Internet infrastructure and competition in digital markets

Philip Hanspach*

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Abstract

Large platform companies increasingly integrate vertically by building Internet infrastructure. These proprietary networks confer cost and quality advantages in digital platform markets. I model competing investment incentives for an upstream player and a vertically integrated platform facing rival platforms without proprietary infrastructure. Investment incentives increase discontinuously both upstream and downstream when the vertically integrated platform has the larger infrastructure. The upstream player benefits from "commodification" when it has the smaller network. The resulting increase in investment is socially efficient but the effect on the contestability is ambiguous.

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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.[1] Reigning in and regulating "big tech", a catch-all for diverse companies known by acronyms such as GAMAM or BAT, is on the political agenda in China, the EU, and the US. Economists have explained the size and power of "big tech" with 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 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.

The scale and ownership of the physical aspect of the Internet - data centers, Internet exchanges, Internet backbone - have undergone drastic changes in the past decade. Traditionally, large voice carriers connected local networks. These carriers deliver data packages based on principles of net neutrality and best-effort. The largest 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" (operated by private companies nonetheless) with their own investments. The investments made by some of the largest digital companies have created parallel, proprietary infrastructures.[2] These networks enable higher quality or guaranteed reliability contracts without violating net neutrality rules. This is essential for quality- or latency-sensitive applications, ranging from entertainment to corporate and security-related applications that require near 100% uptime.

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

[1] Techmonitor, Digital power: How Big Tech draws its influence (2021)

[2] 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. A transatlantic example, *Havfrue/AEC-2* connects the United States, Ireland, Denmark and Norway and is owned by Aqua Comms, Bulk, Meta, and Google. Both cables became ready for service in 2020.

[3] The 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.

[4] Bundeskartellamt (2016) Working Paper: Market power and platforms [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.

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 proprietary infrastructure and enabling competition policy objectives such as maintaining contestable markets.

Based on data by Telegeography, we show that Meta, Microsoft, Google, and Amazon Web Services are owners or co-owners of 20% of submarine cables scheduled to go online in 2022, and more than 25% of those scheduled in 2023. 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.

I expand a model of competition for a competitive bottleneck by a vertical dimension. A pure upstream player invests in infrastructure and bargains with downstream firms over infrastructure access which allows platforms to reach consumers. Downstream, a vertically integrated content platform and a universe of fringe platforms compete for consumers and collect advertisement revenues. The vertically integrated platform can increase the consumer market it can address with a costly investment in proprietary infrastructure and has market power towards this segment of the market.

Preliminary results indicate that investment incentives increase for all investing firms when the integrated firm has the larger infrastructure. I explain this in terms of "commodification" of the upstream firm. This increase in investment by both firms is socially efficient but the effects on the contestability, measured as the market share of fringe platforms, are ambiguous. The model predicts that extending net neutrality to infrastructure providers would result in foreclosure of small platforms and higher consumer prices. Finally, I describe competition between vertically integrated firms. The model serves as a flexible tool for antitrust enforcers to analyze the role of upstream infrastructure in a digital market.

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 complementarity between broadband and content. These papers typically focus on the monopoly standing of last-mile ISP with respect to residential connections. By contrast, the infrastructure I am describing appears at an earlier stage in the value chain where big tech firms are vertically integrating. The example in the following section clarifies the distinction.

Our paper is closest to Buehler, Schmutzler, and Benz (2004) and Avenali, Matteucci, and Reverberi (2014). The former studies investment incentives by an upstream industry when network quality is not verifiable and the downstream (retail) industry is one-sided. They argue that vertical separation enhances incentives to invest in network quality most of the time. One main channel here is the quality sensitivity of retail demand. However, Buehler, Schmutzler, and Benz (2004) study a chain of monopolies and do not consider vertical integration. My two-sided market setup allows a segmentation of the downstream market into competitive regions and regions with market power.

Avenali, Matteucci, and Reverberi (2014) analyze functional and ownership separation for broadband networks and find ambiguous effects of vertical integration. By contrast, my setup of competing investment incentives is not about access foreclosure but competing investment by pure infrastructure providers (for example, content delivery networks) and a vertically integrated content platform. I do not analyze the last-mile connections in which broadband providers have monopoly access but focus on the area in which large content providers integrate vertically.[5]

The main reason for these infrastructure investments is to improve data management in the presence of net neutrality. Net neutrality is the imposition of zero-termination fees[6] and non-discrimination of data by carriers. Even though net neutrality is controversial and not uniformly enforced (for an early overview of the literature, see Schuett, 2010), 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 studies the investments into infrastructure that enables network management practices that arise to cope with the

[5] Some attempts at competing in this area by content providers, such as Google Fibre, have failed in the past and do not play a large role in the marketplace.

[6] For example, an ISP such as AT&T cannot charge Netflix for traffic that terminates in an AT&T network such as a residential building. The price paid by the final consumer to the ISP is understood to compensate the terminating network, no matter where data packages originate.

limitations of net neutrality.[7] It contributes to the debate on net neutrality by modeling investment incentives into the network management practices that already exist to adapt to net neutrality restrictions.

This paper innovates the modeling of two-sided markets with regards to investment incentives and vertical relationships. Our setting differs from papers that call agreements with one market side "vertical" (Robin S 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).

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). Depending on the business model, private infrastructure can result in cost decreases because of hardware that is fit for purpose or increasing connection quality from faster delivery of data packages at the router of the last-mile ISP.

This paper is a first approach to analyze the effects of this shift in Internet ownership structure. Stocker, Knieps, and Dietzel (2021) document the geographic and virtual dimension of private networks and their implications for firm costs, service quality, and innovation. Lehr et al. (2019) and Balakrishnan et al. (2021) describe the functional disparities between services that rely on the public Internet versus services that are supported by proprietary networks and clouds. Using data from Telegeography, we add to the description of proprietary networks by showing that an increasing number of submarine cables and an increasing share of submarine cables has firms including Amazon Web Services, Meta, Microsoft, and Google among their owners (see Appendix A). 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).

[7] For example, infrastructure that ensures that one content provider's data packages arrive earlier and in a specific order at a router from where on they are treated on a first-come-first-served basis with the data packages of other content providers. Thus this infrastructure improves speed at the stage preceding the point where the net neutrality principle comes into play. See Easley, Guo, and Krämer (2018).

3 An illustrative example

To provide intuition for the model setup, I use the example of a video-sharing platform service.[8] This includes services such as hosting videos that are uploaded by users, making them accessible to other users, and selling advertisement space on this platform. A well-known example of such a platform is Google's YouTube. Other applications offering broadly comparable services include TikTok, Facebook Watch, and Instagram TV. There are (or were) numerous smaller competitors including Dailymotion, Metacafe, and (now discontinued) byte, Vine, or Clipfish. Other services that offer video-sharing that are specialized or curated include Twitch (which focuses on live streaming), Nebula, or Skillshare. Most of these services offer at least some premium features that users can pay for (for example, YouTube Premium). Some of these services are mainly or exclusively advertisement financed while others are mainly paid for by users.

On the technical side, users will access the content hosted by the platform through their own Internet connection for which they pay, e.g., a local ISP in the case of residential access or their data plan provider in the case of mobile devices. In the model, we will assume that consumers all have an Internet connection. We do not model the market for Internet connectivity, which can be justified by high Internet penetration rates in most developed countries[9] and the fact that any particular digital service might only represent a small part of the bundle of digital services that consumers are interested in.

The content may be stored on servers that the platform can rent from third-party providers. Servers can be rented from traditional telcos or purchased and operated individually, but operating a service at scale typically requires a much faster and more efficient delivery is provided via content delivery networks by firms such as Akamai and Limelight. In the model, a universe of atomistic, small video platforms operate using only these third-party solutions.[10] We refer to them in aggregate as the fringe player (or FP).

