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Evaluating competition in the Internet's infrastructure: a view of GAFAM from the Internet exchanges

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ABSTRACT

The Internet has given rise to online platforms offering unrivalled access to diverse markets and services. At the application-layer, consolidation and concentration is framed as a threat to competition and diversity, with dominant players facing antitrust challenges in the US and the EU. Within the infrastructure though, concentration creates economies of scale that makes many of the resource-intensive building blocks of the Internet economy – such as global content delivery and distributed hosting – available to even the smallest innovator. This work complements existing analyses by exploring the links between these layers, differentiating between the implications of application-layer consolidation and the efficiencies of concentration at lower layers of the Internet's infrastructure. In particular, these differences are presented from the vantage point of Internet exchanges, evaluating consolidation in terms of the distribution of these essential building blocks and how IXes' governance norms lower barriers to accessing these resources. While promising, the spectre of predatory practices at the application layer remains. This article concludes by arguing that the indicators presented here highlighting regulatory interventions must effectively account for the complex interdependencies among these platforms.

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1. Introduction

Early on, GAFAM – Google, Amazon, Facebook, Apple and Microsoft[1] – benefitted from the Internet's open architecture[2], pioneering innovative platforms that offer unrivalled access to diverse global markets and services. Today, GAFAM's application-layer platforms face antitrust scrutiny on multiple fronts (Bartz and Nellis 2019, to name a few; Couturier 2015; Hanbury 2019; Kang and Roose 2018), framing GAFAM as first movers that have translated successful platforms into architectures of consolidation and control[3], foreclosing on the very kinds of innovation that contributed to their success. While this scrutiny is justified, critics *also* frame the success of supporting platforms, here in particular, hosting and content delivery, as further indicators of these firms' market power. Looking bottom-up from the interconnection layer, where hosting and content delivery platforms deploy the network and compute resources that facilitates their global reach, tells a more nuanced and complex story of diverse firms engaging in local, regional and

global connectivity, hosting and content delivery markets. This work disambiguates the kinds of gatekeeping and control available to application-layer platforms from the more general-purpose roles of lower-layer platforms. Rather these lower-layer platforms provide critical, general-purpose building blocks of the modern Internet economy, highlighting that hosting and content delivery should not be framed as merely another tool of consolidation and control. The central question explored in this article is: how does *application-layer* consolidation affect opportunities and incentives for innovation historically available at lower layers of the Internet's infrastructure?

Following the definition presented by the Internet Society, Internet consolidation is the concentration of market power and control that is seemingly restructuring how both businesses and individuals engage in the Internet Economy.[4] Cloud hosting[5] and content delivery[6] are critical lower-layer platforms in the modern Internet economy, facilitating development and global deployment resources otherwise unavailable to all but the largest, established firms. GAFAM and content delivery pioneers (such as Akamai and Limelight), made substantive investments in research, operational development and deployment early on, innovating and refining these into general-purpose, commodity resources that allow even the smallest actor to deploy their content and services globally. To evaluate the implications of consolidation, this article first disambiguates applications-layer platforms (such as the Android Play Store and Amazon's Marketplace) from two classes of lower-layer platforms:

(1) *hosting and content delivery platforms*; and
(2) the *interconnection platforms* that facilitate connectivity among the individual networks that make up the global *Inter*net.

Building on this distinction, this work highlights the implications for innovation in these platforms' governance norms and practices, paying special attention to how platform management and control shapes access to the resources that currently facilitate even the smallest actors to innovate at Internet scale. In particular, access to markets such as mobile application markets and e-commerce markets are intermediated by application-layer platforms such as Apple and Google's respective mobile application stores and Amazon's Marketplace.[7] These are provisioned and managed by single firms, often according to their business preferences. In contrast, while markets for hosting and content delivery are characterised by large players, these platforms are not in the same markets as their clients and do not impose the same degree of control over how their clients engage in their respective markets. They do not have the same incentives to 'prey on' their clients that have been presented in the media and recent work.[8]

To characterise these differences, this article evaluates the consolidation and distribution of these platforms from the vantage point of interconnection platforms in the Internet's infrastructure, in particular, associational membership IXes. A commonly articulated – although certainly not universal – prerequisite for a successful IX is the presence of a global CDN. Despite the influence of these large networks, the platform governance norms and practices of associational membership Internet eXchanges (IXes, a particular type of interconnection platform, see Section 3.1), introduce important checks on the influence and market power of GAFAM and dominant CDNs on IX platforms and the attendant interconnection services markets. Rather, IXes provision platforms facilitate open markets for infrastructure services, here in particular access to diverse hosting and content delivery

platforms, lowering local barriers to accessing resources that facilitate global reach for local small- and medium-sized innovators. To illustrate, this work builds on Sowell's diversity metric (Sowell 2013) to provide a high-level view of the global distribution of hosting and content delivery platforms, across IX platforms and in relation to IX norms.

To elaborate the implications of IX norms for hosting and content delivery platform distribution, Section 3 describes the role of associational membership IXes as external platforms that, in contrast to application-layer platforms managed by *single* firms, these interconnection platforms are governed by a diverse *collective* membership (platform participants), to create a more equitable market for critical infrastructure services, highlighting the kinds of governance mechanisms that can provide insights into more nuanced structural governance strategies for application-layer platforms. Given this context, diversity metrics are presented in Section 4, offering a more concrete view into the distribution of hosting and content delivery platforms relative to one another *and* relative to local actors that benefit from the global reach facilitated by these platforms. Finally, Section 5 offers an initial analysis of the implications of application-layer consolidation on the opportunities for innovation in the Internet's infrastructure.

While the opportunities and resources remain available to deploy innovative services, the threat of 'apex predators' (as the media has framed GAFAM) (Swisher 2019) creating 'technolgical kill-zones' (Smith 2018; The Economist 2018) substantively diminishes the incentives of small actors to take advantage of these opportunities.

While this seemingly agrees with the assessment of GAFAM critics, the nuanced differences in the governance and management strategies of application-layer, hosting and content delivery and interconnection platforms, and the implications of these strategies for the attendant markets for those goods and services, matters. The article concludes by first contrasting conventional strategies for regulating application-layer platform's use of control mechanisms to distort attendant markets. Second, it highlights that, while the indicators developed in this article do highlight complex interdependencies, further indicator development is necessary to support sustainable, effective and non-disruptive regulatory interventions.

2. Generativity, platforms and control

The innovation attributed to Internet technologies is frequently attributed to its open, general-purpose character.[9] As Internet communication technologies evolved, new architectures were introduced to simplify redundant, complicated and operationally intensive tasks. Here in particular, application-layer and content and hosting platforms have been developed to simplify the distributed development and deployment of the compute and network resources, improving overall quality of experience while reducing the costs of deploying content and resources at a global scale. Many of these platforms were developed by single firms, introducing control points that, depending on their design, potentially allow managers of these platforms to observe user data and behaviours, support or limit features deployed using that platform, and, one of the key issues in the Internet consolidation debate, grant or rescind access to markets facilitated by these platforms.

Control points are a necessary feature of these complex systems. They enable the monitoring and instrumentation necessary to ensure:

(1) quality of service and/or experience;
(2) effective resource allocation and utilisation; and
(3) privacy and security features.

In effect, they are necessary for good platform management. That said, how these technical capabilities are used, is an issue of platform management and governance. Issues around the anticompetitive implications of consolidation arise when the firms managing those platforms use their control – in particular access to markets in which they themselves participate – to unfairly promote the interests of their products and services over third parties. This section frames anticompetitive critiques in terms of this notion of control to evaluate consolidation in terms of who has control over these platforms, and how these actors use that control. Here in particular, this framing compares the types of control available to application-layer platforms with hosting and content delivery platforms.

2.1. Generative foundations

Zittrain's notion of generativity provides one conceptual framework for understanding both:

(1) how the general-purpose character of the Internet fosters innovation; and
(2) the trade-offs between generativity, security and control.

Zittrain argues that the Internet's substantive capacity to foster innovation is a consequence of its fundamentally open, generative character. Zittrain's notion of generativity characterises technologies that have a high capacity for *leverage* to make diverse sets of problems easier; that can be *adapted* easily to a broad range of 'previously unforeseen purposes' (Zittrain 2006, 1981); for which skills necessary to adopt and adapt the technology are *easy to master*; and which are *accessible* for a broad range of actors to use and control in terms of both availability and the information necessary to make use of that technology. The appeal of a generative Internet is that anyone could build on open standards and application programming interfaces (APIs) to develop innovative, connected applications.

In the late 1990s and early 2000s, an increasingly commercial Internet saw growth in users and demand for technologies that improved performance (especially for audio and video streaming), as well as low-cost access to distributed resources. At that time, many of the firms that ultimately developed the application-layer platforms under scrutiny today were innovators vying for marketshare among technologies that served this demand. Hosting[10] and content delivery technologies were still in their adolescence, just moving from research projects to commercial endeavours.[11] The key to these firms' early success was not lockin – they did not *yet* have either the necessary marketshare or dependency on their technologies or platforms to exert that kind of influence or control.

Rather, a strategy common to the firms developing these new services was to foster the network effects necessary to reach economies of scale. More specifically, these actors moved to '"platform thinking", … define[d] as understanding the common strands that tie the firm's offerings, markets, and processes together, and exploit[ing] these commonalities to create leveraged growth and variety'.[12] Gawer and Cusumano (2014) provide

insight into how 'industry platforms relate to managing innovation within and outside the firm as well as to dealing with technological and market disruptions and change over time' (2014, 417). Gawer and Cusumano distinguish between internal platforms and external platforms. They 'define *internal* (company or product) *platforms* as a set of assets organized in a common structure from which a company can efficiently develop and produce a stream of derivative products'.[13] Instances of internal platforms include commonalities upon which features can be added or modified to meet the demands of different customers, such as common chipsets within a mobile phone or common drive-trains within a line of automobiles. They define '*external* (industry) *platforms* as products, services, or technologies that are similar in some ways to [internal platforms] but provide the foundation upon which outside firms (organised as a "business ecosystem") can develop their own complementary products, technologies, or services'.[14]

The platforms discussed here do aspire to incorporate *some* of the elements of generativity. That said, the scope of generativity is limited to their interests, in particular uses that can either be monetised or create network effects. Refactoring internal platforms into external platforms is a form of leverage, making it much easier for third parties (especially resource constrained small to medium sized actors) to deploy an e-commerce platform (viz. Amazon Marketplace) or integrate single-signon authentication mechanisms such as offered by Google, Facebook and others. To facilitate uptake and network effects, they certainly invest in ease of mastery, making it easy for third parties to take advantage of the leverage offered. Adaptibility 'refers to both the breadth of a technology's use without change and the readiness with which it might be modified to broaden its range of uses' (Zittrain 2006, 1981). While refactoring from an internal platform to an external platform is an adaptation, it is limited in the scope of uses and, more importantly to this work, unlike more genuinely generative technologies, the range of its adaptability is limited by the firm managing that platform. For instance, the application development tools available on social media platforms such as Facebook allow for the creation of a variety of apps, but those applications may be constrained by the platform manager.[15]

Finally, Zittrain's definition of accessibility speaks directly to control: '[t]he more readily people can come to use *and control* a technology, along with what information might be required to master it, the more accessible the technology is' (Zittrain 2006, 1982, emphasis added here). Similar to adaptability, access to the platforms discussed here is controlled by the firm, which may revoke access for a number of reasons. In the benevolent case, access may be revoked for violating use policies, such as exporting social network data outside the platform; in cases that trouble antitrust analysts, platform managers may deny, or limit access to those competing with either core features of the platform or competing applications developed by the platform manager. The Internet Society indicates:

> [F]ull service environments operate at a scale that allows entrepreneurs to do things they could not otherwise, like access a far larger customer base, resources, and expertise that no small business could tap using its own limited resources or time. While platform environments unleash huge opportunities, they could also limit innovation by promoting the interests of the platforms over those of users, thereby limiting competition and user choice. (Internet Society 2019, 8)

In the abstract, platforms share many of these objects. In terms of their generative characteristics, and subsequently, the capacity to foster innovation, application-layer, hosting

and content delivery and interconnection platforms differ significantly in both 'how generative' they are and whether they limit other forms of generativity. For this work, the question is: how do these three classes of platform differ in terms of generativity, control, and how these differences intermediate access to their clients' target markets?

