \quad Q_{CP}^m = \begin{cases} X_{CP}, & \text{if } P_{CP}^m \leq v \\ 0, & \text{otherwise.} \end{cases}$$

The last component of this model is the setting of transfers T_{CP} and T_{FP} between

⁵This is similar to the familiar “competitive bottleneck” configuration (Armstrong and Wright, 2007) in that the platforms are monopolists towards advertisers over access to consumers.

platforms and ISP.⁶ Think of the infrastructure offered by the ISP X_{ISP} as an intermediate good (“connectivity”) that is needed to serve consumers and which the ISP produces at zero marginal cost for given X_{ISP} . I model the price setting between the platforms and the ISP as Nash-bargaining for the bundle of “connectivity” for the total amount of buyers and sellers that each platform wants to serve, where the total value to be split is $X_{ISP}R/2$ for the FP and $R/2(X_{ISP} + 2X_{CP}) + vX_{CP}$. The outside option of the CP is to provide services only using its proprietary network at a value of

$$\Gamma = X_{CP}R/2 + \max(0, (X_{CP} - X_{ISP})(R/2 + v)).$$

This choice of outside option represents the simplified view that the infrastructure represented by X_{CP} can be utilized in the same way as X_{ISP} , allowing the CP to offer services on which it can generate advertisement revenue and possibly monopoly pricing towards consumers. Therefore, as long as $X_{CP} < X_{ISP}$, the outside option only includes split advertisement revenues on the competitive section. When the inequality is reversed, even in the outside option the CP collects full advertisement revenue and monopoly prices on some part of the demand. The marginal change in the outside option is discontinuous at $X_{CP} = X_{ISP}$.

The FP and the ISP each have an outside option of 0 as they are pure downstream and upstream players, respectively, while value in this model is generated downstream only in combination with the upstream (intermediate) good. Access to X_{ISP} is non-rival, both platforms can use it simultaneously without causing congestion. Both platforms expect that the rival platform will agree with the ISP and that negotiations do not break down in equilibrium. In principle, one could imagine, e.g., that the ISP offers not to make a deal with the FP to charge a higher price to the CP. As the FP does not add to the market, this could even be profitable (although this is not guaranteed as the FP has a lower outside option than the CP and possibly a lower bargaining weight). However, I rule out this negotiation strategy altogether as most antitrust laws forbid a powerful upstream firm to deny access to an essential input. Therefore, this model is not an example of Nash-in-Nash bargaining.

In summary, this yields the following profit functions:

$$\Pi^{ISP} = T_{CP} + T_{ISP} - k_{ISP}(X_{ISP}) \quad (1)$$

$$\Pi_{FP} = Q_{FP}^c(R + P_{FP}^c) - T_{FP} \quad (2)$$

$$\begin{aligned} \Pi^{CP} = & Q_{CP}^c(R + P_{CP}^c) + \\ & Q_{CP}^m(R + P_{CP}^m) - T_{FP} - k_{CP}(X_{CP}) \end{aligned} \quad (3)$$

I solve for a subgame-perfect Nash equilibrium (SPNE).

⁶In reality, platforms pay the ISP who connects them to the Internet (paid peering) but under net neutrality they do not pay termination fees to the network in which their content terminates. In the model, I do not introduce a distinction between connecting and terminating ISP, instead taking a simplified view of the upstream industry.

The setup is standard except for the way that upstream investment determines the size of the downstream market. Intuitively, this one-dimensional measure of consumer demand encompasses both the intensive margin of demand (existing customers demanding additional services as bandwidth increases) and the extensive margin of demand (new customers are won as networks improve and bandwidth increases). Larger investment either by the ISP or the CP expands the market by reducing congestion and increasing network speed and reliability: more latency-sensitive services become increasingly feasible if bandwidth is high enough (think of VoIP, online multiplayer games, cloud gaming services).

This is a simple approximation of an ecosystem market: Large tech companies such as Google sell a variety of services, such as email, cloud storage, video streaming, VoIP, or game streaming to different customers. As Google expands the available bandwidth, additional consumers (that might have previously suffered from excessive latency) will demand additional services. In reality, many different services are offered concurrently at different price points (e.g., Gmail being free, Youtube having free and paid tiers, Google Stadia being a paid premium service). Then, the CP competes intensely for a service in which it faces intense competition (e.g., e-mail services) while being able to set its own price on other services for which the fringe platform does not compete (e.g., cloud gaming services).