In addition, we consider one vertically integrated firm, such as YouTube/Google (the content platform, or CP, in the model) that has the financial, technical, and operational capacities to invest in its own infrastructure. This can be for example a proprietary

[8]The example is purposefully chosen to coincide with a "core platform service" as defined in the DMA.

[9]See, for example, World Bank Data, Individuals using the Internet (% of population), based on data by International Telecommunication Union (ITU) World Telecommunication/ICT Indicators Data, https://data.worldbank.org/indicator/IT.NET.USER.ZS

[10]An article by Gigaom describes bottlenecks and scale requirements for video services 10 years ago and an outlook for the future that emphasizes how increased consumer demand results in increasing requirements for CDN to keep up with growing consumer demand. In particular "The paper goes on to say that because even an awesome data center can only provider a few hundred gigabytes per second of throughput to end users, it's almost impossible to create a service with the scale to deliver the hundreds of terabytes needed to support video." See Gigaom, Inside Akamai and the scary future of streaming video (2011), https://web.archive.org/web/20121211015527/http://gigaom.com/video/inside-akamai-and-the-scary-future-of-streaming-video/, last retrieved 10.11.2022.

network of connected data centers that acts as a content delivery network.[11] In reality, the infrastructure of a vertically integrated firm is not limited to one class of infrastructure (such as data centers) but a complex arrangement of different parts that all work together to optimize parameters of transmission quality.[12]

CP competes with FP for consumers on its video-sharing platform service. All can purchase access to the infrastructure (for example CDN) provided by the upstream industry, U, in our model. FP do not have the outside option of building an alternative network, so they have to strike a deal with the upstream firm if they want to serve consumers. CP, by contrast, invests in its proprietary infrastructure as well. On path, this proprietary infrastructure exists on top of the existing infrastructure, which is why additional investment allows CP to make cost or quality gains where this is most economical. For example, CP may add an intra-ISP server inside the local ISP network of a high-demand location to reduce response times.

This quality gain translates into market power for CP on some segment of consumer demand. As CP can offer a superior quality, it can sell premium services. For example, Netflix offers streaming at higher resolutions for its premium tier while YouTube offers background streaming and downloads for paid tiers. In the model, CP competes neck-to-neck with FP for services at standard qualities but can charge higher prices on such premium services. This tiered service is captured by our model where greater infrastructure allows CP to a) sell more services and b) charge higher prices on these additional services for which FP cannot compete.

In the logic of the model, CP chooses the size of its infrastructure by comparing its marginal costs of investment with the marginal revenue. A marginal increase in its network quality allows it to serve additional content to consumers that previously preferred to use their time otherwise, increasing the total view-time during which consumer attention can be sold to advertisers. U, who acts as a monopolist in the model, chooses an investment level that depends on its own marginal cost and the marginal revenue provided by selling infrastructure access to CP and FP.

The price that U can ask for access to its infrastructure depends on what CP and FP would do otherwise. If CP's proprietary network is relatively small compared to U's network, it cannot differentiate itself from smaller players when these have access to U's larger network. This results in low prices for the services that CP and FP offer, and split advertisement revenues. The marginal value of investing in infrastructure is low for CP as long as additional investment keeps it in this "competitive" segment of the market. However, this scenario is "off-path", so it is never optimal for CP not to negotiate access to U's network precisely to avoid this scenario. Here, CP has a lower outside option (i.e., the profit CP would make absent an agreement) which grants a "strategic role" for U,

[11] For example, YouTube videos are stored, backed-up, and retrieved from one of Google's data centers based on location. HowItWorks, How does YouTube work? (2016), https://www.howitworksdaily.com/how-does-youtube-work. Last retrieved 10.11.2022.

[12] Stocker, Knieps, and Dietzel (2021) proposes "economies of specialization" as a main advantage of these proprietary networks over third-party solutions and documents the ownership of such infrastructure assets by almost all big tech firms. For a stylized example of such an infrastructure consider the following overview by Google of its own network: https://peering.google.com/#/infrastructure.

by allowing CP to differentiate its service from competitors by employing proprietary networks.

By contrast, if the size of CP's proprietary network already exceeds U's, and consequently what is available to FP, CP's outside option is better: it has market power over some segment of demand even without the U's infrastructure. Still, on-path CP will still want to secure access to additional infrastructure. The marginal effect of U's infrastructure on CP's service offering is greater now: every additional improvement in infrastructure fully falls into the region where CP has market power over consumers and need not share advertisement revenue with competitors (as it attracts all consumers in this range where FP is not active). This happens at least on some range of demand with or without access to U's infrastructure. I speak of "commodification" of U in this case: U's contribution becomes a commodity that is transformed by CP into additional revenues at a constant rate and fully interchangeable with additional investment by the platform itself.

4 Model

I model the decision of an upstream player (U) and a downstream content platform (CP) to invest in infrastructure and the effect of this investment on downstream competition between CP and a universe of fringe platforms (FP) which do not invest. For simplicity, the FP are hence referred to as a single agent; the outcome does not depend on this distinction.[13] I assume that FP cannot invest in infrastructure for lack of scale.

The key mechanism that the model shines light on is the "commodification" of the infrastructure of the upstream player U. When CP's infrastructure exceeds U's, U's contribution to CP's profits also grows. Under Nash bargaining, this allows U to claim a larger share of the pie. The substitutability of the two infrastructures is a key assumption for this. I discuss the implications of this model for net neutrality and network regulation as well as its applicability to other markets.

I describe the setup in Section 4.1 and solve for an equilibrium in Section 4.2. I then discuss social welfare and contestability in Sections 4.3 and 4.4. Extensions and departures from the basic model discuss efficient side-payments (Section 4.5), net neutrality for infrastructure providers (Section 4.6) and competition between vertically integrated firms (Section 4.7). Section 4.8 concludes with a discussion of the most important assumptions and extensions.

4.1 Setup

I consider a game with full information between the three players U, CP, and FP. Think of U as a firm such as Akamai, investing in and operating some kind of infrastructure, for example a Content Delivery Network (CDN). CP can be Google, FP can be an entrant video-sharing platform. FP rents access to U's CDN and offers video-sharing services to consumers. CP rents access to U's CDN and adds its own CDN on top to offer video-sharing services to consumers. CP and U simultaneously invest in their infrastructure.

There is a unit mass of consumers interested in watching videos. A platform that has access to more infrastructure can show more content to consumers, for example by decreasing the latency and it more attractive to watch videos on the platform. A platform that has more infrastructure than its rival has market power over some part of its service, allowing it to charge a price that is unconstrained by the rival for that segment of demand. Both CP and FP also sell access to consumers on their platform to advertisers.

