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RESEARCH ARTICLE

GAFA's information infrastructure distribution: Interconnection dynamics in the global North versus global South

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Abstract

We analyze public points of interconnection of Google, Amazon, Facebook, and Apple (GAFA) in the global North versus the global South to determine the degree to which their location preferences differ, if at all. We find that there is a statistically significant difference in GAFA locating in the global North versus the global South—a difference based on a country's wealth, specifically as given by per capita GNI. Approximately 38% of countries classified as global North have a GAFA public point of interconnection, while 16% of those classified as global South do. Apple has approximately 92% of its presence in the global North, followed by Amazon (82.5%), Facebook (73%), and Google (72%). Our findings suggest that competition and antitrust policy discussions of digital platforms should include information on the dynamics of interconnection infrastructure distribution, and for that, such information must be available. We also assert that a global consideration of the digital platforms market is necessary.

KEYWORDS

content delivery networks, competition policy, GAFA, global South, internet exchange points

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INTRODUCTION

It typically is accepted that the purpose of competition policy is to improve economic welfare; however, in practice, competition policy impacts businesses and societies in ways that cannot be fully predicted.[1] Economists and lawyers have not come to consensus on the optimal competition policy in practice for a given industry or industry structure. As such, quantification of the production and distribution of goods and services is needed to understand a given market, and to subsequently analyze possible gains and losses that might follow implementation of such policy.

This study focuses on the digital market industry. Few if any markets are more fluid in growth and more dominated by a few firms than that of digital markets. Digital markets are dependent on digital platforms, which serve as infrastructure in which information, goods, and services are exchanged between producers and consumers. These platforms take on a variety of forms. For example, Twitter and LinkedIn serve as social media platforms; YouTube is a media sharing platform; and Uber and Airbnb are service-oriented platforms. The critical element in each of these cases is that the community of users is essential, and without those users, the platform has little value. Amazon, Apple, Facebook, and Google currently are the four dominant platforms in the digital markets industry and consequently, have the greatest impact on the community of users. Collectively known as GAFA, these four digital platforms provide a variety of services built on transnational infrastructures that sustain their leading positions and create a gulf in relation to any new entrants in their markets.[2,3]

Amazon, Apple, Facebook, and Google are at the center of recent antitrust inquiries into potentially anti-competitive behavior in technology businesses (Bourne, 2019; Federal Trade Commission, 2019; Romm, 2019; The US Department of Justice, 2019; US House Judiciary Committee, 2020). In a recent report of the US House Judiciary Committee's Subcommittee on Antitrust, Commercial and Administrative Law, the chairman stated: "These firms typically run the marketplace while also competing in it—a position that enables them to write one set of rules for others, while they play by another, or to engage in a form of their own private *quasi* regulation that is unaccountable to anyone but themselves" (US House Judiciary Committee, 2020). Ciriani and Lebourges (2018) offer an analysis of European and US antitrust approaches to managing these dominant digital platforms. We add to these recent policy debates by including data on infrastructure that to date has been overlooked in the discussions of digital markets, and by expanding the discussion to the global South.

Cases of possible anti-competitive behavior range from the practice of favoring their own products and brands in searches and mobile stores, to the long-term results of acquisition of competitors, which may increase barriers to entry in the market, and also may generate new possibilities of exploiting users' personal data by joining information from different platforms (e.g., Facebook's acquisition of Instagram and WhatsApp, and Google's acquisition of YouTube) (Romm, 2019; Salinas, 2019; Swartz, 2019; Swartz & Owens, 2019). These companies may use their position as platforms to other services to collect data about usage trends of third-party apps and merchants that are utilizing their infrastructure. They then can use that data to inform their commercial decisions. For instance, Amazon can determine when a third-party product is popular and it may start selling the same product under Amazon's own brand, potentially at a lower price. Furthermore, because they work as an infrastructure service, they also may offer more attractive shipping options. In the same vein, Google can determine when a third-party app is attracting more customer interest in its Android mobile operating system, and that information may guide plans of acquisition that reduce the number of new market entrants thereby increasing market concentration (US House Judiciary Committee, 2020).