3.2 Solution

Proposition 1: The optimal investment decision is a discontinuous function that depends on investment cost, downstream revenues, and the relative bargaining weight of CP and ISP with a jump where $X_{ISP} = X_{CP}$. The marginal value of investment is higher for both players when $X_{CP} > X_{ISP}$.

Proof: At the third and last stage, both platforms choose prices for consumers and advertisers. Assume that both platforms have access to the ISP's network. The consumer demand they face is $Q_{CP}^c + Q_{CP}^m = X_{ISP}/2 + X_{CP}$ and $Q_{FP}^c = X_{ISP}/2$, respectively. The CP can set a different price on the segment of demand on which it faces competition from the segment on which it does not. Given Bertrand competition for the shared segment of demand and zero cost, both platforms charge 0 and face a demand of $X_{ISP}/2$. The CP charges a price of v for the segment X_{CP} on which it has monopoly power for profits

$$\Pi_{FP} = X_{ISP}(R/2) - T_{FP} \quad (4)$$

$$\Pi_{CP} = X_{ISP}(R/2) + (v + R)X_{CP} - T_{CP} - k_{CP}(X_{CP}) \quad (5)$$

Given third-stage profits and the outside options described above, Nash-bargaining results in transfers

$$T_{FP} = \delta_{FP} (R/2) X_{ISP} \quad (6)$$

$$T_{CP} = \delta_{CP} [R/2(X_{ISP} + 2X_{CP}) + vX_{CP} - \Gamma] \quad (7)$$

Finally, at the first stage, the ISP and CP maximize profits over their choice of investment. First rewrite the ISP's profit in terms of transfers and investment cost:

$$\Pi^{ISP} = T_{CP} + T_{ISP} - k_{ISP}(X_{ISP}) \quad (8)$$

where

$$T_{CP} = \begin{cases} \delta_{CP} \left[\frac{R}{2}(X_{ISP} + X_{CP}) + vX_{CP} \right], & \text{if } X_{ISP} \geq X_{CP} \\ \delta_{CP}[(R + v)X_{ISP}], & \text{if } X_{CP} > X_{ISP} \end{cases} \quad (9)$$

The first order condition yields

$$\frac{\partial \Pi^{ISP}}{\partial X_{ISP}} : [k_{ISP}(X_{ISP})]' = \delta_{CP} \frac{R}{2} \quad \text{if } X_{ISP} \geq X_{CP} \quad (10)$$

$$[k_{ISP}(X_{ISP})]' = \delta_{CP}(R + v) \quad \text{if } X_{CP} > X_{ISP} \quad (11)$$

So the ISP has stronger investment incentives when its network is smaller than that of the CP. The intuition is that in this case, the CP's outside option includes charging monopoly prices and gaining full advertisement revenue R (as opposed to shared advertisement revenue $R/2$) on part of its demand. By increasing its own network, the ISP has a stronger impact on the CP's outside option than if the CP's outside option was restricted to the less lucrative, competitive segment of demand. The solution for the CP takes a similar form:

$$\Pi^{CP} = X_{ISP} \frac{R}{2} + (v + R)X_{CP} - T_{CP} - k_{CP}(X_{CP}) \quad (12)$$

resulting in first order conditions

$$\frac{\partial \Pi^{CP}}{\partial X_{CP}} : [k_{CP}(X_{CP})]' = v + R - \delta_{CP} \left[\frac{R}{2} + v \right] = \quad (13)$$

$$(1 - \delta_{CP})v + \left(1 - \frac{\delta_{CP}}{2} \right) R \quad \text{if } X_{ISP} \geq X_{CP}$$

$$[k_{CP}(X_{CP})]' = v + R \quad \text{if } X_{CP} > X_{ISP} \quad (14)$$

So investment incentives depend on the curvature of the investment cost functions which I allow to differ at this point. The optimal investment function is also discontinuous and has a jump because the investment incentives here depend upon which network is larger. If the CP has the larger network, its marginal value of investing increases because a marginal expansion of capacity results in a market increase on the more lucrative (monopoly) segment in the outside option. The ISP also has higher investment incentives when the platform has a larger network, but the reason here is different: in this case, ISP investment increases both the total market and reduces the bargaining power of the platform. Consider the case $k_{CP} = k_{ISP}$. In this case, $X_{CP} > X_{ISP}$ as v and R are strictly positive and $\delta_{CP} < 1$. The reverse case will only occur when the marginal cost of investment is much lower for the ISP. CP investment only depends on its relative bargaining strength when it has the smaller network.