The game proceeds in three stages: At $t = 1$, U and CP simultaneously invest in private infrastructure of size $X_i \in [0, \infty)$, $i = CP,\ U$ at some cost that is described by an increasing, strictly convex, and differentiable function $k_i(X_i)$. Its inverse and the inverse of its first derivative exist. At $t = 2$, CP and FP negotiate non-rival access to the network of U. 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

[13] I discuss this in Section 4.8.

the surplus captured by U when bargaining with platform j and T_j the transfer paid by platform j to U. At $t = 3$, CP and FP simultaneously set non-negative 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, therefore advertisers only care about the consumer-side demand that they can reach. There is a unit mass of small advertisers with a willingness-to-pay of R for placing their ads alongside a unit of services sold to consumers. Platforms charge advertisers a price that is conditional on the number of consumers on their platform. Although the prices to consumers and advertisers are posted simultaneously, the equilibrium on the consumer-side is unique. Therefore, there is no uncertainty about consumer participation and the value of the platform to advertisers. In equilibrium, platforms will generate revenues on the advertiser side proportionate to the consumer demand that they serve.[14]

Both platforms serve a mass of consumers that is equal to total amount of infrastructure that they have access to. In the example of video-sharing and CDN infrastructure, better infrastructure might allow a platform to deliver its content at a higher bandwidth to more consumers. Conditional on negotiating access to U's network, CP can utilize both its own infrastructure X_{CP} and U's infrastructure X_U. FP can only use U's infrastructure. We relax this assumption further below. We say that a platform with access to infrastructure of size X **serves** a market of size X. When both platforms have access to X_U and $X_{CP} > 0$, CP serves a market equal to its own investment as a monopolist while both platforms serve a market equivalent to the size of U's infrastructure. Over the market that both platforms serve, CP and FP compete *à la* Bertrand where demand is equally split in case of equal prices. This is summarized in Figure 1.

As CP faces no competition on the right-most segment of demand of Figure 1, it can charge a separate price here. This section is labeled "monopoly", as CP pricing to consumers is only constrained by consumers willingness-to-pay and unconstrained by competition from FP on this segment. Consumers value each unit of demand at v. The platform's cost of serving consumers and advertisers is normalized to 0.[15] Platform i charges consumer prices $P_i^k \in \mathbb{R}_+$ on sections $k = c(ompetition), m(onopoly)$. This results in the following demand functions Q_i^k:

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

[14] Similar to the familiar "competitive bottleneck" configuration (Armstrong and Wright, 2007) in that the platforms are monopolists towards advertisers over access to consumers. The pricing is taken from the "per-reader advertising charges" in Armstrong (2006).

[15] This is a common assumption to focus on pricing in two-sided markets (Hagiu and Robin S. Lee, 2011; D'Annunzio, 2017). At $t = 3$, platforms have access to a given level of X and face zero marginal cost of serving demand up to the level of infrastructure that they can access and infinite cost beyond that level.

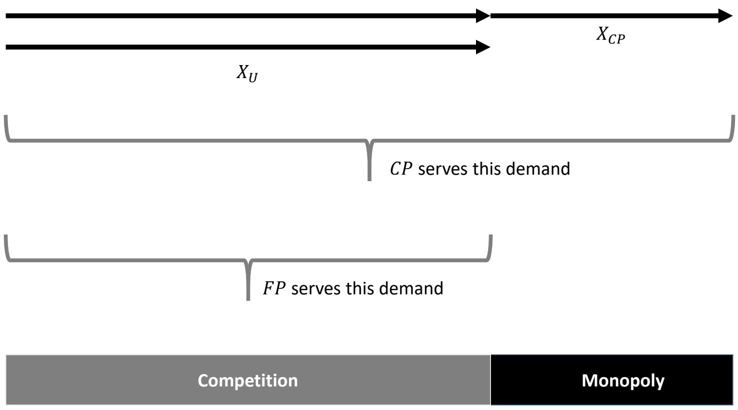

Figure 1: Demand and competitive conditions when CP and FP have access to U's infrastructure.

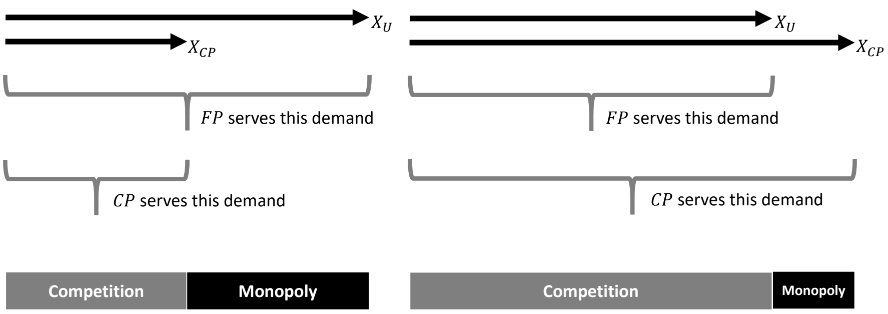

Figure 2: Demand and competitive conditions when only FP has access to U's network. Left: $X_{CP} < X_U$, right $X_{CP} > X_U$. These situations will be off-path relative to the equilibrium but determine outside options during the bargaining stage.

The last component of this model is the setting of transfers T_{CP} and T_{FP} between the platforms and U. I model the price setting between the platforms and U as Nash-bargaining. In other words, U and each platform split the surplus from agreeing on the platform using X_U, which can be thought of as the bundle of "connectivity" for the total amount of services that each platform wants to serve. The total value to be split is $X_U R/2$ for FP and $R/2(X_U + 2X_{CP}) + vX_{CP}$ for CP. The outside option of CP is to provide services only using its own infrastructure at a value of

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

This is represented in Figure 2. In the left panel $X_{CP} < X_U$, so the outside option for CP (not adding X_U to its network) results in sharing demand X_{CP} with FP, resulting in split advertisement revenues on this (competitive) section.[16] In the right panel of Figure 2 the inequality is reversed. Then, even in the outside option CP collects full advertisement revenue and monopoly prices on some part of the demand ($X_{CP} - X_U$ to be precise). Therefore, the marginal change in the value of the outside option is discontinuous at $X_{CP} = X_U$.

FP and U 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_U is non-rival, both platforms can use it simultaneously without causing congestion. Both platforms expect that the rival platform will agree with U and that negotiations do not break down in equilibrium. In principle, one could imagine, e.g., that U offers not to make a deal with FP to charge a higher price to CP. This could even be profitable as the presence of FP does not bring in new customers into the market. However, I rule out this negotiation strategy altogether as most antitrust laws forbid a powerful upstream firm to deny access to an essential input. The base model is not an example of Nash-in-Nash bargaining. This assumption makes the model tractable but might be less plausible when the upstream industry is not well described by a monopolist. We reconsider the possibility of exclusion when U posts a uniform price in an extension in Section 4.6.

In summary, this yields the following profit functions:

$$\Pi^U = T_{CP} + T_U - k_U(X_U) \tag{3}$$
$$\Pi_{FP} = Q^c_{FP}(R + P^c_{FP}) - T_{FP} \tag{4}$$
$$\begin{aligned}\Pi^{CP} =& Q^c_{CP}(R + P^c_{CP}) + \\ & Q^m_{CP}(R + P^m_{CP}) - T_{FP} - k_{CP}(X_{CP}).\end{aligned} \tag{5}$$

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

[16] In this case, the FP would have access to more infrastructure and can act as a monopolist over a market of size $X_U - X_{CP}$.

4.2 Subgame-perfect Nash equilibrium

Proposition 1: The marginal value of investment for CP and U is higher when $X_{CP} > X_U$ rather than $X_{CP} < X_U$ in equilibrium.