2.2. Application-layer control

For many of GAFAM's application-layer platforms, access to and participation on their respective platforms means access to a substantive portion of the market. As the gatekeepers to their respective application-layer platforms, GAFAM controls not only entry and access, but also information about transactions and consumer behaviours on their platforms, the features platform participants can use to engage with their customers, the costs of engagement, policies regarding how participants engage with their customers, and even what services and features may be offered. Critics argue that GAFAM is abusing this control to:

(1) give their products and services unfair advantages; and
(2) diminish opportunities to bring innovative new products and services to the market.

For third party sellers, Amazon Marketplace offers the opportunity to sell their goods to a global market. Critics argue that Amazon's access to these transactions give it substantive (arguably unprecedented) insight into pricing and consumer shopping behaviour and preferences, giving Amazon an unfair advantage identifying trends in product and service markets. Critics further argue that when Amazon moves into these markets, it uses this data to engage in predatory pricing – leveraging its capital to intentionally lower prices to the point at which it drives other competitors (typically smaller competitors) operating closer to the margin out of the market.[16]

Platform managers have also been critiqued for using their control to prioritise their products over their competitors. For instance, critics argue that Amazon uses its control to prioritise its increasing array of private label goods over others, further exacerbating pricing pressures.

> Amazon is utilizing its knowledge of its powerful marketplace machine — from optimizing word-search algorithms to analyzing competitors' sales data to using its customer-review networks—to steer shoppers toward its in-house brands and away from its competitors, say analysts … Even as Amazon takes away market share and eats into their profit margins, they have little choice but to continue to sell on Amazon's platform in order to get themselves in front of millions of potential customers. (Creswell 2018)

Apple is facing similar scrutiny, that it prioritises its applications over its competitors: 'Apple's apps have ranked first recently for at least 700 search terms in the store, according to a New York Times analysis of six years of search results compiled by Sensor Tower, an app analytics firm' (Nicas and Collins 2019).

Platform policy is yet another means to exert control. Spotify, a top competitor to Apple's Music application, accused Apple of delaying updates because Spotify did not comply with policies it contends are 'continually changing … to harm competitors' (Satariano and Nicas 2019). Spotify further claims 'Apple punishes companies that do not use its payment system by restricting their ability to communicate with customers and

preventing the release of app updates', and that Apple limits Apple competitors from making use of other services it controls such as 'Siri, HomePod and Apple Watch' (Satariano and Nicas 2019). The case of small Apple resellers on Amazon Marketplace is a more poignant case of how application-layer platforms' policies control market access. In 2018, Amazon and Apple struck a deal that 'limit[ed] all but the largest companies and specially authorized providers from selling Apple products', on Amazon (Statt 2019). In effect, this policy change denied smaller Apple resellers access to Amazon, forcing resellers to either:

(1) rely on smaller markets such as Etsy and eBay; or
(2) rely on traffic to their own websites (Fingas 2019).

In each of these cases, the platform manager is (allegedly) leveraging its control over the platform to disadvantage competitors in the attendant markets. In some cases, control is through manipulation of data available on the platform to engage in predatory pricing (Amazon Marketplace) or control of how consumers interact with the platform (Google's prioritisation of search results, Apple's application ranking, or auxiliary services such as limiting Spotify's access to related Apple platforms).

Control of the platform is not limited to technical means. Platform policy, such as limiting or delaying particular features (Spotify and Apple) or denying access to an entire class of third-party participants (Amazon Marketplace, Apple and third-party Apple resellers) is another mechanism for controlling how actors use the platform, and, by proxy, their engagement with the attendant market. In the application-layer cases described here, the platform is managed by a single actor (firm), establishing generative characteristics necessary to create network effects, but (allegedly) limiting the use of those to serve its own interests or promote its products and services over its competition. In contrast, while hosting and content delivery platforms do have technical and policy control mechanisms, those platforms do not directly intermediate the relationship between their clients and their clients' markets in the same way as application-layer platforms. Rather, as described in the next section, hosting and content delivery platforms have historically focused on facilitating the provision of more general-purpose, distributed content delivery, compute and network resources.

2.3. Hosting and content delivery platforms

In the course of developing the application-layer platforms they are best known for, GAFAM, following large CDNs such as Akamai *also* invested in the development and deployment of hosting and content delivery platforms. In the case of GAFAM, many of these platforms were initially developed as internal platforms. In effect, these firms were investing in an internally scoped form of generativity. For those firms, early hosting and content delivery platforms created leverage, were adaptable, easy to master and accessible, but only in service of *their* product lines. In the case of Amazon, the pursuit of internal efficiencies in the attempt to develop support for third party sellers gave rise to two external platforms: Amazon Marketplace and Amazon Web Services (AWS). Amazon evolved from selling books, to selling a much more diverse set of goods, to needing an (internal) platform supporting the provisioning general purpose network and compute resources

necessary to support the development of an (external) platform that facilitated third party sellers' access to Amazon's global market presence. In the course of this development, Amazon also realised it could market its internal platform as AWS (Miller 2016). As their services reached critical mass and these platforms matured, GAFAM capitalised on its intensive, global investments, opening internal platforms for use by third parties, selectively incorporating some (but not all) of the elements of generative technologies.

In contrast to application-layer platforms that directly intermediate the relationship between client and the attendant market, hosting and content delivery facilitate access to distributed resources, but do not intermediate the relationship itself. Cloud hosting services provide a variety of services: on demand generalised compute and network resources in the form of virtual machines and containerised general purpose applications such as databases and webservers. As an external platform, cloud hosting resources provide flexible access to configurations of compute and network resources that can be dynamically increased and decreased without the investment in either operational capabilities necessary to maintain these resources or the capital expense of the underlying infrastructure. Following Zittrain's argument that there is no more generative platform than the modern PC and the Internet to which it is connected, cloud compute services have the potential to contribute to generativity that has the immediate scaling benefits of distributed cloud platforms.

General-purpose CDNs, such as Akamai, Limelight and Cloudflare, facilitate delivery of *diverse* classes of content, serving equally diverse clients across many different market segments. Since then, these innovations have been commodified. Netflix[17] and Apple have since developed their own *internal, single-purpose* CDNs, dedicated largely to their media streaming services. These single-purpose CDNs are effectively internal platforms that are the products of generativity and the commodification of earlier innovations. These internal platforms do contribute to lower-latency access to their respective media streaming services for their customers, but do not necessarily contribute to the generativity of the Internet writ broadly. That said, they do not substantively diminish that generativity either.

General purpose CDNs such as Akamai, Limelight, Level-3 and Cloudflare, more closely resemble external platforms. These firms' primary value proposition is content delivery, leveraging their investment in overlays to ensure client-generated content (regardless of origin) is as proximate to the end user as possible. General purpose CDNs facilitate an improved global performance for a range of actors, from those with substantive existing (yet local) infrastructure that produce content that would benefit from global distribution to small enterprise actors that want to ensure web site content performs well globally.

2.4. Markets and apex predators

As noted earlier, a number of the application-layer platforms considered here are also gatekeepers to markets in which they themselves also participate. Critics argue that the predatory practices also indirectly limits new entrants' opportunities to bring innovative products to market. The dialogue around startups in the Internet economy is increasingly using terms like '"kill-zone[s]" around [technology] giants' (The Economist 2018), referring to GAFAM tech giants as 'apex predators', highlighting 'Google and Facebook as the most

obvious' of these predators (Swisher 2019). In effect, if a product or service appears to be too similar to an existing product or service offered by one of the technology giants, it is very likely this will simply be replicated and offered either for free or for a price substantively less than what a startup may be able to match. Under this framing, the 'kill zone' of technology startups adjacent to GAFAM applications and services is a consequence of dominant firms' substantive capital, existing infrastructure (in particular application-layer digital platforms), and deep knowledge of consumer behaviour. Critics argue that venture capitalists are wary of investing in innovative startups that, in the course of demonstrating the viability of an application or service, become susceptible to being pushed out of the market by the GAFAM 'apex predators'.

In effect, startups innovating in the technology giants' 'kill zones' face two limitations. First, even with the availability of global hosting and content delivery platforms, without investment they may not have access to the capital necessary to contract the digital infrastructure necessary to be competitive in terms of delivery and performance. Second, they may not have access to the 'troves' of consumer behaviour data available to GAFAM that would allow them to maximise the potential in these markets. While this argument is largely presented in terms of resources and capabilities, the existence of a 'kill zone' implies the perceptions of these predatory practices are limiting the opportunities in markets where technology giants' application-layer platforms are the gateways to a given market. Taking the generative characteristics of hosting and content delivery alongside the investment environment described by GAFAM critics paints a picture in which permissionless innovation is still nominally possible, but for which the rewards and opportunities for the growth enjoyed by GAFAM early on are limited by predatory practices.

At the root of this problem is the confluence of architectural conditions (control of application-layer platforms) and governance practices (abuse of that control). It is important to highlight that, based on the cases briefly presented here, there is some evidence of anticompetitive practices facilitated by each firm's exclusive control over market-specific application-layer platforms. That said, the same incentives and opportunities to control access to markets do not seem to be present among GAFAM-managed (or other) hosting and content delivery platforms. These actors provide critical resources that lower the costs of global deployment.

To illustrate, contrast the network effects for a third-party seller on Amazon Marketplace with that of the economies of scale that benefit third parties contracting a general purpose, commodity CDN. In addition to the cost benefits of having well-designed and stable marketplace tools, Amazon Marketplace participants benefit from the ability of consumers to easily find their products and services on one of the largest online marketplaces in the Internet. Moreover, they also benefit from listings such as 'people frequently bought these items together', creating additional potential consumer traffic the seller may not have realised in a smaller online market specialising in only specific goods or services.

In contrast, clients of CDNs benefit from the geographic distribution of CDN deployment that improves the efficiency of the delivery of their content. Greater marketshare and revenue facilitates investment in economies of scale, but it does not create the kind of network effects that drive online marketplaces to other application-layer platforms. Further, general purpose CDNs facilitate content delivery for very diverse organisations such as MIT (higher education), American Idol (entertainment), the American Red Cross (non-profit aid), Frank and Oak (clothing), the NBA (sports), Thomson Reuters (publishing),

among many others. Each of these represents a different market very distinct from the others and that of general purpose CDN. CDNs would not benefit from appropriating innovations in those markets.[18] While there is some lock-in to the CDN platform as a result of investing in CDN specific tools for deploying customer content, the barriers to exit are not nearly as significant as a seller shifting their business to a market with less traffic and fewer opportunities for traffic from consumers viewing complementary goods within the same broader marketplace.

As discussed earlier, the markets for hosting and content delivery do have dominant players, but these players themselves must engage in geographically diverse interconnection markets necessary for their platforms to offer equally geographic deployment options. Access to these markets facilitate deploying their resources much closer to both potential customers and end users. Local interconnection platforms – here in particular associational membership IXes – facilitate access to these local, regional and global interconnection markets. Moreover, it is typically recommended to have one – at most two – IXes in a given metropolitan region. Given the demand for CDN-delivered content such as video and music streaming, what limits GAFAM and CDN's influence on these platforms? In the next section (3), associational membership IX are presented in terms of their functional role contributing to the *deployment* of hosting and content delivery platforms, but, perhaps more importantly, the governance norms and practices that ensure access to these connectivity markets.