3.3 Expansions

3.3.1 Net neutrality

Net neutrality is the absence of termination charges, i.e., content providers do not pay the ISP in whose network their traffic is delivered. According to other definitions, net neutrality does not allow ISP to offer a “fast lane” in exchange for payment. However, precisely this happens in the model when the upstream industry negotiates with platforms over the split of profits one-by-one as companies pay unequal prices for the same good.

I consider a net neutrality scenario in which both platforms access X_{ISP} under equal conditions. Then, access to this infrastructure can be described as a price posted by the upstream industry instead of the bilateral bargaining of the base model. More precisely, after investment decisions in X_{CP} , X_{ISP} have been made, the ISP posts a price under which platforms can purchase non-rival access to X_{ISP} . Platforms then decide whether to pay the price, and finally downstream competition takes place. In contrast with the previous section, I allow for non-discriminatory prices that are high enough to potentially exclude a platform. This is in line with the prevailing antitrust doctrine of protecting competition, rather than competitors, and generally permitting input prices that allow “as-efficient-competitors” (relative to a dominant firm) to remain in the market.

Proposition 2: Under net neutrality, the ISP will set a price that extracts the whole surplus of the CP. It will find it always profitable to exclude the FP.

Proof: The highest price that the FP is willing (and able) to pay for access to X_{ISP} is $X_{ISP}(R/2)$, i.e. the profit it makes under competition on the segment X_{ISP} . The total revenue of the ISP when charging this price to FP and CP is then $X_{ISP}R$. The other candidate price is $X_{ISP}(R+v)$, charged to the CP, which is strictly higher. The ISP has no interest in downstream competition as it reduces industry profit. Consumer prices increase as the CP is now a monopolist over the whole range of services. Net neutrality thus harms entry as the FP is essentially excluded from the market and consumers who pay higher prices.

3.3.2 Network access regulation

In the setting described above, it would be interesting to understand what happens if the FP also gains access to X_{CP} . Indeed, this is happening already to some extent, for example through the deployment of third-party software products hosted by cloud services such as Amazon Web Services. In this model, it seems sensible to ask what would happen if the FP can purchase access to X_{CP} . We model this as pricing, rather than bargaining for the same reason as in the previous section: In line with prevailing antitrust doctrine, we assume that the CP has to offer access under “fair” and “reasonable” terms. In particular, this means that prices cannot be so high that the CP would not be able to profitably supply its own services at these prices. We therefore define a “negotiated access” scenario where at $t = 2$ the FP negotiates simultaneously with the

ISP and CP for network access. The CP is constrained to charge no more than a price that would let itself break-even absent competition, i.e., a maximum price of $X_{CP}(R+v)$ (which, under zero costs, is equal to revenue).

Conjecture 1: The FP rejects to purchase access to X_{CP} at any price greater than $X_{CP}(R/2)$. The CP optimally charges any price higher than $X_{CP}(R/2+v)$. No trade can take place. The equilibrium configuration and prices remain unchanged from the base model.

Argument: If the CP negotiates with the FP over access to its network X_{CP} , allowing the FP to treat it like accessed capacity of the upstream player, it will contest the entire demand in the market. Therefore, it is not optimal for the CP to charge less than the loss of revenue on the previous monopoly segment, which is $X_{CP}(R/2+v)$. The FP can always guarantee itself revenue of at least $X_{CP}(R/2)$ on the newly purchased segment of the market by setting a consumer price of 0. However, if the price of X_{CP} is greater than $X_{CP}(R/2)$, the FP needs to charge a higher price for the purchase of additional network access to be profitable. Then, the CP can undercut the FP, and capture the whole demand. Therefore, there is no price at which CP and FP can agree to trade.

3.3.3 Efficient side-payments

This setting explains the observed side payments that some large content platforms, such as Netflix, have made to traffic carriers. This model can explain why such side payments can occur when the ISP network is only used to a limited extent by the FP. I make two assumptions: the FP cannot serve more than some amount \bar{Q} of services and the CP and ISP can agree, before the beginning of the game, that the CP will pay a certain transfer T' to the ISP that is conditional on building a network of a certain size. To make the model interesting, we consider cases where \bar{Q} is binding in equilibrium.

Conjecture 2: If the FP is capacity constrained and conditional side-payments are possible, the ISP and CP's incentives to invest align and the CP may pay the ISP for additional investment.