Proof: At the third and final stage, both platforms choose prices for consumers and advertisers. Assume that both platforms have access to U's network from stage two. The consumer demand they face is $Q^c_{CP} + Q^m_{CP} = X_U/2 + X_{CP}$ and $Q^c_{FP} = X_U/2$, respectively. 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 $P^c_i = 0$ and face a demand of $X_U/2$. Additionally, CP charges a price of $P^m_{CP} = v$ for the segment X_{CP} on which it has monopoly power. This results in the following profit functions:

$$\Pi_{FP} = X_U(R/2) - T_{FP} \tag{6}$$

$$\Pi_{CP} = X_U(R/2) + (v + R)X_{CP} - T_{CP} - k_{CP}(X_{CP}). \tag{7}$$

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

$$T_{FP} = \delta_{FP} X_U \,(R/2) \tag{8}$$

$$T_{CP} = \delta_{CP} \left[(X_U + 2X_{CP})R/2 + vX_{CP} - \Gamma\right]. \tag{9}$$

Note the presence of Γ, CP's outside option. It's inclusion makes T_{CP} conditional on the relative size of X_U and X_{CP}. In particular, all terms related to X_{CP} cancel out whenever $X_{CP} > X_U$. Finally, at the first stage, U and CP maximize profits over their choice of investment. First rewrite U's profit in terms of transfers and investment cost:

$$\Pi^U = T_{CP} + T_U - k_U(X_U) \tag{10}$$

where

$$T_{CP} = \begin{cases} \delta_{CP}\left[\frac{R}{2}(X_U + X_{CP}) + vX_{CP}\right], & \text{if } X_U \geq X_{CP} \\ \delta_{CP}[(R + v)X_U], & \text{if } X_{CP} > X_U \end{cases} \tag{11}$$

The first-order-condition for maximizing U's profit as a function of investment X_U yield:

$$\frac{\partial \Pi^U}{\partial X_U}: \quad [k_U(X_U)]' = \delta_{CP}\frac{R}{2}, \qquad \text{if } \; X_U \geq X_{CP} \tag{12}$$

$$[k_U(X_U)]' = \delta_{CP}(R + v), \qquad \text{if } \; X_{CP} > X_U. \tag{13}$$

The second-order-condition follows from the assumptions on $k_U(X_U)$. U has stronger investment incentives when its network is smaller than that of CP. The intuition is that in this case, 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, U has a stronger impact on CP's outside option than if CP's outside option was restricted to the less lucrative, competitive segment of demand. The solution for CP takes a similar form:

$$\Pi^{CP} = X_U \frac{R}{2} + (v + R)X_{CP} - T_{CP} - k_{CP}(X_{CP}) \tag{14}$$

resulting in first-order-conditions

$$\begin{aligned} \frac{\partial \Pi^{CP}}{\partial X_{CP}}: \quad & [k_{CP}(X_{CP})]' = v + R - \delta_{CP}\left[\frac{R}{2} + v\right] = \\ & \qquad (1-\delta_{CP})v + \left(1 - \frac{\delta_{CP}}{2}\right)R, && \text{if } X_U \geq X_{CP} \quad (15) \\ & [k_{CP}(X_{CP})]' = v + R, && \text{if } X_{CP} > X_U. \quad (16) \end{aligned}$$

Investment incentives depend on the curvature of the investment cost functions which I have allowed to differ. The optimal investment is discontinuous and has a jump because the investment incentives depend on the larger infrastructure. If $X_{CP} > X_U$, CP's marginal value of investing increases because a marginal expansion of X_{CP} results in a market increase on the more lucrative (monopoly) segment in the outside option. U also has higher investment incentives when CP has the larger infrastructure, but the reason is different: in this case, U investment increases both the total market and every additional unit of X_U increases the surplus to be split by more than the additional competition from FP lowers is. Consider the case $k_{CP}(X_{CP}) = k_U(X_U)$. Denoting he resulting equilibrium values with *, $X^*_{CP} > X^*_U$ 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 U. CP investment only depends on its relative bargaining strength when it has the smaller network.

Equilibrium profits for given equilibrium levels of X_U and X_{CP} are as follows: FP makes a profit of $(1 - \delta_{FP})X_U(R/2)$, irrespective of who has the larger network. CP profit is given by equations 14 and 11. U's profit is given by 8, 10, and 11. □

Proposition 1 is important for two reasons: First, it illustrates the rise of proprietary networks which has been documented in the literature and our own analysis of submarine cable investment (Section A). From this model, we see that the rise of proprietary networks is not by accident. Instead, the incumbent firm that operates as a pure upstream player gains from dealing with the vertically integrated firm especially when the latter has larger infrastructure.

Second, the mechanism illustrates the logic of "commodification": U loses its strategic role of "pushing" CP into the region where it has market powers for some services (by granting access to X_U, relative to the outside option). Therefore, each additional unit of X_U adds a constant amount of value $(v + R)$ to CP's revenue, which is why I call it a "commodity" in this context. The idea of commodification, in the more prosaic sense of becoming a supplier for an interchangeable input, is common in the discussion of industrial policy surrounding vertical integration of some big tech firms, for example in the automotive sector. One concern is whether automotive firms will become mere suppliers of hardware as the value generation shifts to the digital sphere and the data generated by cars and drivers. The model tells us that this possibility is real. If we step aside from the static nature of the investment game and think about dynamic investment, one could say that incumbents have a profit incentive to "accommodate" the investments of large platform companies.

4.3 Social welfare

In the previous section, we analyze the subgame-perfect Nash equilibrium. How does it perform with respect to the social optimum, i.e., the sum of consumer and producer welfare? The corresponding social welfare function is:

$$S = (v + R)(Q_U + Q_{CP}) - k_U(X_U) - k_{CP}(X_{CP}). \tag{17}$$

Proposition 2: Equilibrium investment is below the socially optimal level independent of whether CP or U has the larger network. Private investment is closer to the social optimum when $X^*_{CP} > X^*_U$ rather than $X^*_{CP} < X^*_U$.

Proof: Conditional on CP agreeing with U, each additional unit of investment, either by U or CP, expands the market served, yielding a social benefit of $v + R$ from selling one additional unit of services to consumers and selling advertisement of a total value of R. If the marginal unit of infrastructure is added by CP, it captures both $v + R$ as profit. If the additional unit of infrastructure is added by U, the surplus v is captured by consumers, as the additional services are provided at zero cost to consumers both by CP and FP, while the advertisement revenue R is split between CP and FP.

To clarify why this is the case, consider the off-the-equilibrium-path case where CP and U fail to agree on CP using X_U. In this case, we would have two separate infrastructures and only an increase in the larger network would add new services. By contrast, a marginal increase in the smaller network, whichever this may be, will result in a marginal unit of services provided competitively, rather than by only one firm, and therefore a shift of producer to consumer rent, and a split of advertisement revenue.

As negotiation does not break down in equilibrium, however, a marginal increase in either network increases the total sum of consumers served and always adds $v + R$. Therefore, and from the fact that cost functions are increasing, convex, and differentiable, it follows that social welfare is maximized when $[k_U(X^*_U)]' = v + R$ and $[k_{CP}(X^*_{CP})]' = v + R$. From the proof of proposition 1, we know that the optimal investment is obtained at a lower level of investment than this except in the special case when $\delta_{CP} = 1$ and CP invests more in equilibrium. When $X^*_{CP} > X^*_U$ is larger, its investment obtains the social optimum and U's investment is a fraction of the social optimum that scales directly with δ_{CP}. □

This result confirms that the increase in investment incentives at the margin is efficient in the sense that it increases total welfare in the model.

4.4 Contestability

How does vertical integration into Internet infrastructure by CP impact the "contestability" of the downstream market? Contestability is a key term in the discussion of market power of digital markets in the European context, where the upcoming DMA legislation is concerned, for example, with tipping. A straightforward way to approach this question in the context of our model is to look at how the market shares of CP and FP (both on the advertising side and the consumer side) behave. This section illustrates the intricate relationship between the parameters that govern the profitability on the two market sides downstream, their impact on investment upstream, and the resulting market outcomes of the two platforms downstream.

A direct proxy for this is the relative change in revenues on the competition and monopoly segment as in Figure 1. We have studied the increase in investment incentives for both CP and U when CP has the larger equilibrium network. While the increase in X_{CP} increases the size of the market on which it has market power, the increased investment by U increases the market size for both platforms. While increasing investment by either firm always increases the total market size, it is ex-ante unclear whether the simultaneous jump in investment incentives results in a greater increase in the contested segment or the monopoly segment at the margin.