3. Internet exchanges as markets for intermediary platforms

In the late 1990s, IXes were created with a simple topological objective: 'keep local traffic local'. In those early days of the modern Internet small to medium sized networks connected to the rest of the Internet through transit (backbone) providers that offered least cost, but not necessarily the shortest routes, from source to destination. For instance, the London Internet Exchange (LINX), was created 'to save the coast and time delay involved in routing data across the Atlantic to US Internet exchanges'(LINX 2015) creating a platform upon which networks could negotiate direct interconnection (peering), reducing both costs and latency. During this time period, IXes were emerging around the world: in Amsterdam, Frankfurt, Palo Alto, Seattle, Sao Paolo and Buenos Aires, to name some of the largest and most well known. The utility of establishing interconnection at IXes goes beyond savings on transit and reduced latency: network operators indicate that the Internet exchange ecosystem facilitates (1) developing new (unique) interconnection relationships and (2) enhancing the resilience (redundancy) of existing interconnection relationships.[19]

Today, IXes have further evolved into platforms supporting neutral markets for interconnection and infrastructure services. As will be developed in this section, especially in contrast to application-layer platforms, IX governance norms limit platform controls to exclusively focus on ensuring resilience and stability. In further contrast to both application-layer and hosting and content-layer platforms, associational membership IXes are managed by the collective of platform participants. Among other norms, neutrality fundamentally eschews the kind of market access controls alleged at the application layer.

While critics of GAFAM do mention the role of supporting infrastructure (such as cloud computing and CDNs), they often frame it largely in terms of infrastructure that, along

with 'data troves', create substantive advantages for GAFAM firms. Hosting and content delivery platforms do provide advantages, but in contrast to application-layer platforms, they do not control market access in the same way. In contrast, as will be developed in the case studies in Section 3.2, hosting and content delivery platforms create a number of direct and collateral benefits for local and regional interconnection markets. Section 4 builds this framing to examine the distribution of participation in IX-mediated interconnection markets, in particular that of hosting and content delivery platforms. This provides initial insights into the reach of hosting and content delivery platforms, in particular, IXes' role ensuring access to and choice among *diverse sets* hosting and content delivery platforms.

To understand the relationships between IXes and hosting and content delivery platforms in relation to the consolidation debate, this section presents a brief overview of associational membership IX norms, governance and organisational structure, with a focus on how collective governance limits control of and influence on IX platform management. For instance, CDNs have been framed by a number of network and IX managers as 'king-makers': an IX has a much greater chance of attracting the critical mass necessary for a diverse interconnection market if a major CDN cache is present. On the surface, this seems to fit the consolidation narrative – these firms have substantive potential influence (control) over IX management and *may* abuse this influence to distort markets. Rather, IX governance norms, in particular neutrality norms, ensure that, despite the importance of CDNs for catalysing the network effects necessary for a successful IX, these participants are not afforded any special privileges within the IX platform. This section briefly describes the institutional norms and governance structure of associational membership IX platforms; how platforms contribute to diverse, neutral interconnection markets; and offers case studies illustrating how IXes and CDNs have collaborated to improve access to local and regional interconnection markets.

3.1. Institutional norms[20]

In contrast to the privately managed application-layer and hosting and content delivery platforms discussed earlier, associational membership IXes are typically non-profits guided by three distinct norms – mutuality, neutrality and non-compete. These norms contribute to creating more transparent markets for the exchange of routes and traffic that, for the purposes of this work, substantively lower barriers to accessing the hosting and content delivery platforms (among many other kinds of networks) critical to participating in the modern Internet economy.

3.1.1. Mutuality

Mutuality is the foundational norm for associational membership IX management, from which neutrality (Section 3.1.2) and non-compete (Section 3.1.3) are derived. In interviews with leadership and representatives of longstanding members of a number of IXes, these actors have reiterated that 'the *collective* membership is the single stakeholder in the IX [firm]'.[21] In contrast to application-layer and hosting and content delivery platforms, managed by a single firm and its interests, associational membership IXes are managed by participants in the interconnection market they serve.[22]

Modern associational membership IXes comprise three distinct sets of actors: the collective membership of the IX; a (typically non-profit) firm that manages the IX

infrastructure itself; and a board that oversees the firm. The firm is delegated the authority to manage day-to-day operations. The IX board is typically a subset of the collective membership whose role is to oversee the firm, ensuring adequate performance of day-to-day operations and that the firm does not overstep its operational authority, i.e. it does not implement unnecessary controls or engage in only the network monitoring necessary to ensure the stability and resilience of the platform. In many associational IXes, a key objective is to ensure the board represents the major sub-industries within regional market, for instance, comprising individuals that represent a CDN, a large ISP, a small ISP, government-run networks, academic and research networks, etc. The objective of a 'balanced' or 'diverse' board is to ensure no single constituency or sub-industry dominates the board, or their oversight of the firm. In effect, this balance limits the influence and control of otherwise dominant market players. Finally, while the collective membership has delegated some of its authority to the board and to the firm, some decisions, especially those related to decisions that will have a substantive financial impact on the IX, strategic decisions such as deploying a platform in another metro, or those decisions that represent a modification of neutrality and non-compete norms, require a decision from the collective membership.

3.1.2. Neutrality

At a conceptual level, neutrality means that no single actor or interest group contributing to the function of the IX is privileged over another. In terms of infrastructure economics, it means that the operation, financing, pricing and management of the IX is non-discriminatory. In contrast to the critiques of prioritisation in the application-layer, neutrality norms ensure that there is no prioritisation of participants on the IX platform and that any network that respects the technical rules (controls) ensuring the stability of the platform can participate.

As a form of non-discrimination, neutrality means that the pricing structure for all members of the IX is the same. Membership fees and port fees (fees based on the volume of capacity contracted on an IX platform) are uniform and transparent, regardless of the size or market power of a member in the broader market. Neutrality also extends to access to the IX: if a network is willing to pay the membership fee and port fees for the desired volume of capacity, with limited exceptions, they will not be denied membership. Neutrality is also applied to the selection of colocation facilities[23], intra-platform connectivity[24] and routing and switching equipment.[25]

3.1.3. Non-compete

The ideal form of the non-compete norm asserts that IX services *will not* compete with the services of its members. Another articulation of this ideal form is that participation on the IX will not adversely affect the revenues of its participants. The ideal form conveys the spirit of the non-compete norm, but is impossible to implement in practice. This is in stark contrast to application-layer platforms, where products produced by the platform manager compete directly with third parties. The non-compete norm exists to avoid exactly the kinds of anticompetitive conflicts of interests critics have levied against GAFAM.

For instance, consider the original objective of the IX: reduce transit costs for traffic exchanged among geographically proximate members. While this goal does not

provide a complete substitute for transit, when participants shift their traffic to the IX, it does reduce the revenue from the transit provider they would have otherwise used to deliver that traffic. That said, nearly all networks need some form of transit, and the neutrality norm ensures that transit providers may be members of the IX, where they can compete with others to provide connectivity options, potentially broadening their market.

More generally, and especially salient to the consolidation debate, non-compete means that IXes will not start offering network services provided by its members, such as transit, transport or dark fibre services. As it relates to consolidation, this is another contrast with application-layer platforms. For instance, a number of critics of Amazon claim that, in its role as both a platform facilitating third party e-commerce and an e-commerce platform in and of itself, it has privileged access to data that would allow it to observe pricing and demand trends for products and services offered by third parties it facilitates, then offer substitutes on its own e-commerce platform, leveraging other horizontally integrated services to undercut those third parties. In effect, the platform leverages its privileged position as an intermediary to move into markets based on trend data otherwise unavailable. Among associational membership IXes, the non-compete norm ensures that the IX does not engage in this kind of practice, even for adjacent services it easily has the resources to provide.

3.1.4. Norms and consolidation

As it relates to consolidation, these norms ensure that IX remains neutral and does not compete with the services provided by its members. Mutuality is key to enforcing these norms. IXes, like other platforms, rely in part on network effects. It is not sufficient to just have a large number of members. It is necessary to have a *diverse* set of members, those that fall into the gross categories of both eyeballs (access networks, university networks full of students, enterprise networks consuming cloud-based web-applications, etc.) and content (video, web-hosting, cloud-based file-sharing and web-based applications, etc.). This diversity not only creates a valuable market for different types of traffic and routes, but also helps ensure that both the collective membership and the board remain balanced. In effect, no single sub-industry can drive the direction of the platform. Such a check on the power of both the platform provider and powerful constituencies, such as transnational transit providers and CDNs, stands in distinct contrast with the application-layer platforms managed by a single private actor, such as the platforms provisioned by GAFAM.

3.2. Case studies[26]

These make the concepts above more concrete and further drive home the contrast between IX platforms and the application-layer platforms that drive demand for content and services. Three brief case studies are presented: the London INternet eXchange (the LINX, Section 3.2.1), France-IX (Section 3.2.2) and Cabase (Section 3.2.3). These illustrate IX norms' impact platform management, how this limits the exercise of control, and the benefits for interconnection and infrastructure services markets, in particular uniformly lowering access to these markets.

3.2.1. LINX

The LINX is one of the oldest associational membership IXes. In this brief case study, three decisions made by the LINX are presented to illustrate IX norms and the evolution of the LINX structure: the demutualisation threat; contention over the provision of connectivity between IX nodes; and expansion outside of the London metro.

The LINX demutualisation event illustrates an instance of an IX transitioning from a relatively ad hoc, volunteer organisation to a firm-based structure. The late 1990s and early 2000s were the peak of the dot-com bubble, and there was substantive interest in investing in interconnection platforms. At the time, the LINX was faced with two problems:

(1) whether a non-profit could raise the capital necessary to keep pace with demand; and
(2) whether the LINX should move its management model closer to that of a commercial firm or even become commercial itself.

Further confounding the issue, new colocation facilities were emerging in the London area, demanding that the LINX either host a node in their facility or start their own IX. Whether they knew this or not, these new facilities were threatening to fragment the interconnection market. The collective membership ultimately decided to remain mutual. It refined its model to delegate more of its day-to-day operations to the firm, while retaining the collective membership and the board's oversight of a cost neutral fee structure rather than risk its fees being set by a for-profit entity driven by external stakeholders.

As the LINX grew, space became scarce at the facility hosting its first node, which is now Telehouse North. The LINX needed to expand to other facilities, and to do so, needed connectivity between those facilities. In the strict, ideal form of the non-compete norm, providing transport between two nodes could be seen as competing with metro dark fibre and/or transport networks. Among the membership, especially among metro dark fibre and transport networks there was some contention over this decision. Membership ultimately decided to relax the non-compete norm, contracting its internode connectivity with existing members and limiting traffic on the platform such that it could not be used as a substitute for metro transport between participant facilities. Moreover, the decision to develop additional nodes within the London metro became an operational decision that would be reviewed by the board and the membership, but did not require the decision to invoke an explicit consensus among the membership.

As the LINX membership grew further in the early 2010s, it began to see demand for the creation of additional IX platforms, both within the UK and in the US. Like the previous two decisions, this was a significant shift in the strategic direction of the LINX as well as a substantive financial investment. LINX Manchester, the first of the LINX's UK platforms outside of the London metro, was created at the request of LINX members that wanted more options to peer within the Manchester area. After consultation with the broader LINX membership, the LINX invested in LINX Manchester, which now has nodes in Equinix Joule House, Equinix Williams House and M247 (also illustrating data centre neutrality). Perhaps a bigger decision was to cross the pond to develop LINX NoVA (Northern Virginia, in Ashburn, Virginia). Again, the LINX leadership developed a strategic plan for development. As an illustration of the role of the collective membership in strategic decision making, the first plan was withdrawn to be revised after consultation and

recommendations from the membership. After these revisions, the membership did come to a consensus to develop the LINX NoVA platform. Today, the LINX NoVA platform comprises three nodes: Digital Realty Ashburn, Evoswitch Manssas and Coresite Reston, illustrating neutrality and diversification across three different facilities providers.