Argument: If the FP is capacity-constrained in that it can serve only a portion of the demand that it could potentially address via the upstream player's network, the investment incentives of the upstream player and the CP align. When investment is cheaper for the upstream player, the CP will find it profitable to offer a side payment conditional on a certain level of investment which is accepted in equilibrium. The optimal level of investment equates the marginal value of X_{ISP} with the marginal investment cost of the ISP.

3.4 Discussion

This model is intended as a first modeling attempt at the issues posed by the vertical integration of technology platforms. Both competition in downstream markets and as well as Internet infrastructure are highly complex and technical issues, and sector-specific regulation differs between Europe, North America, and other regions of the world. As such, it is not the purpose of this model to predict exactly the behavior and contracts that will arise in the market. Instead, the model illustrates key features of proprietary Internet infrastructure: the potential efficiency and new goods and services provided by big tech investment, but also the interaction in the market place with smaller players which can be harmed by well-intended regulation.

Also, the model predicts a change in the relationship between the traditional carriers of data on the Internet and big platforms, which is captured by the drastic, non-continuous change in investment incentives depending on which network is larger. In fact, this points to issues beyond digital services. Other industries that have started to collaborate closely with technology companies, such as the automotive industry, are anxious about the future focus of value creation. This model shows that the shift in outside options through vertical integration together with value creation can have a disruptive impact on an industry.

I make several conscious omissions for the purpose of approaching this complex modeling challenge. This model illustrates the incentives for a platform to invest in proprietary internet infrastructure. It takes an extremely simplified view of digital markets by folding many different products downstream and many different kinds of infrastructure upstream into a very simple framework. Among the main model assumptions that can be relaxed and expanded upon, I see the following as priorities for further investigation:

- Upstream competition between Internet Service Providers is another setting besides the monopoly setting considered in this paper that is of interest.
- In the base model, the FP is undifferentiated. Its existence does not create any additional welfare or efficiency. In reality, small fringe services, for example for search engines or e-mail, are differentiated from the competing offers of large platforms by emphasizing environmental or privacy benefits. While some of these features, for example compensation for the CO2 footprint of operations, could be imitated by large firms, others are inherently difficult to provide for the large tech firms, for example a credible commitment not to use private and sensitive data for their other services, for example in the form of targeted advertising. A model variation could assign to the FP an (exogenous or endogenous) differentiation factor that creates demand only the FP can address. This would add to the discussion on the profitability of exclusion.
- While the motivation to study proprietary networks is partly also the ability of platforms to steer innovation in their ecosystems, innovation is not an explicit model feature. However, the expanded demand as a result of increased investment

can be understood as demand for innovative services that only become feasible with increased infrastructure.

- The outside option of the CP assumes that its infrastructure and the upstream player's infrastructure is fully interchangeable. This is not the case for all kinds of infrastructure as the large technology platforms design their networks to interconnect with, rather than replace, existing infrastructure. Duplication of fixed costs and the presence of network effects make it unfeasible to fully forego the use of existing Internet infrastructure even for the largest tech firms. The outside option in our model may be appropriate, however, for cases such as Content Delivery Networks, where companies can make a genuine make-or-buy decision. This suggests that the bargaining power of upstream players may be higher than our model suggests.

4 Conclusion

The Internet has affected the global economy on many levels, having enabled some platform businesses to grow to spectacular scale. A solid understanding of the economics underpinning its infrastructure is key to successful economic policy and regulation. In particular, an effects-based assessment of regulation, potential anti-competitive conduct and merger review needs economic guidance. The paper illustrates the economic effects of the increasing vertical integration by large content firms and platform.

This model illustrates investment incentives for Internet infrastructure in combination with competition in a digital market downstream. I show that investment incentives increase both upstream and downstream when the downstream platform owns the larger network. The intuition is that in this case, the additional demand that the platform is able to serve results in additional revenues that the platform can fully appropriate. In a sense, the infrastructures of the upstream industry becomes fully commoditized. At the same time, the upstream player faces strong incentives to improve its bargaining position by expanding its own network. As a consequence, this model predicts that the rise of private, proprietary infrastructure will continue as downstream content platforms have stronger investment incentives than pure upstream players.

Furthermore, the model points at questions beyond digital services. Large technology firms have begun vertical integration in other fields, including automotive, where questions about the future focus of value creation have also been asked. The model allows for many rich expansions as discussed above. In addition, the analysis can be expanded by appropriate data to test model predictions empirically.

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