Market shares are typically measured in terms of revenue. Revenue on the advertising side is proportional to the number of connected users. Revenue on the consumer side is zero for FP due to Bertrand competition and $X_{CP}v$ for CP due to market power on a segment of demand. Market shares in terms of revenue in the downstream platform market across both sides follow from the discussion preceding Equation 2. They can be simplified by dividing by R, making market share a function of consumers and advertisers as well as the ratio of the value generated on these two sides (v/R).

$$MS_{FP} = \frac{R(X_U/2)}{R(X_U + X_{CP}) + vX_{CP}} = \frac{(X_U/2)}{(X_U + X_{CP}) + (v/R)X_{CP}} \tag{18}$$

$$MS_{CP} = \frac{R(X_U/2 + X_{CP}) + vX_{CP}}{R(X_U + X_{CP}) + vX_{CP}} = \frac{(X_U/2 + X_{CP}) + (v/R)X_{CP}}{(X_U + X_{CP}) + (v/R)X_{CP}} = 1 - MS_{FP} \tag{19}$$

We analyze the change in MS_{FP} at the margin where investment incentives change. Consider a small shift in k_{CP} to g_{CP} such that $g_{CP}(X_{CP}) < k_{CP}(X_{CP})$ $\forall$ X_{CP} but g_{CP} inherits all properties of k_{CP}. We will say that g_{CP} has a lower curvature than k_{CP}. Let X^{**}_{CP} be the equilibrium value of X_{CP} implied by $g_{CP}(X_{CP})$ and parameter values such that $X^{**}_{CP} > X^*_U > X^*_{CP}$. This describes a setup where the "commodification" effect comes into play and both U and CP see their investment incentives increase. We will therefore refer to this situation as the "commodification scenario". In the following proposition, we examine two things: first, how does FP's market share change when we vary a parameter (for example, the curvature of the investment cost function) such that both U and CP choose higher investment. Second, what are the comparative statics with respect to the remaining parameters?

Computing the conditions under which FP market share increases is possible when choosing an explicit form of k, g. Absent that, Proposition 3 summarizes the factors that increase or decrease FP market share at the margin where investment incentives shift.

Proposition 3: In the commodification scenario, MS_{FP} is decreasing. MS_{FP} is decreasing in R, increasing in v, decreasing in δ_{CP}.

Proof: The change in market share of FP is described by

$$\frac{(X_U^{**}/2)}{(X_U^{**}+X_{CP}^{**})+(v/R)X_{CP}^{**}} - \frac{(X_U^{*}/2)}{(X_U^{*}+X_{CP}^{*})+(v/R)X_{CP}^{*}} \tag{20}$$

From equations 12, 13, 15, 16 and the invertibility of the cost function, we know

$$X_U^* = [k_U'(\delta_{CP}(R/2))]^{-1} \qquad X_{CP}^* = [k_{CP}'((1-\delta_{CP})v + (1-\frac{\delta_{CP}}{2})R)]^{-1} \tag{21}$$

$$X_U^{**} = [k_U'(\delta_{CP}(R+v))]^{-1} \qquad X_{CP}^{**} = [g_{CP}'(R+v)]^{-1} \tag{22}$$

where $^{-1}$ represents the inverse of the function.

While $X_U^* * > X_U^*$ by assumption, the denominator of the left term in equation 20 grows faster than the numerator, such that FP's overall market share diminishes. As the term in the numerator is divided by 2, any increase of X_U^* leads to a lesser increase in the numerator than in the denominator.

The comparative statics admit a closed form solution only for specific functions for k_U, k_{CP}, g_{CP}. Nevertheless, it is easy to see that v mainly appears on the left-hand-side of 20, i.e., FP's market share in the "commodification scenario". On the right-hand-side, it appears only in the expression for X_{CP}^*. The intuition is that v directly impacts the investment decision of U and CP mainly in the commodification scenario. U's investment decision only reacts to v when it has the smaller network.

The effects of the other variables are less tractable: an increase in δ_{CP} diminishes CP's investment incentives when it has the smaller network but not when it has the larger network. An increase in R leads to a larger increase of X_{CP} than X_U because a) of the lower curvature of g_{CP} compared to k_{CP} and b) because it is multiplied by $\delta_{CP} < 1$ in the formulas for X_U^*, $X_U^* *$, depressing the impact of R on FP's market share. $\square$

4.5 Efficient side-payments

As part of the discussion around the contribution of content firms to telecommunication networks, we observe 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 U's network is only used to a limited extent by FP. I make two assumptions: FP cannot serve more than some amount $\bar{Q}$ of services and CP and U can agree, before the beginning of the game, that CP will pay a certain transfer T' to U that is conditional on choosing a certain value X_U. To make the model interesting, we consider cases where $\bar{Q}$ is binding in equilibrium.

Proposition 4: If FP is capacity-constrained and conditional side-payments are possible, U's and CP's incentives to invest align and CP may pay U for additional investment.

Proof: If 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. Every additional unit X_U can be rented out only to CP, who generates a profit of $v + R(X_{CP} + X_U - \bar{Q}) + R/2\bar{Q} - k_{CP}(X_{CP}) - T' - T_{CP}$. In equilibrium, U and CP can jointly maximize their surplus by setting $[k_U(X_U)]' = v + R$. Call this value X_U^{**}. Then this can be implemented and is incentive compatible when CP offers any value of T' such that $(X_U^{**} - \bar{Q})(v + R) > T' > k_U(X_U^{*}*) - k_U(X_U^{*})$ if and only if $X_U = X_U^{**}$, where X_U^{*} is the optimal value in the Nash equilibrium.

This value exists and is positive from the assumptions on k_U and the fact that equation 16 implies that $X_U^{*}* > X_U^{*}$. Investment incentives of U and CP align. When investment is cheaper for U, 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_U with the marginal investment cost of U. $\square$

This result illustrates that in the base model, FP serves as a friction that prevents U and CP from maximizing their joint surplus. Absent FP, the value X_U that maximizes total surplus is simply the one that equates marginal cost and revenue. An enforceable contract on the equilibrium value of X_U is a simple mechanism to implement the efficient investment level.

4.6 Net neutrality

Net neutrality is the absence of termination charges, i.e., content providers do not pay Internet service providers in whose network their traffic is delivered. According to other definitions, net neutrality does not allow U 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.

The model only translates to this setup approximately as U does not represent an ISP operating last mile networks (as we generally do not observe vertical integration at this stage due to fixed costs that imply a natural monopoly). However, there is some discussion as to whether infrastructure operators should follow the same rules. For example, in the US CDN managed to be exempted from net neutrality rules by lobbying rather than for any technical reason.

I consider a net neutrality scenario in which both platforms access X_U 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_U have been made, U posts a price under which platforms can purchase non-rival access to X_U. 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[17], and generally permitting input prices that allow "as-efficient-competitors" (relative to a dominant firm) to remain in the market.

Proposition 5: Under net neutrality, U will set a price that extracts the whole surplus of CP. It will find it always profitable to exclude FP.