While each of these vignettes describes substantively different strategic decisions, each also illustrates the focus on growth and development to improve access to the local interconnection market. The first eschewed the trappings of commercial interests that could diminish the voice (control) of the participant collective. The second explicitly balanced the interests of transport providers that perceived expansion as competition, avoiding a conflict of interest. The third both responded to demands for increased access and, in revising a flawed plan, illustrated participants still retained control over significant strategic decisions. As alluded to earlier, this is in stark contrast to the management of application-layer platforms, where a single firm's decisions can substantively affect how third parties engage with their respective markets.

3.2.2. France-IX

Of these, the France-IX case is perhaps the best illustration of constructive consolidation, driven in part by representatives from two technology giants – Google and Akamai – to repair a dysfunctional interconnection market. The French interconnection market of the late 2000s comprised a dysfunctional collection of small, poorly managed IXes that fragmented the market. At its peak there were a total of nine small, many 'free' IXes in the Paris region, fragmenting the market among providers with poor service response times and frequent outages. In short, interconnecting in Paris created unnecessarily high transaction costs.

The interconnection community needed to create an IX platform that would not further compound fragmentation and that would garner critical mass quickly. A group of credible industry actors, initially led by Google and Jaguar Networks, and later joined by representatives from Neo Telecom, Akamai and Interxion

(1) solicited community perceptions of interconnection to gauge demand for a new IX; and
(2) leveraged their access to resources necessary to build an IX that could meet market demand in terms of both capacity and professional services.

To gauge demand, they developed a survey that asked the following questions, paraphrased here:

(1) Are you happy with the state of the interconnection market in Paris?
(2) Would you be interested in a carrier neutral IX?
(3) Would you be interested in a data centre neutral IX?
(4) Would you pay for a professionally run IX?

Sent to approximately 200 peering coordinators around the world, approximately 70 percent of respondents indicated that yes, they would pay for a professionally run, associational membership IX in Paris. In December 2009 France-IX came online, with nodes at

Telecity, Interxion and Telehouse data centres. France-IX absorbed a number of the smaller IXes; most of the others have ceased operations.

The France-IX story is compelling as an illustration of the value of association membership IXes, but also as an illustration of how a combination of firms contributed to its development and success. Google and Akamai are both global firms, each with their own content delivery networks. Neo Telecoms and Jaguar Networks are both French providers of dark fibre, cloud services, and data centre operations. Along with Interxion, these actors represent diversity in both the interconnection industry (content delivery, facilities and hosting services) as well as geographic diversity (two global firms and two French firms). Not only did the founding firms contribute, but they also crafted governance rules that purposefully staggered board elections in a way that further ensured a balanced board.

France-IX is also an illustration of innovation in mutuality. In contrast to strategic decisions being taken to the membership before development, the founders intentionally created a 'forgiveness over permission model'. France-IX, as a firm may take strategic decisions on its own, but it is still accountable to the collective membership, which retains the right to monitor, revoke and/or modify those decisions. The intent is for the France-IX firm to have the agility of a commercial firm, but retain its accountability to its membership – it has control, but that control is not unchecked.

3.2.3. CABASE

CABASE (Cámara Argentina de Internet) started in 1988 as the ISP association of Argentina, and in 1998 it formed the CABASE IX as an associational membership IX provider. In contrast to most IX providers, CABASE's 30 platforms cover most of Argentina and are interconnected into a single interconnection fabric. Most IX providers do not interconnect their platforms at this scale. The historical premise of an IX is to keep local traffic local. That said, CABASE has chosen to create an economy-wide interconnection platform, facilitating interconnection among any participants at any of the nodes within its platforms. As an instance of consolidation, it is another instance of an associational membership IX, whose growth is driven by industry demand to both grow its national interconnection market while also lowering barriers to entry.

In terms of improving access, CABASE is especially interesting for two of its operational cost sharing strategies related to inter-platform connectivity and content delivery. In the first case, the costs of connectivity between IX platforms within CABASE is shared in a way that *incents* new participants to join. Each IX platform has distinguished carrier members that provide transport *between* platforms. Transport costs follow a common economies of scale pricing scheme: the cost per unit volume decreases as the volume contracted increases. Rather than each (potentially relatively small) participant at each platform paying the cost corresponding to their *individual* traffic volume to reach other platforms, CABASE contracts with carrier members to aggregate each platforms' inter-platform traffic, charging participants the (lower) rate corresponding to the aggregate volume of the platform. For potential platform participants, especially smaller participants, this creates a substantive incentive to join the IX. Further, this also creates network effects: the more participants, the greater the traffic, and, for individual participants, the lower the transport rate.

The second cost sharing model, filling content delivery caches, illustrates both the value of CDNs to the IX and the role of the IX facilitating lower cost access to content. In the absence of either an interconnection option with a CDN cache on the IX platform or a cache in the participant's network all the (redundant, high demand) content from a CDN would typically be delivered via transit.[27] Given the high volume, costs and latency involved in transit, this is a suboptimal solution. CABASE's solution is to create an opt-in 'cache participant' model that distributes the costs of filling CDN caches among the cache participants. For CDN caches hosted by a participant that has opted into the model or a cache directly connected to the IX, CABASE distributes the transit costs of filling a given cache among the participants based on the proportion of overall cache-to-participant traffic each consumes. For CABASE participants, in conjunction with inter-platform transport cost sharing, the cache-fill cost sharing model further reduces the costs of accessing both local and global content.

3.3. From norms to diversity

The role of associational membership IXes governance norms, both in the abstract and in the cases above, illustrate the different kinds of consolidation and the implications for how platform management and governance affects access to markets and the opportunities to innovate. In each of these cases above, platforms further consolidated to improve access to interconnection markets. In contrast to single, commercial firms leveraging control to buttress their control over market access, and potentially privileging their own products, associational IXes leveraged their control to expand market access. The next section illustrates this dynamic empirically, highlighting how this improves small and medium-sized actors' access to interconnection markets and hosting and content delivery as some of the key building blocks for effectively engaging in the Internet economy.

4. Diversity and access in interconnection platforms

To characterise the dynamics described qualitatively in the previous section, this section presents the diversity metric as one way to quantify access to and diversity facilitated by IX platforms. The generally accepted norm among IX providers is that a metropolitan area should be served by one, or at most two (for instance London) interconnection providers. As illustrated by the France-IX case, a diversity of IX platforms and providers in a given metro is counterproductive: it fragments the market, increasing transaction costs for network participants and undermines the efficiency and efficacy of interacting with a single, professionally run provider. Stated as such, a *superficial* analysis would indicate that IX providers are metro-level monopolies that are consolidating access to interconnection options. Technically, this is the case. That said, as developed in Section 3.1's discussion of IX norms, associational membership IXes are kept in check by both the collective membership and their boards.

This section presents a high level model of the diversity and distribution of network actors within the IX ecosystem. In particular, it illustrates the diversity and distribution of GAFAM and other CDNs' caching infrastructures.

4.1. Diversity metrics

Interviews with peering managers (from various categories and sizes of networks) and IX leadership and operators refer to network effects in terms of the 'gravity' or 'stickiness' of an interconnection platform. A 'high gravity' IX platform comprises participants that a large number of actors would like to interconnect with – in particular, large access networks and content providers. An interconnection platform is 'sticky' in the sense that, once a participant invests in relationships on that platform critical to its value proposition, it does face increased exit barriers. These colloquial industry references speak to a combination of network effects and lock-in. This is different than lock-in to a single application-layer platform provider (such as the Amazon Marketplace or the Android platform) as the exclusive gateway to a particular market. The diversity metrics show that, *across* metro regions, participation in platforms managed by different providers provide multiple, redundant entry points (discussed below) into the interconnection market. In effect, networks do have choices and are not necessarily beholden to a single IX provider.

The diversity metrics presented here improve the understanding of which interconnection platforms are 'high gravity' and what contributes to that characterisation.[28] Among interconnection platforms, two very simple metrics are used to highlight the value of an interconnection platform: the number of participants and the volume of traffic exchanged on that platform. While these are useful initial indicators, the number of participants does not always mean high gravity. For instance, as noted earlier, a platform comprising only one side of the market, either eyeballs or content, is not especially high gravity (or diverse).

The current diversity model asks the following questions:

(1) Which interconnection platforms are 'high gravity'?
(2) What contributes to the gravity of these platforms?
(3) Which participants significantly contribute the gravity of a platform?

Diversity metrics build on two (ideal form) strategic objectives of networks' decision making processes: uniqueness and redundancy. When optimising for *uniqueness*, a network is attempting to identify platforms with participants they can only find on those platforms, or on a select few platforms – i.e. those unique to a relatively small set of platforms. When optimising for *redundancy*, a network is seeking platforms with participants with which it already has a relationship elsewhere – i.e. it is seeking to add reliability and redundancy to a valued business relationship.

To clarify these metrics, Table 1 lists the top 30 networks, ranked by their diversity metric scores. *Topological diversity*, or simply *participant diversity*, is based on the number of participants in an interconnection platform, but weights those participants based on how many *different* platforms any given participant engages in. The *diversity score* of a given *network* is the number of unique interconnection platforms that network participates in; for instance, if an ISP in the UK participates in the London Internet Exchange (LINX) and LONAP (another IX platform in London), as well as LINX platforms in Manchester and Scotland, that ISP has a diversity score of 4. The diversity score of a given *interconnection platform* is the sum of the diversity scores of all the networks participating on that platform.

The intuition attempts to follow the community's notion of high gravity, namely that a network that carries traffic or routes valuable in many local and regional markets (such as a

Table 1. List of the 30 most diverse networks, ranked by their diversity score.

	asn	participant_name	diversity
1	6939	Hurricane Electric	106
2	15169	Google	93
3	20940	Akamai Technologies, Inc.	92
4	3856	Packet Clearing House (PCH)	84
5	42	Packet Clearing House (PCH)	78
6	8075	Microsoft	72
7	13335	Cloudflare Inc.	67
8	22822	Limelight Networks UK Ltd.	60
9	10310	Oath (EMEA) Limited	54
10	32934	Facebook UK Ltd	50
11	16509	Amazon	45
12	26415	VeriSign Netherlands BV	42
13	15133	EdgeCast Networks	38
14	2906	Netflix Streaming Services International B.V.	36
15	43531	IX Reach	31
16	7713	Telin	29
17	6461	Zayo Group	28
18	6507	Riot Games Ltd	27
19	24482	SG.GS	25
20	36692	Cisco Systems Ltd	25
21	3303	Swisscom PLC	24
22	9002	RETN Ltd.	24
23	13030	Init7 (Switzerland) AG	24
24	15412	Global Cloud Exchange	24
25	20144	CZ.NIC (ICANN L-ROOT)	24
26	44444	Forcepoint Cloud Limited	24
27	1273	Vodafone Limited	23
28	4637	Telstra International Limited	23
29	14026	Simet	23
30	112	RIPE NCC	22

CDN, a large ISP or a gaming network) is more attractive to a wide range of other participants and should contribute to the overall platform diversity more than those whose traffic is in less demand. Table 2 provides a sample of platform diversity measures and is discussed in Section 4.3. As such, it contributes more to the network effects of the platform than others. That said, this is a simplification – a network whose traffic and routes are in high demand, in *particular* local and regional IXes, may have relatively low global demand such as language specific content provided by local CDNs or online government services.