A missing point in this debate is that of interconnection, which is a key aspect of telecommunication services that traditionally has been highly regulated to avoid anti-competitive practices, but in the internet era is historically regulated by the market, increasingly complicated by the way that digital platforms have evolved. Regulation of interconnection services in the United States began in 1910 when the US Congress authorized the Interstate Commerce Commission to regulate telecommunications. Telephone companies were classified as public utilities or common carriers. The public utilities designation applied to carriers that supplied infrastructure for a public service, and therefore were subject to regulation to protect consumers from market outcomes not in the best interests of social welfare. More recently, an alternative justification for regulation has been put forward, stating that networks should be considered as special infrastructure in need of special regulation.[4] (Jamison & Hauge, 2014) challenge the concepts guiding past regulation of communications services and suggest that technologies and markets differ so greatly from those dominating communication industries in that past, that the traditional constructs no longer apply. This landscape is further complicated by the inclusion of relationships among internet service providers (ISPs) and digital platforms, expanding the original carrier interconnection concerns to this broader arena.

In the global North, recent disputes among ISPs and digital platforms and among ISPs themselves have raised questions about whether state regulation of internet interconnection is necessary, leading authors to defend transparency at some levels of internet interconnection arrangements (Clark et al., 2016). For instance, in legal disputes in the US, Netflix was required to pay Comcast and Verizon to deliver its content to their end users. (Gustin, 2014). In Europe, the French regulator mandated that the US transit provider Cogent pay France Telecom for the amount of data delivered to its network (France, 2012). This novel debate is technically motivated by the massive volume of video streaming traffic from digital platforms. It allows one to see "the power of access providers to impose terms for interconnection and on the important role that interconnection plays in the stability and function of the Internet." (Claffy et al., 2020, p. 7). Conversely, in the global South, governments have increasingly passed regulations (e.g., Bolivia and Mexico), to make interconnection mandatory in part because of the resistance of incumbents to interconnect with competitors (Degezelle, 2015; Mexico, 2014). In this paper, we connect the discussions on interconnection and antitrust by addressing the power of GAFA to inform scholarship on regulation of digital platforms.

The European Union (EU) formally recognized the necessity of guiding competition policy in their digital single market strategy announced in 2015 to account for accelerative technology and the impact of such on markets. This initiative is reflective of the realization that cross-border barriers to online content may negatively impact consumers and businesses alike. Despite creation of EU's digital single market initiative, regulators remain constrained by the difficulty of identifying and defining platforms, and by the impossibility of regulating such platforms ex ante. Instead, they can only admonish dominant companies for abuse of their dominant position (if such abuse is found to exist).

The ongoing debate rests on the ability of current antitrust rules and tools to monitor the business practices of large technology platforms. Currently, obligations placed on platforms are largely related to monitoring content, the appropriate use of customer data, and obligations for data localization rather than focusing on market structure or incumbent dominance.[5] GAFA prospers within this regulatory environment, which likely benefits their consumers while potentially handicapping smaller competitors and their customers.

In the midst of these debates, our goal is to address GAFA infrastructure distribution across the global South in comparison to the global North. We focus on these four companies as the most dominant in the digital market industry to raise reflections on how GAFA's choices of interconnection points may result in unbalanced infrastructural conditions

among ISPs. Specifically, we use empirical data of public internet exchange points (IXPs) and private interconnection facilities where Amazon, Apple, Facebook, and Google are present and available to physically interconnect with other networks to enable worldwide access to their content.

We posit two main arguments. First, our data indicates that GAFA's public points of interconnection have an uneven distribution between the global North and the global South, with lower presence in the South. While it is of interest of GAFA to serve all markets well, we explain the possible implications of their current infrastructure distribution for ISPs, suggesting that to understand GAFA's impact on both global market competition—involving ISPs from the global North and South, and local market competition—involving both smaller and larger ISPs—, interconnection infrastructure should be closely analyzed with antitrust lenses. At a local level, telecommunication companies that provide internet services and continue to be incumbents in their national markets, along with small ISPs, all depend on interconnection with digital platforms and GAFA specifically, to provide their services. The ubiquity of digital platforms and the dominance of some companies globally imply that effective and efficient interconnection among GAFA and telecommunications incumbents and GAFA and small ISPs should not be presumed. At a global level, disparities between the global North and the global South should not be normalized as they generate higher internet costs in the South.

Second, this study should open discussions about the importance of treating interconnection data of digital platforms as a matter of public interest, accountable to antitrust and competition policy. Our study uses data on GAFA's *public* interconnection infrastructure distribution. This data, while original in the antitrust debate, is partial given that there also exists *private* interconnection infrastructure distribution. The incompleteness of our data is both a limitation for the study and the reason for the study to exist. On the one hand, the data we collected is the data that all ISPs can equally access to find where GAFA's public points of interconnection are physically located and interconnect to GAFA globally. On the other, some market participants may have private agreements with GAFA and other digital platforms to place their content servers in private localities; there are no publicly available details about where these specific connections are located and who hosts them. For instance, research in Africa has found that only 37.2% of Google's server caches in the continent are under their own autonomous system number (ASN), which are open to any company to access, while the majority was distributed in third-party ASNs—private actors that may be content delivery network companies (CDNs) or ISPs. While these private commercial agreements with GAFA are common in the digital market, the reflection we want to raise for further research is that they may affect local competition among ISPs when made with telecommunications incumbents and big ISPs and not with small ISPs that do not generate commercial interest due to their relatively small customer base. In this scenario, small ISPs are dependent solely on public points of interconnection. If unavailable in their countries, ISPs face international costs for reaching GAFA's public points of presence. Maintaining interconnection infrastructure as private information veils transparency and obscures competition and antitrust research and policy for digital markets.