Proof: The highest price that FP is willing (and able) to pay for access to X_U is $X_U(R/2)$, i.e., the profit it makes under competition on the segment X_U. The total revenue of U when charging this price to FP and CP is then $X_U R$. Another candidate price is $X_U(R+v)$, charged to CP, which is strictly higher. FP exits as U has no interest in downstream competition as it reduces industry profit. U charges $T = (v+R)X_U$, CP charges v to consumers and R to advertisers. Consumer surplus is 0. Investment levels are $[k_U(X_U)]' = [k_{CP}(X_{CP})]' = v + R$, and therefore socially efficient and higher than in the base-model. Consumer prices increase as CP is now a monopolist over the whole range of services. Net neutrality thus harms entry as FP is essentially excluded from the market and consumers pay higher prices. $\square$

4.7 Competition between vertically integrated firms

What happens when U is not a pure upstream player but can integrate downstream as well, for example by providing services? Examples of traditional upstream firms expanding downstream are telecommunications firms, such as Deutsche Telekom, that operate on multiple levels of Internet infrastructure for business customers (including data centers, cloud computing) but which have since expanded into media offerings including sports and streaming for final consumers.[18]

To discuss this case while staying as close as possible to the original model, we consider the following extension. At the first stage, U and CP invest as in the standard model. At the second stage, U posts a price for access to its infrastructure. CP and FP either choose to accept or reject given the price posted by U knowing that at the third stage they compete downstream with U and the other platform. As in the base model, FP only competes if it has access to infrastructure. Thus, we have either two or three firms operating downstream. Also, U and CP compete either separately using only their proprietary infrastructure or they compete after CP purchases access to U's infrastructure. As in the base model, we only allow U to offer access to its infrastructure

[17] See, for example, Motta, 2004.

[18] See Deutsche Telekom website, for business customers, https://geschaeftskunden.telekom.de/digitale-loesungen/infrastructure-as-a-service/dsi-vcloud, for media and entertainment https://www.telekom.de/unterhaltung [both in German].

for now.[19] If both CP and FP purchase access to X_U at this price, we call this scenario *three-way competition.* If neither firm wants to purchase access, we call it *infrastructure separation.* If between CP and FP only one firm but not the other purchases access at the price posted by U, we call this outcome *divide and conquer.*

Proposition 6: It is never optimal for the upstream player to rent out infrastructure to both FP and CP when it is competing downstream. It is optimal for U to rent its infrastructure to CP while competing downstream when its infrastructure is larger.

Proof: Consider the candidate prices of U. By charging a prohibitively high price and using its own infrastructure only for itself, it takes on a role downstream that is similar to FP in the base model off-path. It resembles the setups in Figure 2. The only difference is that it is now U, not FP, that is serving consumers. Competing with CP in this *infrastructure separation* setting yields the following profit for U:

$$\Pi_U^s = X_U R/2 + max(0, X_U - X_{CP})(R/2 + v) - k_U(X_U), \tag{23}$$

resulting in implicitly defined infrastructure sizes

$$[k_i(X_i^*)]' = \begin{cases} R/2, & \text{if } [k_i(X_i^*)]' < [k_{-i}(X_{-i}^*)]' \\ v + R, & otherwise. \end{cases} \tag{24}$$

If U sets a price T that both CP and FP are willing to accept, three firms are operating downstream. Accordingly, we now assume that consumers split equally between all three downstream offers on the competitive segment if prices are equal. Equilibrium profits in the *three-way competition* scenario look as follows:

$$\Pi_U^c = X_U R/3 + 2T - k_U(X_U) \tag{25}$$

$$\Pi_{CP}^c = X_U R/3 + max(0, X_{CP} - X_U)(2/3R + v) - T - k_{CP}(X_{CP}) \tag{26}$$

$$\Pi_{FP}^c = X_U R/3 - T. \tag{27}$$

From the participation constraint of FP, the highest price T that U can charge to get both platforms on board is $X_U R/3$, resulting in a total profit of $X_U R - k_U(X_U)$ and equilibrium investment size of $[k_U(X_U)]' = R$. This is greater than profit under *infrastructure separation* when U has the smaller infrastructure but less than the profit that U can collect when it has the larger infrastructure.

The *divide and conquer* equilibrium will see only one firm purchasing access from U. From the previous paragraph, it is clear that this will be the case when $T > X_U R/3$. As the participation constraint of FP is violated, only CP will be willing to pay this price. At the same time, the decrease in downstream competition makes CP willing to pay a price $T > X_U R/3$. Profits are:

$$\Pi_U^{dc} = X_U R/2 + T - k_U(X_U) \tag{28}$$

$$\Pi_{CP}^{dc} = X_U R/2 + X_{CP}(R + v) - T - k_{CP}(X_{CP}) \tag{29}$$

[19] The case of access to CP's infrastructure is left for a future version.

The upstream player will either prefer *divide and conquer* or *infrastructure separation*, depending on CP's profit, but never *three-way competition*. The trade-off compared to the *infrastructure separation* scenario is that while the upstream firm loses potential revenue when it has the larger infrastructure (the $X_U - X_{CP}$ term in equation 23), it can now charge a higher fee T. The highest fee CP is willing to pay is the difference in profit with and without X_U. The maximum fee CP is willing to pay is increasing in X_U and goes to zero if X_U goes to zero. Therefore, the upstream player can extract a higher transfer under *divide and conquer* the more it invests in the first period and always strictly more than under three-way-competition. The last fact follows from the fact that *infrastructure separation* only yields lower profits than *three-way competition* when U has the smaller infrastructure and it will build $[k'_U(X_U)] = R/2$. As CP's network is larger in this case, it will collect greater profits than U if its cost function is similar. Depending on CP's profit, U prefers to charge a higher transfer T to CP in the *divide and conquer* scenario or to maintain *infrastructure separation* over *three-way competition*. □

4.8 Discussion

This model is intended as a first attempt at the questions posed by the vertical integration of technology platforms through proprietary infrastructures. Both competition in downstream markets as well as Internet infrastructure are 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 any specific geographic or product 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 or marginalized thorugh increased efficiency.

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.

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 U or CP expands the market, for example, by increasing network speed and reliability: on the intensive side, a single service, such as video-sharing, might be more attractive or premium services (e.g., data-intensive high-resolution videos) become viable. On the extensive side, new, more latency-sensitive services become increasingly feasible as bandwidth expands (for example, voice over IP, large conference calls, online multiplayer games, cloud gaming services).

This can also be seen as a simple approximation of an ecosystem market: Large tech companies such as Google sell a variety of services, such as e-mail, cloud storage, video streaming, VoIP, or cloud gaming to different customers. As Google improves its infrastructure, 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). Here, 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).

I make several simplifications for the purpose of approaching this complex modeling challenge. This model illustrates the incentives for a platform to invest in proprietary Internet infrastructure. For this purpose, I fold different products downstream and different kinds of infrastructure upstream into a simple framework that relates the quality of the available infrastructure to the effective quantity of services that can be provided.

As explained above, FP should be seen as representing a large number of small platforms. As they obtain half the customers on the competitive segment of the market, FP as a player is not necessarily small in economic terms. However, in real markets we see leading search engines, video streaming sites etc. with market shares upwards of 90% in some markets. Therefore, it seems reasonable to emphasize the role of FP as a competitive constraint but not as a strategic player.

What is X? As explained in Section 3, we are looking at proprietary networks that consist of many different parts. For the purpose of this model, we are not interested, for example, what share of investment goes towards data centers vs. submarine cables. Instead, we are interested in the service improvement that can be purchased at a given price. Therefore, infrastructure X can be thought of as a measure of real quality gain from a given level of investment. In other words, it is an intermediate good ("connectivity") that expands downstream demand at a ratio of 1:1. This only requires downstream demand to be at least somewhat elastic to the quality improvement induced by investment. The 1:1 ratio is a free variable, as even relatively inelastic consumer demand can be expressed in the slope of $k_i(X_i)$. A steep investment cost function means that it is very costly to expand the market through further investment, either because of physical or geographical features making the investment costly or because a low elasticity of demand with respect to quality improvements implies large investments that are needed to expand downstream demand. The main demands that I formulate towards the investment aspect of the model are therefore that investment costs are convex (improving the network becomes more expensive as efficient and low-cost investment opportunities are realized) and potentially different for U and CP.