4.2. Individual participant diversity

To illustrate participant diversity, Table 1 shows the 30 (of 8760) networks with the highest diversity scores, as calculated based on data from the IX-F IXPDB. For those familiar with the interconnection landscape, there are a number of familiar faces (ASNs) in Table 1. The network with the greatest diversity is Hurricane Electric (HE), a transit and transport provider specialising in IPv6 connectivity. HE is especially illustrative because it has embraced an interconnection strategy focused on diversification through interconnection at IXes – it has also been a longstanding supporter of the development of associational membership IXes. With the exception of Packet Clearing House[29] and Verisign (a DNS infrastructure provider) the remaining top 2–14 networks are engaged in distributed hosting and/or content delivery.

Table 2. List of the top 30 platforms, ranked by their platform diversity score. `count` is the number of participants at a given platform. `part_rand` is the simple ranking of the platform based on number of participants. `plat_div` is the diversity score for the platform. `div_rank` is the rank of the platform based on its diversity score.

count	part_rank	plat_div	div_rank	platform_name
862	1	5563	1	DE-CIX FRA
837	2	5409	2	AMS-IX
776	3	5065	3	LINX LON1
356	8	2854	4	France-IX Paris
366	6	2840	5	Equinix Paris
360	7	2314	6	LINX LON2
159	26	2144	7	Netnod – Stockholm
333	11	2118	8	SIX
208	16	2092	9	DE-CIX NYC
355	9	2050	10	Equinix WA IX
150	28	2040	11	Equinix Ashburn
257	14	1943	12	MIX
340	10	1941	13	NAPAfrica IX Johannesburg
204	18	1920	14	LONAP Network
455	5	1851	15	msk-ix
129	33	1742	16	NYIIX
190	20	1728	17	Equinix Zurich
224	15	1609	18	TorIX
105	41	1607	19	ECIX-FRA
331	12	1604	20	NL-ix
183	21	1559	21	SwissIX
150	27	1549	22	Terremark
102	44	1523	23	Equinix Palo Alto
100	47	1497	24	BCIX
128	34	1463	25	DE-CIX MAD
162	24	1445	26	NIX.CZ
90	57	1400	27	Equinix Chicago
147	29	1387	28	CoreSite – Any2 Los Angeles
98	49	1374	29	INEX LAN1
95	53	1339	30	Equinix San Jose

Among the most diverse networks, Google ranks 2, largely driven by YouTube delivery, but, as noted before, it also provides more general purpose CDN services to its Google Compute Engine and Google Store clients. Akamai, one of the oldest and arguably one of the most general purpose of the CDNs, ranks 3. Like HE, Akamai's network strategy team has been a significant supporter of the IX development, supporting engineers on the boards of the LINX, AMS-IX, and its support of the development of France-IX and later as a board member (Section 3.2.2). Cloudflare, ranked at 7 in this data set, is, as noted earlier, one of the newest entrants in the CDN market.[30] Cloudflare's network strategy team has been exceptionally supportive of the development of associational membership IXes around the world; see Cloudflare (2019). Similarly, Limelight, another general purpose CDN, ranks 8. Oath, formerly Yahoo! and now a Verizon company focused on brands and advertising, inherited Yahoo!'s diverse interconnection portfolio. Facebook ranks 10, its interconnection portfolio driven largely by its internal CDN services supporting the delivery of its social network content. Facebook, and social network content caching in general, is a good fit for the IX ethos of keeping local traffic local, and keeping local social network content cached proximate to the physical locations of participants in those social networks. Finally, Amazon ranks 11. It is also notable that Apple is not as

highly ranked as expected. Recently, Apple has shifted its interconnection portfolio supporting its CDN from IXes to colocation.

Considering the remaining actors in Table 1, these represent a diverse types of actors. Verisign, one of the largest DNS services providers, along with another DNS service provider, CZ.NIC, are also present. EdgeCast is a CDN provider. Global Cloud Exchange provides overlay networks and connectivity to cloud hosting services. Forcepoint provides enterprise cybersecurity, in particular for this context, secure connectivity to cloud services. A number of transit and transport networks are also present. IX Reach, as the name implies, provides transport services specialising in facilitating connectivity to IXes. Zayo, RETN and Telstra are all large network service providers, offering transit and transport services. Returning to the application layer, Riot Games has invested in IX connectivity as one way to improve stability and quality of experience for end users on its gaming platform.

4.3. IX Platform diversity

Table 2 illustrates the ranking of IX platforms in terms of platform diversity. In terms of diversity and one of the conventional measures of a platform's 'gravity', the number of participants (`count`), for diversity rankings (`div_rank`) past 3, the rank based on participation (`part_rank`) and the diversity ranking (`div_rank`) begin to diverge. The top three IX platforms in terms of diversity (DE-CIX FRA in Frankfurt, the AMS-IX in Amsterdam, and the LINX in London) fall into the category of global IX platforms, those that comprise a large number of participants with global reach. That said, most of the IXes listed in Table 2 arguably qualify as global markets for infrastructure services within their region.

For those familiar with interconnection and infrastructure services markets, the platforms present on this list is not surprising.[31] The top three are some of the oldest, most established IX platforms in Europe. France-IX has steadily risen in the ranks, in part due to how it was created. DE-CIX NYC is an even more recent edition, surpassing the more established NYIIX in both diversity and number of participants. Further note that, with the exception of msk-ix (Moscow) and NAPAfrica IX in Johannesburg, the remaining platforms in the top 30 are in North America (TorIX, in Toronto, is the only Canadian IX listed) or Europe. This pattern is in part due to the path-dependent character of Internet development in the US and Europe, but also because this particular diversity calculation is skewed to the global interconnection market. As will be illustrated in the next section, similar regional diversity trends can also be seen in regional IXes such as IXBR in Brazil and within the set of IXes in India.

4.4. An integrated view of interconnection diversity

Figure 1 illustrates a more complete view of global diversity. As discussed earlier, one commonly cited (but not universal) prerequisites of a successful IX is the presence of a CDN. The red and yellow ranges shown at the top of each of the bars in Figure 1 illustrate this trend. Recall from Section 4.2 that GAFAM (minus Apple) and a number of other hosting and content delivery platforms, in particular CDNs discussed in this work, fall into the red and orange ranges of Figure 1. In many of the high diversity platforms, the depth of the red to yellow transition in the bars represent a mix of high diversity participants.

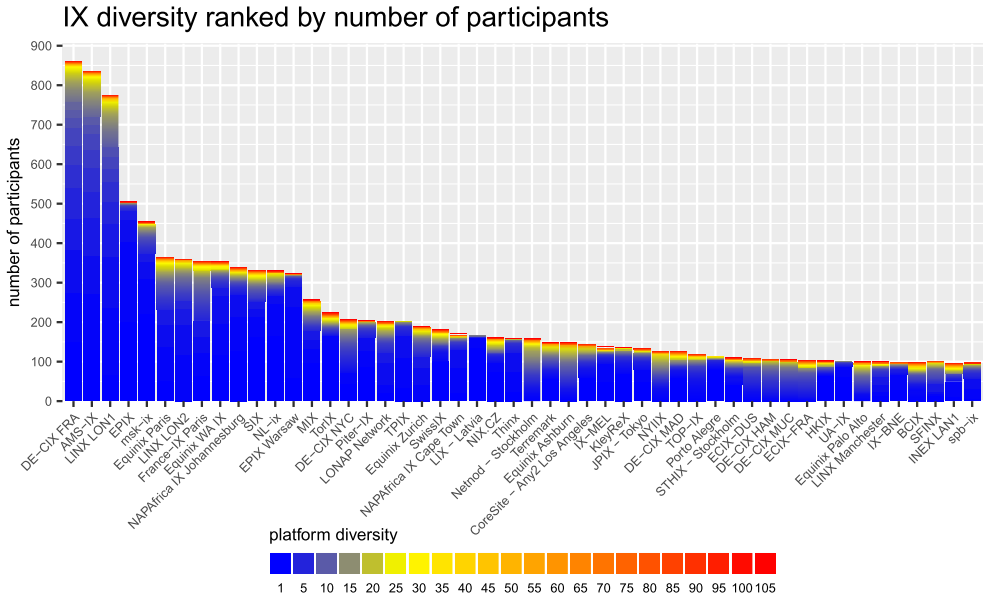

Figure 1. Visual depiction of IX platform diversity in terms of the diversity of its participants. In this depiction, the top 50 IXes (by number of participants) is presented. The height of each bar is the number of participants. The colour range within each bar represents the distribution of diversity scores of participants.

Also notice that, ranked by number of participants, these distributions also illustrate relatively low diversity platforms, for instance EPIX (both platforms, in Krakow and Warsaw), Piter-IX (Russia), TPIX (also in Warsaw, Poland), LIX (in Latvia), Thinx (also in Warsaw, Poland), IX-MEL (Melbourne, Australia), KleyRex (Frankfurt, Germany), JP-IX (Tokyo, Japan), Porto Alegre (Brazil), HKIX (Hong Kong) and UA-IX (Ukraine). While many of these are in Europe, and the prevalence of Polish IXes may imply a fragmented market similar to Paris in 2008, a number of these are also in regions outside of North America and Europe. In each of these cases, the distribution of participant distribution is skewed towards low diversity participants. Again, it is important to note that these are *global* diversity scores; for many of these networks, it may not be necessary to develop an interconnection portfolio outside of their local economy. In many cases, access to hosting and content platforms is sufficient to ensure access to popular global content, while the remainder of local and regional content is produced by other, equally (relatively) low diversity participants that also participate on the IX platform.

While these low diversity platforms may not rank as high as those with a greater number of high diversity participants, higher diversity participants are not completely absent. With the exception of the LIX in Latvia and the UA-IX in the Ukraine (counterexamples to the common assertion that CDNs are a strong prerequisite), all of the other relatively low diversity platforms in Figure 1 have some number of both middle range diversity participants (the yellow to orange range) and some number of high diversity participants. This follows the argument that even a smaller number of high diversity participants still create value for local and regional participants. Even though there may not be as much competition among these hosting and content delivery platforms, their presence

does indicate they value these markets. Further, this also indicates there is demand for these services in those regions, that local and regional players are benefiting from some reduced costs for traffic that would otherwise have been delivered via transit.

4.5. Global diversity in Brazil and India

To illustrate diversity in particular economies, the following briefly describes platform diversity in India and Brazil. Figure 3 illustrates participant diversity in India. Among the high diversity participants, Google, Microsoft, Facebook and Netflix are present at AMS-IX India, accounting for the relatively larger proportion of high diversity participants on that platform. At the NIXI platforms, the high diversity actors are Telstra (an international transit provider), and two Indian firms, Bharti Airtel (a mobile service provider in India) and Sify (a network services provider). Among the lower diversity participants are various local ICT firms and local access network providers (Figure 2).

