Internet infrastructure and competition in digital markets

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Research question

Big tech firms run platforms on proprietary infrastructure.

- Cost #, quality ″ through specialized infrastructure.
- EU policy goals (DMA): “Fairness and contestability” in digital markets.

\Players who generate a lot of tra c that then enables their business" should make a *\fair contribution to telecommunication networks."* (Margrethe Vestager, 2022)

How does vertical integration into Internet infrastructure impact market power in digital markets?

An example: submarine cables

\The latest construction boom, however, seems to be driven by content providers, such [as] Google, Facebook, Microsoft, and Amazon. [...] the amount of capacity deployed by content providers has risen 10-fold between 2013 and 2017, outpacing all other customers of international bandwidth." Bischof et al. (2018)

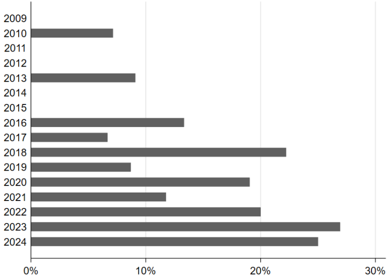


Figure: Share of submarine cables with GAMAM owners by ready-for-service date, calculations based on Telegeography data.

Summary of the paper

Infrastructure firm (I) rents infrastructure to two platforms in return for a bilaterally negotiated access fee.

This infrastructure is used as an input to provide digital services to consumers, generating revenues.

Platforms are asymmetric: one is vertically integrated (V), the other is a pure downstream player (Q). What determines the incentives of I & V to invest in infrastructure?

Summary of the results

Incentives to invest depend on who has the larger network.

When V's network is larger investment incentives for I and V jump up (**commoditization scenario**).

This increase in investment is only *sometimes* socially efficient. It *always* leads to a lower market share of Q.

Applications: *Net neutrality* and *forward-integration* can both harm consumers.

Literature

Classic IO literature:

Broadband investment under demand uncertainty (Buehler et al., 2004) and functional separation/integration (Avenali et al., 2014).

"Vertical integration" in multi-sided platforms (Armstrong, 2006; Lee, 2013; Bedre-Defolie and Biglaiser, 2017; Carroni et al., 2018).

Economic implications of NN (Greenstein, Peitz and Valletti, 2016).

Digital economics:

Internet infrastructure as a novel aspect of digital economics (Greenstein, 2020).

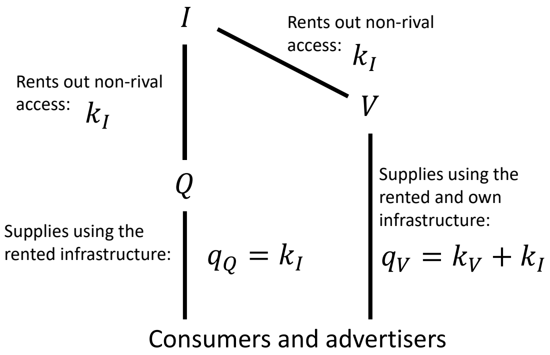
CS/information systems literature:

Proprietary networks: Competitive and innovation dynamics of ecosystems, fragmentation, industry structure (Lehr et al., 2019; Stocker et al., 2021).

Actions and timing

Sequential game, full information

infrastructure firm (I), vertically-integrated firm (V), pure downstream firm (Q).

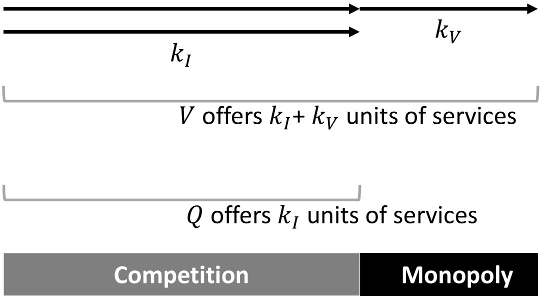


What does infrastructure do downstream?

Each unit of infrastructure allows firms to serve one unit of demand (more infrastructure > lower latency > higher demand).

Services supplied by both firms are undifferentiated. Services supplied by only one firm are monopolistic.

$q_Q; q_V$ are supplied to consumers at zero mc.



Payoff functions

I chooses rental transfers $t_V; t_Q$ and investment k_I to maximize the sum of transfers minus investment cost $c_I(k_I)$.

Platform j sets non-negative consumer prices $p_{j;h}$ on the segment $h = m(onopoly); c(ompetition)$ to control demand $d_{j;h}$. Advertisement revenue r is proportional to demand.

$$\Pi_I = t_Q + t_V \quad c_I(k_I) \tag{1}$$

$$\Pi_V = \sum_{h=c;m} d_{V;h}(p_{V;h} + r) \quad t_V \quad c_V(k_V) \tag{2}$$

$$\Pi_Q = \sum_{h=c;m} d_{Q;h}(p_{Q;h} + r) \quad t_Q \tag{3}$$

Third stage: downstream Bertrand

Consumers buy services from the cheapest firm up to their willingness-to-pay a. When two firms set identical prices for competing services, they split demand equally.