Among the main model assumptions that can be relaxed and expanded upon, I see the following as priorities for further investigation:

- Upstream competition between several firms is another setting besides the monopoly setting in the base model.
- 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.

5 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 into Internet infrastructure by digital platform companies.

This model illustrates investment incentives for Internet infrastructure that impacts competition in a digital market downstream. I show that investment incentives increase both for a pure upstream player and a vertically integrated firm when the latter owns more infrastructure. The intuition is that in this case, the vertically integrated firm has market power over the additional demand generated by its investment even absent the additional infrastructure from the upstream firm. Marginal investment by the upstream firm increases the total surplus to be shared between it and the vertically integrated firm. As each unit of upstream investment results in a constant increase in revenue for the integrated firm, the infrastructures of the upstream industry becomes fully commoditized. As a consequence, this model explains the rise of private, proprietary infrastructure, together with the analysis of submarine cable ownership, as proprietary Internet infrastructure by vertically integrated firms is best accommodated by the upstream industry.

Caution is advised before drawing policy conclusions from a literal reading of the model. It is understood that this model is not a full simulation of any particular downstream market with its generic features such as paid-for premium services and advertisement revenues. Nor does it describe in detail the makeup of digital infrastructure. Instead I purposefully aggregate infrastructure investment into a black box variable to study the effect of quality-improving infrastructure investment. Intervention in any particular market would need to carefully reevaluate the sources of revenue and business models of the downstream market in question and to identify the most important components of Internet infrastructure related to this industry.

Nevertheless, this paper can help policy makers and enforcers ask the right questions both for a competitive analysis of a digital market and for a forward-looking market investigation: First, it describes how even efficient and increasing investment in proprietary and public networks can enhance the unequal footing on which vertically integrated firms and smaller rivals compete. Second, it illustrates the kingmaker role of third-party infrastructure providers, especially when they become active downstream themselves.

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.

A Submarine cable ownership

In this Section I present data on submarine cable ownership by some firms that are traditionally labeled “big tech” firms. The purpose of this exercise is firstly, to motivate the model describing vertical integration by firms offering digital services, and secondly, to justify the assumption that only either very large or specialized infrastructure firms have the scale to make these investments.

Bischof, Fontugne, and Bustamante (2018) describe the increasing role of these firms in the submarine cable infrastructure: “The latest construction boom, however, seems to be driven by content providers, such [as] Google, Facebook, Microsoft, and Amazon. According to Telegeography’s Research Director Alan Mauldin, the amount of capacity deployed by content providers has risen 10-fold between 2013 and 2017, outpacing all other customers of international bandwidth.”

I analyze data from Telegeography on submarine cables underlying the Submarine Cable Map.[20] The data is publicly available and as of September 2022 contains data on 516 submarine cables. The data set also includes location data on the cables which I do not use. Each observation of the data set includes the name of the cable, its length in kilometers, a list of its owners, a list of suppliers, and the year (and sometimes month) when the cable became or will become ready for service, ranging from 1989 to 2026.

A.1 Description

I search among the list of owners in our data set for Google, Amazon, Meta, Apple, Microsoft, Baidu, Alibaba, and Tencent. These firms are sometimes referred to with catch-all abbreviations such as GAMAM (GAFAM, before Facebook changed its name to Meta in 2021) or BAT. Neither Apple nor any of the BAT firms appear on the list of owners, but only Meta, Microsoft, Google, and Amazon Web Services. However, Alibaba does own terrestrial backbone within Asia (Corneo et al., 2021) Thus I identify cables that have one of the above-mentioned firms among its owners. This does not indicate sole ownership. Indeed, except for 7 purely Google-owned cables, all cables listed here as having “GAMAM owners” have co-owners. This is unsurprising, given that submarine cables typically include several fibre-optic cables and firms can own individual fibres.

I also search the list of owners for other firms and as a general observation, I remark that the list of owners includes mostly telecommunications firms and governments, as well as a few electricity companies, but no other firms that mainly sell digital services. While this is just one example of Internet infrastructure, it is consistent with the data previously collected in the literature (see references in this Section and Section 2) that describes the emergence of proprietary networks as a phenomenon driven by just a few of the largest technology firms.

Extending the range of the data of the previous paper by 7 years, I find that among submarine cables getting ready for service 2022-2024, the share of GAMAM climbs to

[20] https://www.submarinecablemap.com/

between 20 and 27% (see Figure 3).[21] This is higher than the share of new cables owned by these first in the previous decade, which only exceeded 20% in one year (2018).

At the same time, the absolute number of new GAMAM-owned cables has quadrupled, from 1.1 new cables per year between 2010 - 2019, to 4.4 new cables for 2020 - 2024 (Figure 4). The overall increase in cables going ready for service has increased by a third during this period, from 15.7 new cables per year to 21 new cables for year. In other words, the cables added with the large technology firms as co-owners contribute more than half of the increase in the number of added cables between the the period before and after 2020. The phenomenon of these firms owning submarine cables is not a recent one, however, with the first such cable registered in 2010. Overall, the data confirms the increasing role of content firms among investors of infrastructure.

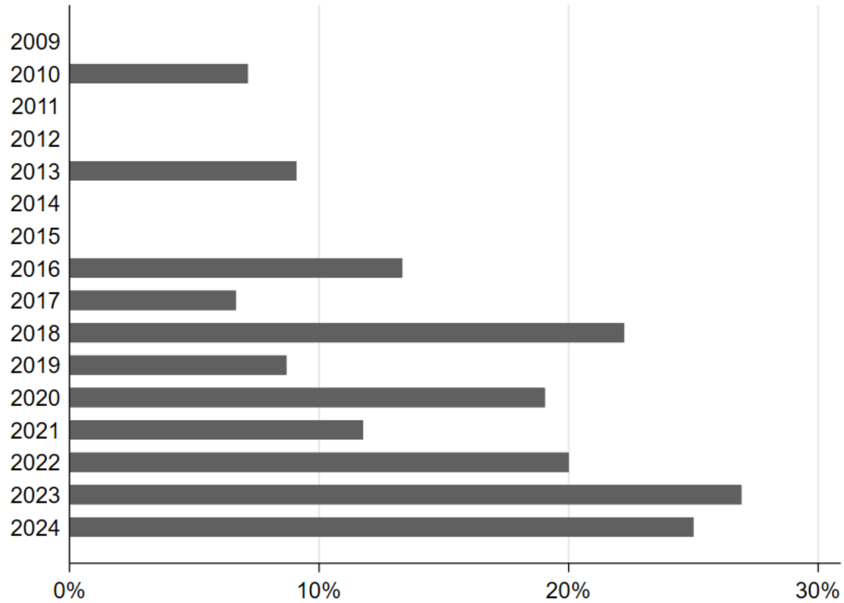

Figure 3: Share of submarine cables with GAMAM owners by ready-for-service date

[21] Only 7 announcements have been made regarding cables that are ready for service in 2025 and only 1 for 2026, none of them involving any of the above-mentioned firms.