The difference in participant diversity between AMS-IX India and NIXI is not surprising. NIXI, the National Internet Exchange of India, has had a troubled past, limiting the interconnection options available to its participants. Although it was developed with the support of the Indian government, these limitations, in particular control over networks that may diminish incumbent marketshare, meant that NIXI was not appealing to transnational networks. Interviews indicated that this was a direct consequence of incumbent transit providers' influence (control), skewing the platform to serve their interests over broader access that would have facilitated local actors' lower-barriers to access to those providers' competition. In contrast, AMS-IX (as a provider) is a well-known associational membership IX and *does* enforce the IX norms that enhance market access. Moreover, it has pre-existing relationships with a large number of high diversity participants (as illustrated in Figure 1). Along with its track record for provisioning a well-run, stable

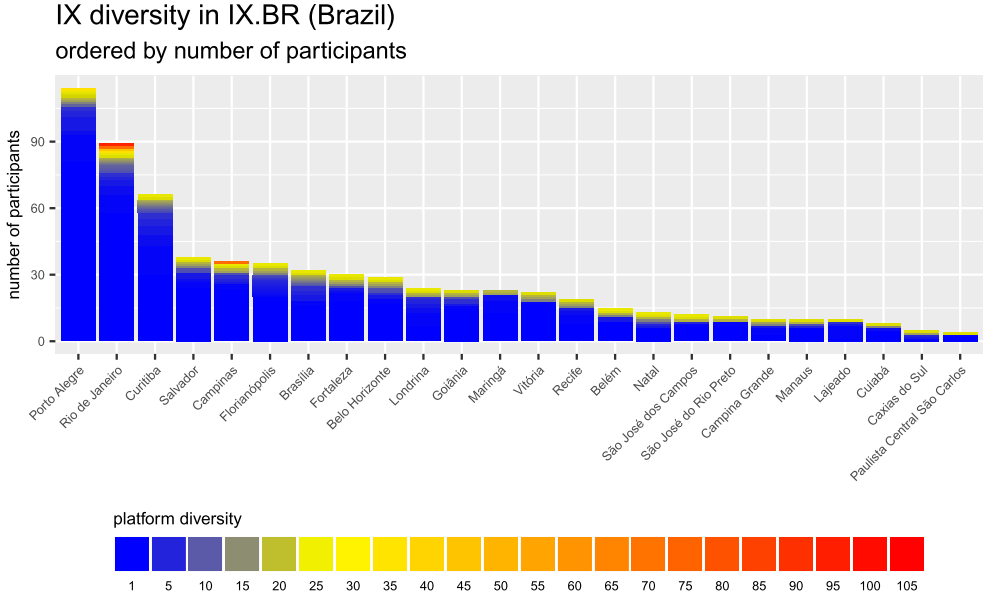

Figure 2. Participant diversity within IX platforms in IX.BR, the IX provider in Brazil.

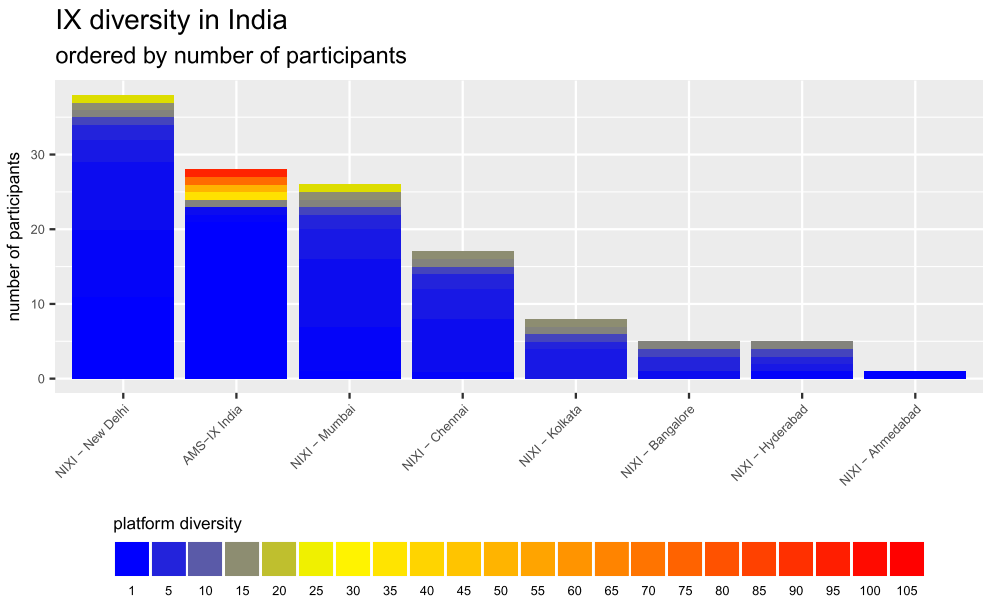

Figure 3. Participant diversity within IX platforms in India.

interconnection platform, it was able to introduce more high diversity actors to the Indian market (Figure 3).

Figure 2 illustrates participant diversity in Brazil, in particular, participant diversity in Brazil's primary IX provider, IX.BR. In terms of norms, IX.BR is a hybrid provider, supported in part by industry and in part by Brazil's government. Among the familiar high diversity actors discussed in this work, Google, Microsoft, Amazon and Netflix are distributed across the Rio de Janeiro and Campinas platforms. The other high diversity actors are CZ.NIC (providing DNS services) and Simet (a network measurement tool). Among the other medium diversity networks (diversity between 5 and 25) are transit providers such as GVT, the research and education network RNP and telecommunications provider Oi.

Within both of these economies, the platform and participant diversity illustrates the role of IX platforms facilitating smaller actors with access to both hosting and content platforms as well as local infrastructure providers. This mix of levels of deployment of GAFAM platforms and local interconnection relationships seem to imply that, in terms of interconnection markets, consolidation is not having a substantive impact. That said, this does not necessarily mean that the effects of 'technology kill-zones' discussed earlier are not limiting investment in application-layer services.

5. Conclusions

The Internet Society has argued that consolidation is reshaping how businesses and end-users engage in the Internet economy. In some cases, consolidation has created positive effects, giving small to medium-sized actors unrivalled access to operational capabilities and markets otherwise out-of-reach to all but the largest firms. In others, platform managers have leveraged control over these platforms to pursue their interests, to the

detriment of third parties, damaging both competition and innovation. While the Internet Society argues that the effects of consolidation *are* evident at multiple levels, more study is necessary to unravel the complex interdependencies necessary to evaluate whether those effects are good or bad (Internet Society 2019, 4–5).

The media's focus on evidence of anticompetitive practices at the application-layer tells a different story. These analyses agree that GAFAM has developed platforms that facilitate unrivalled access to markets such as e-commerce and mobile applications. Critics argue GAFAM is abusing its control of these platforms, distorting the attendant markets to prioritise their own products and services over third parties. Further, critics also attribute some of this power to GAFAM's control of a number of dominant lower layer platforms, in particular hosting and content delivery.

Application-layer platforms do warrant scrutiny, but to understand the implications of application-layer consolidation for lower layer platforms, requires a more nuanced analysis of how and whether these actors' influence and control can create the same market distortions as alleged at the application-layer. More specifically to this work, how does the alleged abuse of application layer consolidation and control affect the opportunities for innovation attributed to the Internet's historically open and generative architecture? This work has argued that the resources and opportunities for innovation, rooted in the *leverage* and *accessibility* facilitated by hosting and content platforms, and arguably enhanced and expanded by interconnection platforms, *does persist*, even in the face of application-layer consolidation. Hosting and content platforms do lower the-barriers to development and global deployment that would be otherwise out of reach of small- and medium-sized innovators. Moreover, while GAFAM-managed hosting and content platforms do hold substantive market-share, there are also a number of non-GAFAM hosting and content platforms that also have substantive regional and local platform diversity, presenting local and regional innovators with viable alternatives and competition. That said, dominant hosting and content platforms not only remain critical building blocks in the modern Internet economy, but also play a substantive role in promulgating associational membership IX platforms that both rationalise and expand access to diverse interconnection markets, further lowering the barriers to development and deployment by small and medium-sized actors.

The key differentiator is how the governance managements of platforms limit abuses of control that allow for anticompetitive practices. Here in particular, the abuses of platform controls that allow for the prioritisation of a platform manager's goods and services over third parties that rely on that platform for access to markets. The use of application-layer platform controls managed by a single actor are relatively opaque, with anticompetitive harms coming to light after the fact. Further, as presented in Section 2.2, these actors do have incentives to privilege their own products within these markets over those of third party competitors. In contrast, the collective management of associational membership IXes illustrate that single platform providers *can* manage equitable markets. Governance norms imposed by the collective participants effectively create and enforce oversight mechanisms that curtail controls that distort the market to prioritise select participants or limit access to interconnection markets. In particular, neutrality and non-compete norms fundamentally preclude the kinds of anticompetitive practices currently levied at application-layer platforms.

IX participants' visibility into and oversight over how the platform is managed is a key element of the accountability engendered in associational membership IX norms. Among association membership IXes, participants are network operators that have sufficient visibility into and willingness to share information about IX operations to identify provider behaviours that violate IX norms that sustain effective economic and market structures. In effect, they have the capabilities and capacity to effectively monitor the platform. GAFAM critics suggest that application-layer platforms have little accountability for how they leverage platform control mechanisms. Moreover, unlike participants on associational membership IX platforms, application-layer platform participants do not have access to the kinds of controls being used and to what end. In terms of controls on data collection, the platforms are opaque – beyond effects-based indicators such as alleged predatory pricing – neither external observers, nor participants can see precisely how data collected is used, and whether it is being abused, or if it is being confounded with strategies for developing critical mass by being a loss-leader. Search prioritisation outcomes are more observable, but absent evidence of precisely how platform control mechanisms are being used to collect what types of data, it is difficult to identify potential incentives to limit those abuses. In effect, without an authoritative external impetus, it is unlikely that application-layer platforms will commit to credible accountability mechanism.

Before diving into the pros and cons of possible solutions, the ideal criteria for such a solution is presented. The insights from associational membership IX platforms do not solve the problems of consolidation writ broadly, nor are they directly transferable to technology giants that control dominant application-layer and hosting and content platforms. They do suggest a template at one end of the regulatory spectrum that illustrates the kinds of capabilities and accountability mechanisms necessary to effectively regulate, while retaining the benefits of economies of scale. The objective of such a solution is to preserve the current economies of scale, but facilitate the kinds of oversight and accountability that can reduce the potential for anticompetitive practices and alleged by GAFAM critics. As highlighted by Khan (2017), price-based remedies are appealing because these indicators are, at least in conventional markets, readily available; that said, Khan and others have also shown that these are flawed. Rather, a structural remedy should provide both participants and regulators with insights into platform management and control mechanisms that can be used to identify, and ideally disincent, anticompetitive behaviours, such as the case of Spotify and Apple, predatory pricing by Amazon, and the issues around search bias facing Google. In terms of the capabilities and capacity necessary for this approach, regulators will need to develop the monitoring capabilities necessary to identify anticompetitive behaviours.

One solution is self-regulation. Self-regulation has been the rule since the early days of the Internet, yet the evidence presented by GAFAM critics increasingly indicates this is not working for application-layer platforms. In the current scenario, firms like Amazon (Marketplace), Apple (App Store) and Google (Play Store) are each gateways to those markets, and, in the absence of the credible threat of mandatory regulation, have little incentive to change their behaviour. For governments to make the threat of mandatory regulation credible, they will need evidence of the abuses of platform control mechanisms. As indicated above, given platforms control over this information as well, short of information leaked by a whistleblower, this information is unlikely to be forthcoming. That said, a number of investigations have been launched into the alleged anticompetitive practices

of application-layer platforms. Even if these investigations do surface evidence of anticompetitive behaviour, this does not guarantee either a credible threat of mandatory regulation. A weak penalty requiring GAFAM to change the particularistic anticompetitive practices at hand will not solve the larger problem of unregulated control.

Another potential family of solution is divestiture. As highlighted earlier, while application-layer platforms do warrant additional scrutiny, hosting and content delivery do not have the same control over the markets in which their clients engage. Given the objective is to resolve immediate and future anticompetitive practices in the markets in which they are occurring (Amazon Marketplace and e-commerce), one solution is to disintegrate these businesses from their larger parent firms and impose mandatory regulations on those firms. Despite the interdependent evolution of application-layer and hosting and content delivery platforms, modern architectures cleanly separate these platforms for efficiency and organisational management purposes.[32] For instance, in the case of Amazon, a structural separation of Amazon Marketplace from Amazon AWS would preserve the global reach and economies of scale of both, but diminish potential cross-subsidization of Marketplace by the much more profitable AWS service. This may be less threatening to Google given it has already created Alphabet, creating initial lines of delineation between its 'Google' products (here Google Search, which includes Ads; Google Cloud; and Android). In contrast, a key element of Apple's value proposition has long been the seamless integration across devices and service. While divestiture may sever these platforms from cross-subsidization by the parent firm, reducing their potential as apex predators, a longer term remedy will still require mandatory regulation.