Q and V sell advertisement space alongside services to advertisers at a constant price of r (irrespective of the segment).

Second and first stage

Second stage. I sets platform-specific rental fees given k_I, k_V and makes TIOLI offer, collects the entire value added by k_I.

Not renegotiation-proof, no credible threat of exclusion.

First stage: V and I choose k_V, k_I, respectively.

Assumptions

As outside option, V can use k_V as a substitute to k_I.

I cannot make an offer conditional on excluding a rival (no Nash-in-Nash).

Convex cost function of the form
$c_i(k) = k \quad + \quad _i(k \quad k_0); \quad > 1; \; _i > 0$ for some exogenous values $\; _i; k_0 \; 2 \; \mathbb{R}_+$, $k \quad 0$, $i = V; I$.

Solution base model

We look for a subgame perfect Nash equilibrium. I show:

Theorem 1: There are two types of equilibrium in which either $k_I > k_V$ or $k_V \quad k_I$. $k_V \quad k_I$ in equilibrium if $_V \quad _K \quad r$=2. The converse is true otherwise.

Both I's and V's optimal level of investment are higher in the equilibrium when $k_V \quad k_I$ than in the equilibrium where $k_I > k_V$.

Theorem 1 intuition

With larger k, V sells services with market power even off-path.

V's marginal value of investing (and its impact on V's outside option) increases, t_V #.

Marginal investment by I expands V's lucrative (monopoly) region (increasing the pie). It also reduces V's outside option by expanding V's ability to compete (increasing U's share of the pie).

Commoditization scenario: I's investment adds a (high) $a + r$, it loses its strategic role.

Proof 1 and back to 1.

Social welfare, theorem 2

Is the **commoditization scenario** desirable or wasteful?

Let's define a social welfare function S:

$$S = (k_I + k_V)(a + r) \quad c_I(k_I) \quad c_V(k_V) \tag{4}$$

Theorem 2: Social welfare is decreasing in marginal costs ${}_I$; ${}_V$ but has a discontinuity when ${}_V \quad {}_I = r/2$. Social welfare increases at this point if

$$(a + r) \quad {}^{1}\left[\frac{2a + r}{}\right] > \left[\frac{2a + r}{}\right] + (\ {}_I + \ {}_V) \quad {}^{1}\left(\frac{a + \frac{r}{2}}{}\right) \tag{5}$$

Social welfare, idea

Each unit of infrastructure adds $a + r$ social value on-path. Increase in investment usually good but some scope for overinvestment.

Absent congestion and downstream bargaining power, I can "double-dip", charging r=2 from Q but also $a + r$ from V.

Overinvestment decreases in robustness checks but always persists except for extremely harsh congestion.

Proof 2 and back to 2.

Market share and "contestability"

EU's Digital Markets Act cares about "contestability"

How does Q's market share change in the **commoditization scenario**?

Both k_V and k_Q increase, so the relative shift is not clear ex-ante.

Proposition 3: In the commoditization scenario, Q's market share is decreasing.

Forward-integration: I buys Q

Suppose I buys Q and forms a merged firm M.

M invests in infrastructure k_M, M rents out its infrastructure to V, and offers digital services downstream.

Two asymmetries between M and V: M rents to V (like I in the base model) but not vice-versa. Marginal costs $_M; \ _V$ can differ.

Two-part proposition: if M can commit to a quantity of digital services after renting out infrastructure, it shuts down its downstream operation, induces monopoly outcome. If M cannot commit to this, outcome as in the base model.

Efficient side payments

When would we expect big tech not to vertically integrate?

Assume Q's output has a binding limit $\bar{q}_Q$.

Assume V can offer to I a side-payment conditional on k_I.

Proposition 5: If Q is capacity-constrained and conditional side-payments are possible and $_V > {}_I + r$=2, I's and Q's incentives to invest align. Investment levels are given by $c_V'(k_V) = c_I'(k_I) = a + r$

Proof 5 and back to 5.

Net neutrality

Suppose CDN were to be included in net neutrality regulation.

Instead of bilateral bargaining, I posts one price t in period 2.

Then, V and Q choose whether to accept this price or not.

Proposition 6: Under net neutrality, I charges $t = k_I(a + r)$ and chooses $c^{\prime}(k_I) = a + r$. In equilibrium, Q chooses not to pay this price and $q_Q = f;g$, $q_V = k_V + k_Q$. $p_{V;m} = a$, $d_{V;m} = q_Q$.

Model discussion

Robustness checks: Congestion, Nash-in-Nash bargaining, product differentiation.

Infrastructure expands demand at a 1:1 ratio, curvature of $c(k)$ carries a lot of information.

Alternatives: consumer elasticity as a function of k, Q differentiated.

Policy implications

Guidance in merger control, DMA enforcement, industrial policy.

Commoditization argument beyond digital markets: Compare situation for automotive - who reaps the rewards, platform or manufacturer?

Application to any particular industry needs to identify:

important upstream infrastructure requirements,
ability of fringe rivals to compete (scarce inputs),
downstream business model.

Wrap-up

Attempt to translate the rise of proprietary networks into economics.