The term global South is central to our analysis; global South is a response to previous nomenclatures that implied both hierarchical and evolutionary meanings (Wolvers et al., 2015), such as “Third World” and the developmental discourse, which tacitly suggests the need for “developing” countries to take the same trajectories as “developed” ones (Grosfoguel, 2011). Thus, the global South is a political concept that refers to shared patterns of inequality in the face of globalized capitalist economies. It infers similarities between countries and social groups beyond national borders (Milan & Treré, 2019; Santos, 2012), and allows for a global understanding of disadvantaged social and economic conditions. Consequently, the term “global South” is not tied to geographic regions or hemisphere.

As (Mahler, 2017) wrote, "there are Souths in the geographic North and Norths in the geographic South." In the same vein, the global North is not a reference to be followed. Rather, it is a methodological counterpoint to allow symmetric analyses at a global level.

This paper is organized as follows. We first contextualize the four GAFA platforms and their CDNs in the internet economy. Next, we present our empirical data and econometric models, and then discuss our empirical results. Lastly, we discuss the limitations of our data, and offer the conclusion.

THE ROLE OF GAFA'S CDNS

Although the internet is generally pictured as a virtual medium, it is essentially material, with physical structures and legal jurisdictions defined by national borders (Daskal, 2018; De La Chapelle & Fehlinger, 2016; DeNardis, 2014; Parks & Starosielski, 2015; Starosielski, 2015). To be accessed, global platforms make their content physically available in servers located in data centers worldwide, selected based on their commercial interests and strategic business plans. Basic and essential components of GAFA's infrastructure are the CDNs where they store (cache) their content, bringing it closer to users and facilitating access of ISPs via points of interconnection. ISPs need to reach these CDNs when their clients request any content from them; for example, when a user at home activates an Apple application update, she requires her ISP to reach a CDN where Apple stores that data to complete such action. Similarly, when a user wants to watch an Amazon Prime video, her ISP needs to connect to the infrastructure where that information is available. In this way, CDN locations influence the routes that ISPs will take online and from where-to-where data will circulate. If GAFA's CDNs and the ISP in search of that data are in the same country, city, or even in the same data center, that requires less time to reach the information, incurring less latency, which means better quality of service and lower cost to interconnect. Stocker et al. (2017, p. 1003) write: "Injecting traffic into a terminating access network in close proximity to end-users typically allows the packet to traverse fewer interconnection points that might be vulnerable to congestion". Given how concentrated the global market is around these platforms, ISPs from all over the globe have their costs and quality of services impacted by GAFA's content localization. Ultimately, GAFA's CDN locations matter for defining the flows of information online.

How Internet service providers interconnect with GAFA

At the level of internet infrastructure, ISPs must maximize their connectivity to be competitive; their connection to other autonomous systems with whom they can exchange traffic and reach, in the most cost-effective way, content demanded by their customers is critical. Such connectivity happens primarily through commercial agreements known as "peering," complemented by customer-provider relationships known as "transit."

Peering is a type of commercial agreement whereby a collaborative relationship is established, customarily, with no monetary payment involved.[6] It occurs primarily among ISPs who exchange traffic based on the routes and internet addresses that they announce, or that they know how to reach. Peering occurs also between ISPs and content providers, such as GAFA, as a way to shorten the path and the cost to reach highly-accessed content on the internet, which if not accessed by peering, must be accessed by "transit."

Transit is a customer-provider relationship established with larger ISPs that guarantee the reach of any address and content on the internet. Excepting for tier-1 ISPs (e.g., AT&T or Verizon) that can reach the whole internet through peering agreements among themselves only, tier-2 ISPs of national and/or regional reach and tier-3 ISPs of smaller and of local

reach always need peering and transit complementarity to reach the entire internet. In this context, ideally, they will secure as many peering agreements as possible to reduce the amount they would need to pay to a tier-1 or tier-2 ISP to take their traffic to its destination via transit. As Metz (2001) points out: "ISPs are driven to lower costs, maximize performance, and generate revenue. The choice of where and with whom to peer or transit directly impacts these driving factors" (Metz, 2001). In such a context, the location of peering facilities and GAFA points of interconnection are critical for ISPs' businesses.