As implied above, a third solution is mandatory regulation of GAFAM, focusing on application-layer platforms. Both effective investigations and mandatory regulation will require regulators to develop a much more nuanced understanding of dependencies between application-layer, hosting and content delivery, and these firms' role in interconnection markets. In particular, despite some reports in the media that couple application-layer abuses with hosting and content delivery dominance as measured by revenue, the hosting and content delivery markets are more nuanced.[33] While this article has provided an initial sketch of these interdependencies and differences, there is substantively more work to be done to paint a more complete picture of these interdependencies. For instance, better understanding of the role of hosting and content delivery for innovation will require looking beyond revenue to differentiate which sizes and kinds of businesses use which hosting and content delivery services. There is some evidence from market analysis firms such as Intricately that highlight key differences between the kinds of firms served by Amazon in contrast to fast growing new entrants such as Fastly and Cloudflare. Despite the disparity in revenue, these differences are additional, significant indicators of market competition necessary for efficient and efficacious regulation. These need to be further informed by improved indicators of market structure. The diversity metrices presented in Section 4 are an initial step to understanding local, regional and global market structures, but, again, more nuance is necessary. For instance, in contrast to the arguments of dominance in hosting and content delivery by the dominant players, there is also evidence of what has been referred to as 'hyper-local' hosting and content delivery services. Ongoing work is further unpacking the diversity metric presented here to develop market diversity metrics that characterise the kinds of value networks present across these platforms, combining automated text-mining and qualitative

(human) validation of platform-client relationships to more precisely characterise local, regional and global markets in the Internet economy.

Notes

1. Microsoft is currently facing scrutiny for its onging anticompetitive practices. It is included here for completeness. This work focuses on the emerging behaviour of Google, Amazon, Facebook and Apple to highlight the growing scrutiny of platform management practices among dominant firms.
2. For an extensive analysis of the relationship between the Internet's architecture and innovation, see van Schewick (2010).
3. The notion of an architecture of control draws on Lessig's framing of architecture as one modality of regulation, alongside markets, norms and law (Lessig 1998, 662–664). For a more extensive treatment, see also (Lessig 1999, 2000).
4. This definition is an adaptation of discussions provided by the Internet Society (2019).
5. Cloud, or distributed, hosting providers lease a client's compute and network resources, often geographically distributed to suit that client's needs. Cloud hosting provides a number of benefits: outsourcing the maintenance of physical resources, flexibility to scale resources up or down and geographic distribution, to name but a few. For a survey of these types of services, see Prodan and Ostermann (2009).
6. Content delivery networks (CDNs) provide the infrastructure necessary to ensure content (media such as video and audio streams; social network content) are as close to consumers as possible, reducing latency and improving end users' experience. For a survey of CDNs see Coileáin and O'Mahony (2015); for a recent review of the complexity of CDNs, see Stocker et al. (2017).
7. There is an extensive literature on the role of intermediaries. When addressing the infrastructures evaluated in this work, especially the application layer, the definition presented by Cotter (2006), citing Leickly (2004, 1), is certainly applicable:

   > An intermediary works as an economic agent who helps buyers and sellers find each other and execute a transaction. Equally important, they help to sort, classify, and distribute market information and goods … Historically, intermediaries found a niche in markets where transaction costs were high, and they served both the buyer and the seller in reducing these costs. Cotter (2006, 68)

   That said, this work focuses on these infrastructures as platforms, the control of which is certainly necessary, but may also be abused, effectively limiting innovation (see in particular the discussion in the next section).
8. In the media, see Smith (2018), The Economist (2018), and Foroohar (2019). In recent work, see in particular Khan (2017) and (Sussman 2019) for critiques of Amazon's pricing practices.
9. As noted earlier, one of the most complete sociotechnical works on the relationship between the Internet's architecture and innovation is van Schewick (2010). This section draws on (Zittrain 2006); see also (Zittrain 2008) as well as Lessig's work for analyses of the role of code as law (1999) and architecture as one modality of regulation and control (1998, 2000).
10. Here, hosting means modern, geographically diverse virtual machine hosting, not simply hosting a web page on a single web server.
11. The canonical instance of this is Akamai, which started as a research project in that Algorithms Group at MIT's Laboratory for Computer Science, was selected as a finalist in the MIT $50,000 Entrepreneurship competition in 1997, was founded by Professor Tom Leighton shortly thereafter, and enabled the online delivery of March Madness for ESPN in 1999, demonstrating the technology's capability to handle historic levels of user demand (Akamai 2020).
12. Gawer and Cusumano (2014, 419), citing Sawhney (1998).
13. Quote from Gawer and Cusumano (2014, 419, emphasis added here), citing (Meyer and Lehnerd 1997; Muffatto and Roveda 2002).

14. Quote from Gawer and Cusumano (2014, 419, emphasis added here), citing (Gawer 2011; Gawer and Cusumano 2002).
15. One articulation of platform constraints can be found in platform developer guidelines. Many of these are framed in terms of user safety, ensuring that applications do not surreptitiously share data without the user or enterprise's consent. For instance, Microsoft's developer guidelines for Windows Defender Application Control, which 'restricts which applications users are allowed to run and the code that runs in the system core', opens with:

> In most organizations, information is the most valuable asset, and ensuring that only approved users have access to that information is imperative. However, when a user runs a process, that process has the same level of access to data that the user has. As a result, sensitive information could easily be deleted or transmitted out of the organization if a user knowingly or unknowingly runs malicious software. (Microsoft 2020)

Apple provides guidelines for the App Store review process (Apple 2020); for users, Apple indicates that:

> The safest place to get apps for your Mac is the App Store. Apple reviews each app in the App Store before it's accepted and signs it to ensure that it hasn't been tampered with or altered. If there's ever a problem with an app, Apple can quickly remove it from the store. (Apple 2019)

As a final instance, Facebook also provides developer guidelines, with topics on user safety, privacy, and consent, but also highlighting Facebook's ability to observe how developer's apps function on the Facebook platform (Facebook 2020). As noted above, these constraints *are* necessary for ensuring end user safety, but they also illustrate the control mechanisms available to application layer platform managers.
16. For a detailed analysis of Amazon's suspected predatory pricing, see Sussman (2019). Khan (2017) makes similar arguments.
17. For instance, in Netflix's early days as a video streaming platform, it contracted three different general purpose CDN platforms to deliver its traffic: Akamai, Limelight and Level-3. See (Adhikari et al. 2015) for a detailed analysis of this architecture and how CDNs use DNS to facilitate content delivery. For each video delivery session, Netflix monitored the performance of each, then selected which was performing the best and selected that one as a way to ensure end user quality of experience. In this case, in terms of platforms, Netflix was a client of three external platforms. In 2012, Netflix announced that it was shifting its streaming traffic to a 'single purpose Netflix content delivery network' called OpenConnect (Savitz 2012). Netflix shifted from using general purpose (external) CDNs to developing its own internal platform specifically for its video services.
18. CDNs do have access to demand information that is useful for resource provisioning necessary to their primary value proposition, but that could also provide similar insights into market segments for which they have a number of competing customers.
19. Sowell (2013) describes the value of participating in IXes in terms of uniqueness and redundancy, developing the diversity metric elaborated later in this section. The small, but growing literature on IXes can be roughly categorised into two groups. The first, and larger of the two, focuses on the technical aspects of Internet routing, traffic, and Internet measurement. Ager et al. (2012) provides the most complete characterisation of a large European IX; select others include (Xu et al. 2004; Augustin, Krishnamurthy, and Willinger 2009; Camilo and Stanojevic 2012; N. Chatzis, Smaragdakis, Böttger, et al. 2013; N. Chatzis, Smaragdakis, Feldmann, et al. 2013; Giotsas et al. 2015; Fanou, Valera, and Dhamdhere 2017; Fanou et al. 2019; Müller et al. 2019). The second group focuses on the economic benefits of IXes; see (Jensen 2009; Kende and Hurpy 2012; Weller and Woodcock 2013; Woodcock and Frigino 2016).
20. For an extensive treatment of these norms, see Sowell (2015, 262–274).

21. This quote is one of the most precise, and concise articulations of mutuality. Of course, every interviewee did not utter this *exact* quote, but, across these interviews, the essential norms of collective decision making and management was consistent.
22. This does not mean that all participants in a given interconnection market participate in the local IX. Successful IXes aspire to attract as many as possible to ensure the platform provides a single point at which to access as much of the market as possible.
23. For platforms spanning multiple data centres, the platform should not rely exclusively on one data centre provider.
24. The platform should not rely exclusively on one transport provider or dark fibre provider for all of the links between disparate facilities.
25. Larger providers often provide redundant peering fabrics, using one equipment provider for one, and a different provider for the other, serving not only neutrality, but also resilience through design and implementation diversity.
26. The case studies presented here are based on interviews and case studies conducted during Sowell's dissertation work. See Sowell (2015, Chap. 6) for additional details.
27. There are exceptions. For instance, a large local network may have the volume to warrant a CDN placing a cache in their network, then charge smaller networks partial-transit to access that cache. The large local network would certainly price its partial-transit below the cost of more general transit, but it is not guaranteed they would charge cost or marginally above cost.
28. For an early, detailed specification of the family of diversity metrics and their relationship to interconnection options, see Sowell (2013).
29. PCH, a nonprofit dedicated to infrastructure development, infrastructure measurement, and supporting the DNS infrastructure
30. Cloudflare has recently expanded its service offerings, introducing transit services for its enterprise customers (Wondra 2019).
31. When the diversity metric was first developed, early rankings were vetted with a number of network strategists from high diversity networks. These actors, and historical documentation of these platforms, confirm that the kind of diversity ranking presented in Table 2 is consonant with their intuition of which platforms are 'high gravity'.
32. Most notably, AWS CEO Andy Jassy tells the story of unintentionally developing AWS as external platform. As Amazon grew in the early 2000's, despite hiring new software engineers, they 'weren't building applications any faster', (Miller 2016). In effect, Amazon's diverse subdivisions were all building their own infrastructure. Upon realising this, Amazon first rationalised this process to develop common internal infrastructures (platforms).

> As the team worked, Jassy recalled, they realized they had also become quite good at running infrastructure services like compute, storage and database (due to those previously articulated internal requirements). What's more, they had become highly skilled at running reliable, scalable, cost-effective data centers out of need. As a low-margin business like Amazon, they had to be as lean and efficient as possible.
>
> It was at that point, without even fully articulating it, that they started to formulate the idea of what AWS could be, and they began to wonder if they had an additional business providing infrastructure services to developers. (2016)

Although not explicitly, Amazon followed an almost canonical path of developing an internal platform for its own efficiency purposes, then realising its potential as an external platform.

33. For instance, Intricately (2019) distinguishes between the kinds of customers a CDN serves (enterprise, mid-market, small- to medium-sized businesses, and those with less than 10 employees); types of CDN and supplementary services (hosting, sercurity, distributed denial of service [DDOS] mitigation), and 'hyper-local' CDNs focusing on regional customer demands. Taken together, while actors like Amazon and Akamai are pervasive, the market is quite diverse.

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References

Adhikari, V. K., Y. Guo, F. Hao, V. Hilt, Z. L. Zhang, M. Varvello, and M. Steiner. 2015. "Measurement Study of Netflix, Hulu, and a Tale of Three CDNs." *IEEE/ACM Transactions on Networking* 23 (6): 1984–1997. doi:10.1109/TNET.2014.2354262.