Link physical Internet infrastructure to competition in digital markets.

Location and infrastructure likely to become more important (edge computing, decentralized 5G networks).

Table 1: The Emergence and Growth of Large Private Networks

Provider Name	Number of Datacenters[1]	Number of Peering Points[2] (Public/Private)	Private Backbone[3]	Off-Net Caches/ Intra-ISP servers[4] (number of ASes in which servers are deployed in 2013 and 2021 [maximum number of servers if not in 2021])
Google	26	344/130	Yes	Yes (2013: 1044; 2021: 3810)
Amazon	EC2: 21 Lightsail: 13	225/131	Yes	Yes (2013: 0; 2021: 62)
Microsoft	40	300/135	Yes	No**
Apple	5	130/62	Yes*	Yes/No (2013: 0; 2021: 0; [2020: 6])
Facebook	15	323/95	Yes	Yes (2013: 0; 2021: 2214)
Netflix	--	196/75	No	Yes (2013: 47; 2021: 2115)
Akamai	--	216/126	Yes	Yes (2013: 978; 2021: 1094; [2018: 1463])
Alibaba	21	46/26	Yes (not global)	Yes (2013: 0; 2021: 136; [2018: 184])
Limelight	n.a.	107/68	Yes	No (2013: 0; 2021: 32; [2020: 42])

Sources: Authors; [1] based on Corneo et al., 2021a (Table 1 at p. 296) and Datacenters.com, 2021a,b; [2] own calculations based on PeeringDB.com data; [3] based on Corneo et al., 2021a (Table 1 at p. 296), Arnold et al., 2020a, Kaufmann, 2018, Bischof et al., 2018, Kugler, 2019, Limelight, 2021, Jimenez Fernandez and Kwok, 2017; [4] based on Gigis et al., 2021 (Table 3 at p. 521) [note: number of ASes does not necessarily equal number of (eyeball) ISP networks]; * inferred by authors from PeeringDB.com data; ** based on explanations in Gigis et al., 2021 (p. 522).

Source: Stocker et al., working paper, 2021.

Google's peering network

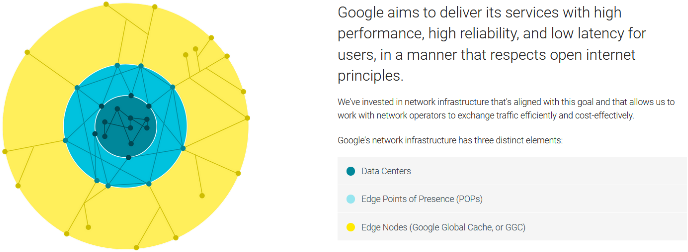


Figure: Visualization by Google (2021).

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Proposition 1 proof

U's and FP's outside option is 0. CP's outside option is

$$\Gamma = X_{CP} R{=}2 + max(0; (X_{CP} \quad X_U)(R{=}2 + v)): \qquad (6)$$

This results in transfers

$$T_{FP} = {}_{FP} X_U (R{=}2) \qquad (7)$$

$$T_{CP} = {}_{CP} [(X_U + 2X_{CP})(R{=}2) + vX_{CP} \quad \Gamma]: \qquad (8)$$

FOC for X_U differ (X_{CP} similar)

$$\frac{@\Pi^U}{@X_U}: \quad [k_U(X_U)]^{0} = ({}_{CP} + {}_{FP})(R{=}2); \quad \text{if } X_U \quad X_{CP} \qquad (9)$$

$$[k_U(X_U)]^{0} = {}_{CP}(R + v) + {}_{FP}(R{=}2); \quad \text{if } X_{CP} > X_U: \qquad (10)$$

Back to the proposition 1 Proof 1

Proposition 2 proof

A marginal increase in either network increases the total sum of services served to consumers and always adds $R + v$. Therefore, and from the fact that cost functions are increasing, convex, and differentiable, it follows that social welfare is maximized when $[k_U(X_U)]' = R + v$ and $[k_{CP}(X_{CP})]' = R + v$.

From the proof of proposition 1, we know that the optimal level of investment is lower than this when $X_U > X_{CP}$. When $X_{CP} > X_U$, CP's investment obtains the socially optimal level.

From comparing

$$[k_U(X_U)]' = \ _{CP}(R + v) + \ _{FP}(R{=}2); \qquad \text{if } X_{CP} > X_U: \quad (11)$$

with the social optimum, and recalling the assumption that limits U's bargaining weight, U's investment never exceeds the social optimum.

Back to the proposition 2 Proof 2

Efficient side payments, sketch of proof

Proposition 5: If Q is capacity-constrained and conditional side-payments are possible, I's and V's incentives to invest align and V may pay I for additional investment.

Proof: I and V can maximize joint surplus at $[c_I(k_I)]' = a + r$. Call this level of investment k_I .

V has an incentive-compatible side payment T' that induces k_I .

V offers any T' such that
$(k_I \quad k_I)(a + r) > T' > k_I(k_I \;) \quad k_I(k_I)$
if and only if $k_I = k_I$.
This T' exists from the properties of the cost function.

Back to the proposition 5 Proof 5