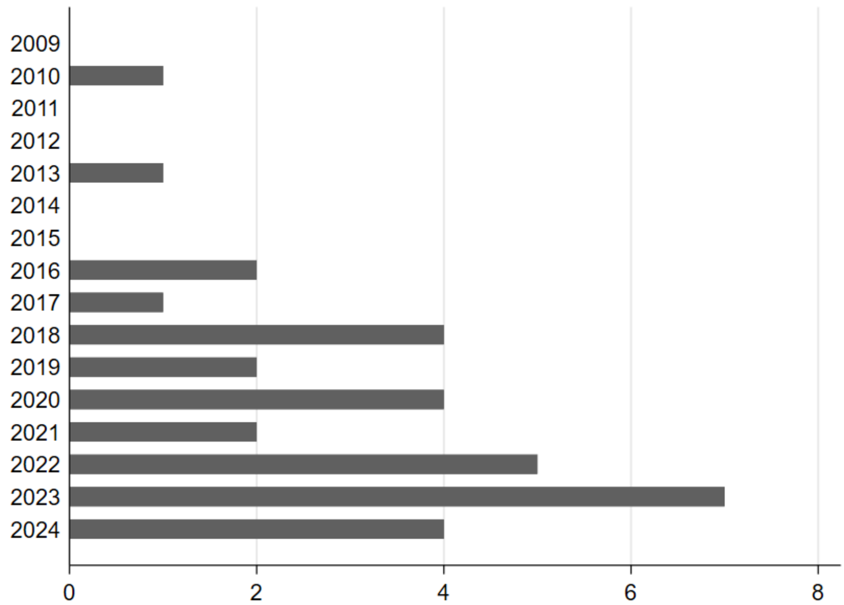

Figure 4: Sum of submarine cables with GAMAM owners by ready-for-service date

References

Armstrong, Mark (2006). "Competition in two-sided markets". In: *The RAND Journal of Economics* 37.3, pp. 668–691. DOI: 10.1111/j.1756-2171.2006.tb00037.x.

Armstrong, Mark and Julian Wright (2007). "Two-sided Markets, Competitive Bottlenecks and Exclusive Contracts". In: *Economic Theory* 32.2, pp. 353–380. DOI: 10.1007/s00199-006-0114-6.

Arnold, Todd (2020). "Understanding Cloud Network Performance". PhD thesis. Columbia University.

Arnold, Todd et al. (2020). "Cloud provider connectivity in the flat internet". In: *Proceedings of the ACM Internet Measurement Conference*, pp. 230–246.

Avenali, Alessandro, Giorgio Matteucci, and Pierfrancesco Reverberi (Sept. 1, 2014). "Broadband investment and welfare under functional and ownership separation". In: *Information Economics and Policy* 28, pp. 70–82. DOI: 10.1016/j.infoecopol.2014.07.003.

Balakrishnan, Hari et al. (Apr. 11, 2021). "Revitalizing the public internet by making it extensible". In: *ACM SIGCOMM Computer Communication Review* 51.2, pp. 18–24. DOI: 10.1145/3464994.3464998.

Bischof, Zachary S., Romain Fontugne, and Fabián E. Bustamante (Nov. 15, 2018). "Untangling the world-wide mesh of undersea cables". In: *Proceedings of the 17th ACM Workshop on Hot Topics in Networks*. HotNets '18: The 17th ACM workshop on Hot Topics in Networks. Redmond WA USA: ACM, pp. 78–84. DOI: 10.1145/3286062.3286074.

Buehler, Stefan, Armin Schmutzler, and Men-Andri Benz (Feb. 1, 2004). "Infrastructure quality in deregulated industries: is there an underinvestment problem?" In: *International Journal of Industrial Organization* 22.2, pp. 253–267. DOI: 10.1016/j.ijindorg.2003.07.004.

Carroni, Elias, Leonardo Madio, and Shiva Shekhar (2018). "Superstars in Two-Sided Markets: Exclusives or Not?" In: *SSRN Electronic Journal*. DOI: 10.2139/ssrn.3243777.

Chaturvedi, Rakesh, Souvik Dutta, and Kiriti Kanjilal (Nov. 2021). "An economic model of the last-mile internet". In: *Journal of Economic Behavior & Organization* 191, pp. 620–638. DOI: 10.1016/j.jebo.2021.09.025.

Corneo, Lorenzo et al. (Apr. 19, 2021). "Surrounded by the Clouds: A Comprehensive Cloud Reachability Study". In: *Proceedings of the Web Conference 2021*. WWW '21: The Web Conference 2021. Ljubljana Slovenia: ACM, pp. 295–304. DOI: 10.1145/3442381.3449854.

D'Annunzio, Anna (2017). "Vertical integration in the TV market: Exclusive provision and program quality". In: *International Journal of Industrial Organization* 53, pp. 114–144. DOI: 10.1016/j.ijindorg.2017.05.002.

Easley, Robert F., Hong Guo, and Jan Krämer (June 2018). "Research Commentary—From Net Neutrality to Data Neutrality: A Techno-Economic Framework and Research

Agenda". In: *Information Systems Research* 29.2, pp. 253–272. DOI: 10.1287/isre.2017.0740.

Greenstein, Shane (May 1, 2020). "The Basic Economics of Internet Infrastructure". In: *Journal of Economic Perspectives* 34.2, pp. 192–214. DOI: 10.1257/jep.34.2.192.

Greenstein, Shane and Tommy Pan Fang (2020). "Where the Cloud Rests: The Economic Geography of Data Centers". Harvard Business School.

Greenstein, Shane, Martin Peitz, and Tommaso Valletti (May 1, 2016). "Net Neutrality: A Fast Lane to Understanding the Trade-offs". In: *Journal of Economic Perspectives* 30.2, pp. 127–150. DOI: 10.1257/jep.30.2.127.

Hagiu, Andrei and Robin S. Lee (2011). "Exclusivity and Control". In: *Journal of Economics & Management Strategy* 20.3, pp. 679–708. DOI: 10.1111/j.1530-9134.2011.00302.x.

Lee, Robin S (Dec. 2013). "Vertical Integration and Exclusivity in Platform and Two-Sided Markets". In: *American Economic Review* 103.7, pp. 2960–3000. DOI: 10.1257/aer.103.7.2960.

Lehr et al. (2019). "Whither the Public Internet?" In: *Journal of Information Policy* 9, pp. 1–42. DOI: 10.5325/jinfopoli.9.2019.0001.

Motamedi, Reza et al. (Oct. 2019). "On Mapping the Interconnections in Today's Internet". In: *IEEE/ACM Transactions on Networking* 27.5. Conference Name: IEEE/ACM Transactions on Networking, pp. 2056–2070. DOI: 10.1109/TNET.2019.2940369.

Motta, Massimo (Jan. 12, 2004). *Competition Policy: Theory and Practice.* Google-Books-ID: J3xZnDSlfC8C. Cambridge University Press. 650 pp.

Petit, Nicolas (2020). *Big Tech and the Digital Economy: The Moligopoly Scenario.* Oxford University Press.

Schuett, Florian (June 1, 2010). "Network Neutrality: A Survey of the Economic Literature". In: *Review of Network Economics* 9.2. Publisher: De Gruyter. DOI: 10.2202/1446-9022.1224.

Sermpezis, Pavlos, George Nomikos, and Xenofontas Dimitropoulos (June 22, 2017). "Re-mapping the Internet: Bring the IXPs into Play". In: *arXiv:1706.07323 [cs].* arXiv: 1706.07323.

Stocker, Volker, Günter Knieps, and Christoph Dietzel (2021). "The Rise and Evolution of Clouds and Private Networks Internet Interconnection, Ecosystem Fragmentation". In: *SSRN Electronic Journal.* DOI: https://dx.doi.org/10.2139/ssrn.3910108.

Stocker, Volker, Georgios Smaragdakis, and William Lehr (2020). "The State of Network Neutrality Regulation". In: *ACM SIGCOMM Computer Communication Review* 50.1, pp. 45–59.

Wilson, Kyle, Mo Xiao, and Peter F. Orazem (Feb. 2021). "Entry threat, entry delay, and Internet speed: The timing of the U.S. broadband rollout". In: *Journal of Economics & Management Strategy* 30.1, pp. 3–44. DOI: 10.1111/jems.12407.