Ager, Bernhard, Nikolaos Chatzis, Anja Feldmann, Nadi Sarrar, Steve Uhlig, and Walter Willinger. 2012. "Anatomy of a Large European IXP." In *Proceedings of the ACM SIGCOMM 2012 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communication*, 163–174. SIGCOMM '12. Helsinki, Finland: ACM. doi:10.1145/2342356.2342393.

Akamai. 2020. "Company History." https://www.akamai.com/us/en/about/company-history.jsp.

Apple. 2019. "Safely Open Apps on Your Mac." *Apple Support*. https://support.apple.com/en-us/HT202491.

Apple. 2020. "App Store Review Guidelines." *Apple Developer*. https://developer.apple.com/app-store/review/guidelines/.

Augustin, Brice, Balachander Krishnamurthy, and Walter Willinger. 2009. "IXPs: Mapped?" In *Proceedings of the 9th ACM SIGCOMM Conference on Internet Measurement*, 336–349. IMC '09. Chicago, Illinois, USA: ACM. doi:10.1145/1644893.1644934.

Bartz, D., and S. Nellis. 2019. "Exclusive: Antitrust Probers in Congress ask Spotify to Detail Alleged Apple Abuses – Sources." https://www.reuters.com/article/us-tech-antitrust-apple-exclusive-idUSKBN1WJ1Y3.

Camilo, Cardona RestrepoJuan, and Rade Stanojevic. 2012. "A History of an Internet Exchange Point." *ACM SIGCOMM Computer Communication Review* 42 (2): ACM: 59–64. doi:10.1145/2185376.2185384.

Chatzis, Nikolaos, Georgios Smaragdakis, Jan Böttger, Thomas Krenc, and Anja Feldmann. 2013. "On the Benefits of Using a Large IXP as an Internet Vantage Point." In *IMC '13: Proceedings of the 2013 Internet Measurement Conference*, 333–346. Barcelona, Spain: ACM. doi:10.1145/2504730.2504746.

Chatzis, Nikolaos, Georgios Smaragdakis, Anja Feldmann, and Walter Willinger. 2013. "There Is More to IXPs Than Meets the Eye." *ACM SIGCOMM Computer Communication Review* 43 (5): ACM: 19–28. doi:10.1145/2541468.2541473.

Cloudflare. 2019. "What is an Internet Exchange Point? How do IXPs Work?" https://www.cloudflare.com/learning/cdn/glossary/internet-exchange-point-ixp/.

Coileáin, DÓ, and D. O'Mahony. 2015. "Accounting and Accountability in Content Distribution Architectures: A Survey." *ACM Computing Surveys* 47 (4): 59:1–59:35. doi:10.1145/2723701.
Cotter, Thomas F. 2006. "Some Observations on the Law and Economics of Intermediaries." *Michigan State Law Review* 2006 (1): 67–82.
Couturier, K. 2015. "How Europe is Going After Apple, Google and Other U.S. Tech Giants." *The New York Times*.
Creswell, J. 2018. "How Amazon Steers Shoppers to Its Own Products." *The New York Times*.
Facebook. 2020. "Platform Policy." *Facebook for Developers*. https://developers.facebook.com/policy/.
Fanou, Rodérick, Victor Sanchez-Agüero, Francisco Valera, Michuki Mwangi, and Jane Coffin. 2019. "A System for Profiling the IXPs in a Region and Monitoring Their Growth: Spotlight at the Internet Frontier: A System for Profiling the IXPs in a Region and Monitoring Their Growth: Spotlight at the Internet Frontier." *International Journal of Network Management* 29 (2): 1–22.
Fanou, Rodérick, Francisco Valera, and Amogh Dhamdhere. 2017. "Investigating the Causes of Congestion on the African IXP Substrate." *Proceedings of the 2017 Internet Measurement Conference on – IMC '17*, 57–63. London, United Kingdom: ACM. doi:10.1145/3131365.3131394.
Fingas, R. 2019. "Apple's Deal to Sell on Amazon Directly is Crushing Small Resellers by Design." https://appleinsider.com/articles/19/05/21/apples-deal-to-sell-on-amazon-directly-is-crushing-small-resellers-by-design.
Foroohar, Rana. 2019. "Lina Khan: 'This Isn't Just About Antitrust. It's About Values'." *Financial Times*, March.
Gawer, A. 2011. *Platforms, Markets and Innovation*. Cheltenham, UK: Edward Elgar Publishing.
Gawer, A., and M. A. Cusumano. 2002. *Platform Leadership: How Intel, Microsoft, and Cisco Drive Industry Innovation*. Boston, MA: Harvard Business School Press.
Gawer, A., and M. A. Cusumano. 2014. "Industry Platforms and Ecosystem Innovation." *Journal of Product Innovation Management* 31 (3): 417–433. doi:10.1111/jpim.12105.
Giotsas, Vasileios, Georgios Smaragdakis, Bradley Huffaker, Matthew Luckie, and kc claffy. 2015. "Mapping Peering Interconnections to a Facility." In *Proceedings of the 11th ACM Conference on Emerging Networking Experiments and Technologies – CoNEXT '15*, 1–13. Heidelberg, Germany: ACM Press. doi:10.1145/2716281.2836122.
Hanbury, M. 2019. "Amazon is Facing a 'Full-blown' Antitrust Investigation From the Woman who has Fined Google and Apple Billions." https://www.businessinsider.com/amazon-antitrust-probe-eu-margrethe-vestager-2019-7.
Internet Society. 2019. *Internet Society Global Internet Report 2019: Consolidation in the Internet Economy*. Reston, VA: Internet Society.
Intricately. 2019. "2019 Intricately CDN Market Report".
Jensen, Mike. 2009. "Promoting the Use of Internet Exchange Points: A Guide to Policy, Management, and Technical Issues." Technical report 03/09. Reston, VA: Internet Society. https://www.internetsociety.org/resources/doc/2012/a-summary-report-promoting-the-use-of-internet-exchange-points/.
Kang, C., and K. Roose. 2018. "Zuckerberg Faces Hostile Congress as Calls for Regulation Mount." *The New York Times*.
Kende, Michael, and Charles Hurpy. 2012. "Assessment of the Impact of Internet Exchange Points—Empirical Study of Kenya and Nigeria." Report for the Internet Society 20945-144. Internet Society.
Khan, L. M. 2017. "Amazon's Antitrust Paradox." *The Yale Law Journal* 126 (3): 710–805.
Leickly, Bethany L. 2004. "Intermediaries in Information Economies." M.A. Thesis, Washington, DC, USA: Georgetown University.
Lessig, L. 1998. "The New Chicago School." *Journal of Legal Studies* 27 (1): 661–691.
Lessig, L. 1999. *Code and Other Laws of Cyberspace*. New York, NY: Basic Books.
Lessig, L. 2000. *Architecting for Control* . Keynote, Cambridge: Internet Political Economy Forum, Cambridge Review of International Affairs. https://cyber.harvard.edu/works/lessig/camkey.pdf.
LINX. 2015. "History of LINX." https://www.linx.net/about/history-of-linx/.
Meyer, M. H., and A. P. Lehnerd. 1997. *The Power of Product Platforms: Building Value and Cost Leadership*. New York, NY: Free Press.

Microsoft. 2020. "Application Control for Windows – Windows Security." *Application Control*. https://docs.microsoft.com/en-us/windows/security/threat-protection/windows-defender-application-control/windows-defender-application-control.

Miller, R. 2016. "How AWS Came To Be." http://social.techcrunch.com/2016/07/02/andy-jassys-brief-history-of-the-genesis-of-aws/.

Muffatto, M., and M. Roveda. 2002. "Product Architecture and Platforms: A Conceptual Framework." *International Journal of Technology Management* 24 (1): 1. doi:10.1504/IJTM.2002.003040/.

Müller, Lucas, Matthew Luckie, Bradley Huffaker, Kc Claffy, and Marinho Barcellos. 2019. "Challenges in Inferring Spoofed Traffic at IXPs." In *Proceedings of the 15th International Conference on Emerging Networking Experiments and Technologies*, 96–109. Orlando, Florida: ACM. doi:10.1145/3359989.3365422.

Nicas, J., and K. Collins. 2019. "How Apple's Apps Topped Rivals in the App Store it Controls." *The New York Times*.

Prodan, R., and S. Ostermann. 2009. "A Survey and Taxonomy of Infrastructure as a Service and Web Hosting Cloud Providers." *2009 10th IEEE/ACM International Conference on Grid Computing* 17–25. doi:10.1109/GRID.2009.5353074

Satariano, A., and J. Nicas. 2019. "Spotify Accuses Apple of Anticompetitive Practices in Europe." *The New York Times*.

Savitz, E. 2012. "Netflix Shifts Traffic to its Own CDN; Akamai, Limelight Shares Hit." *Forbes*.

Sawhney, M. S. 1998. "Leveraged High-Variety Strategies: From Portfolio Thinking to Platform Thinking." *Journal of the Academy of Marketing Science* 26 (1): 54–61. doi:10.1177/0092070398261006.

Smith, N. 2018. "Big Tech Sets Up a 'Kill Zone' for Industry Upstarts." *Bloomberg.com*.

Sowell, J. H. 2013. "Framing the Value of Internet Exchange Participation." In *Proceedings of the 41st Research Conference on Communication, Information and Internet Policy*, edited by TPRC. Arlington, VA: Telecommunications Policy Research Consortium.

Sowell, J. H. 2015. *Finding Order in a Contentious Internet* (PhD Thesis). Cambridge, MA: Massachusetts Institute of Technology.

Statt, N. 2019. "How Apple's Deal With Amazon Screwed Over Small Recycling Businesses." https://www.theverge.com/2019/5/21/18624846/amazon-marketplace-apple-deal-iphones-mac-third-party-sellers-john-bumstead.

Stocker, Volker, Georgios Smaragdakis, William Lehr, and Steven Bauer. 2017. "The Growing Complexity of Content Delivery Networks: Challenges and Implications for the Internet Ecosystem." *Telecommunications Policy*, Celebrating 40 Years of Telecommunications Policy A Retrospective and Prospective View 41 (10): 1003–1016. doi:10.1016/j.telpol.2017.02.004.

Sussman, S. 2019. "Prime Predator: Amazon and the Rationale of Below Average Variable Cost Pricing Strategies Among Negative-Cash Flow Firms." *Journal of Antitrust Enforcement* 7 (2): 203–219. doi:10.1093/jaenfo/jnz002.

Swisher, K. 2019. "Taming the Apex Predators of Tech." *The New York Times*.

The Economist. 2018. "American Tech Giants are Making Life Tough for Startups." *The Economist*.

van Schewick, B. 2010. *Internet Architecture and Innovation*. Cambridge, MA: The MIT Press.

Weller, Dennis, and Bill Woodcock. 2013. "Internet Traffic Exchange: Market Developments and Policy Challenges." 207. OECD.

Wondra, N. 2019. "Magic Transit: Network Functions at Cloudflare Scale." https://blog.cloudflare.com/magic-transit-network-functions/.

Woodcock, Bill, and Marco Frigino. 2016. *2016 Survey of Internet Carrier Interconnection Agreements*. San Francisco, CA, USA: Packet Clearing House (PCH).

Xu, Kuai, Zhenhai Duan, Zhi-Li Zhang, and Jaideep Chandrashekar. 2004. "On Properties of Internet Exchange Points and Their Impact on AS Topology and Relationship." In *Networking 2004*, edited by Nikolas Mitrou, Kimon Kontovasilis, George N. Rouskas, Ilias Iliadis, and Lazaros Merakos, 284–295. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer. doi:10.1007/978-3-540-24693-0_24.

Zittrain, J. L. 2006. "The Generative Internet." *Harvard Law Journal* 119: 1974–2040.

Zittrain, J. L. 2008. *The Future of the Internet–and How to Stop It*. New Haven, CT: Yale University Press.