Public and private peering facilities are the places at which autonomous systems interconnect physically and logically to materialize their commercial agreements. On the internet interconnection ecosystem, all organizations are identified by a unique number, the ASNs, and are considered autonomous systems operators. While an organization may have numerous ASNs, for peering purposes they usually have a central one. At public peering facilities, known as IXPs, autonomous systems can interconnect with multiple peers at once through a switch device, which is known as multilateral peering. Autonomous systems also can establish a one-to-one interconnection at IXPs, known as bilateral peering, following their own peering and business policies.[7] At private peering locations, only bilateral peering relationships are possible. GAFA presence at IXPs means that they can reach many tier-3 ISPs at once. At private facilities, GAFA commonly connect to tier-2 ISPs to access a larger number of internet clients through ISPs that prefer private facilities and bilateral interconnection only.[8] As we show in the following section, GAFA companies are present in both types of facilities according to their own business policies and preferences.

We contribute to the literature by examining the data on GAFA interconnection and by raising the importance of including internet interconnection commercial arrangements in the discussions of international antitrust regulation. When content providers with market power effect commercial agreements with large ISPs in private facilities, they contribute to establishing a market advantage for such ISPs, given that the ISP that is locally connected to GAFA will have lower costs to reach the highly demanded data. Furthermore, if GAFA are not present in a given public infrastructure, smaller providers are required to interconnect internationally to public facilities as IXPs to reach GAFA's content, which means higher operation costs. As claffy and colleagues point out: "The diverse set of paths connecting two parties may have different performance and economic characteristics. (…) [I]t can make a huge economic difference to the interconnecting parties. (Claffy et al., 2020, p. 12). For these reasons, we suggest that commercial negotiations at the level of interconnection, and specifically GAFA's negotiations, play an important role in the level of competition among ISPs in a given market.

DATA AND METHODOLOGY

To examine the physical points of interconnection of GAFA companies worldwide, we use publicly available data from PeeringDB, which is an online database used to facilitate peering among ISPs and to assist them to find physical locations of content providers located in public and private facilities.[9] PeeringDB is a crowdsourced platform in which ISPs, content providers, IXPs, and private facilities can inform and update their data. Although it suffers from the same reliability problems of any crowdsourced database, it is the most used data set by the peering community and is accredited by researchers exploring its data (Lodhi et al., 2014). Companies benefit from keeping their data updated, as current information facilitates ISPs finding the closest points of interconnection for peering. This investigation shows that PeeringDB, in conjunction with other economic datasets, can also be a valuable source of information for policy scholarship.

The PeeringDB data refers to GAFA ASNs largely known in the community as the main ASNs used for peering with other autonomous systems. The data includes extensive information on each IXP organization, including the name, exact location, media type, and

TABLE 1 GAFA's public and private points of interconnection

GAFA	Points of interconnection at IXPs	Observations at IXPs (including multiple ports)	Points of interconnection at private facilities
Amazon (AS16509)	109	171	111
Apple (AS714)	62	128	60
Facebook (AS32934)	127	273	83
Google (AS15169)	168	212	118
Total	466	784	372

Abbreviations: GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points.

speed, among other public peering exchange data, as well as similar information for all private peering exchanges in which GAFA are present.

Table 1 shows GAFA's 466 public and 372 private global points of interconnection registered at PeeringDB. The column "Observations at IXPs (including multiple ports)" sums total GAFA observations at IXPs; this accounts for the propensity of larger autonomous systems to have more than one router connected at an IXP, mainly for redundancy purposes to avoid data transmission disruptions and to make their data capacity transmission more robust. In total there are 784 GAFA observations at public facilities.[10]

To the peering data we added World Bank demographic data on population by country, per capita gross domestic product and gross national income, literacy rate, life expectancy, fixed broadband subscriptions per 100 people, electric power consumption, and political regime for every country and territory in the world, and Global Freedom Score data, among other related variables. Finally, we included total area and land area data for each country (Freedom House, n.d.; World Bank, 2018; Worldometer, n.d.). We delineated countries by sub-region, region, continent, and finally, global North and global South.

To operationalize the concept of global North and global South for quantitative analysis, we used the World Bank's annual classification of economies as the main source of information. (World Bank, 2018). Its classification has four categories: high income, upper middle income, lower middle income, and low income, based on countries' per capita gross national income (GNI). The income groupings use GNI per capita in US dollars, converted using the Atlas conversion factor.[11] The classification presents a large difference between high-income economies and all others; in our data, those countries identified either as high income or developed are classified as global North and all others as global South. To have the most extensive list of countries possible, we merged the World Bank data set with the United Nations list of 249 countries and recognized areas. The list of countries by global North and global South classification and GAFA presence is provided in the Appendix.

GAFA's points of interconnection distribution

A consistent characteristic of interconnection distribution is the disparate distribution of points of interconnection to GAFA across the global North and global South. We consider the presence of GAFA in IXPs and private facilities, both excluding multiple ports that a company may have to account for redundancy, and including such multiple ports. We also consider public and private facilities separately and then together to have a complete understanding of the distribution of GAFA's points of interconnection worldwide.

Figure 1 charts GAFA location choice in the global North and global South, omitting counts of multiple ports. Apple is the most Northern-oriented company, with approximately 93% of its points of interconnection in the global North. This is followed by Amazon with 84%, Facebook with 75%, and Google with 74% of points of interconnection in the global North.

To help visualize GAFA presence, the maps below show points of presence at IXPs and at private facilities.

Figure 2 quantifies GAFAs propensity for presence in public (IXPs) and private facilities by company. Apple and Amazon present similar proportions of IXPs and private facilities by location; however, Facebook and Google are found more in IXPs than in private facilities in both the global North and global South.

When adding the use of multiple ports (Figure 3), we find in the global South the use of multiple ports is slightly more prevalent than in the global North. These numbers may indicate companies' resilience strategies in the global South that coincide with their more concentrated presence in this region and fewer independent points of interconnection. For instance, if they are dependent on few IXPs in a given country to reach many ISPs at once,

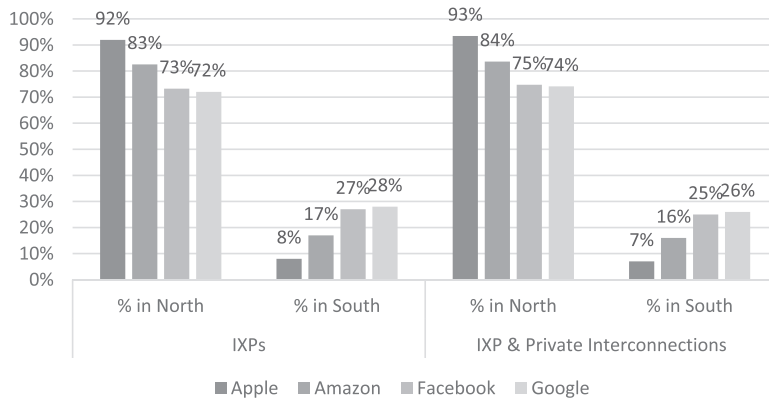


FIGURE 1 GAFA Location by North and South, by percentage. GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points

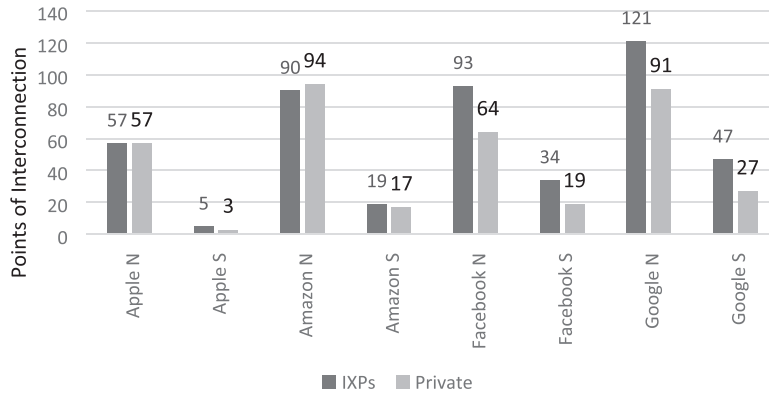


FIGURE 2 GAFA's points of interconnection by global North and global South. GAFA, Google, Amazon, Facebook, and Apple

in the face of a technical disruption, their services may suffer from undesirable instability; having multiple ports is a useful remedy for such difficulties (Maps 1 and 2).

Map 3 illustrates the data in Figure 3, whereby larger circles indicate more duplicate ports.

Empirical analysis

The presence or absence of multiple ports is important to our analysis as we seek to determine similarities and differences across the global North and global South; as such, it is important to test whether the geographic disparity in multiple ports shown in Figure 3 and Map 3 is statistically significant. For this, we utilize a binary probit model in which the dependent variable indicates duplicate presence. Independent variables include an indicator of location, and the GAFA companies:

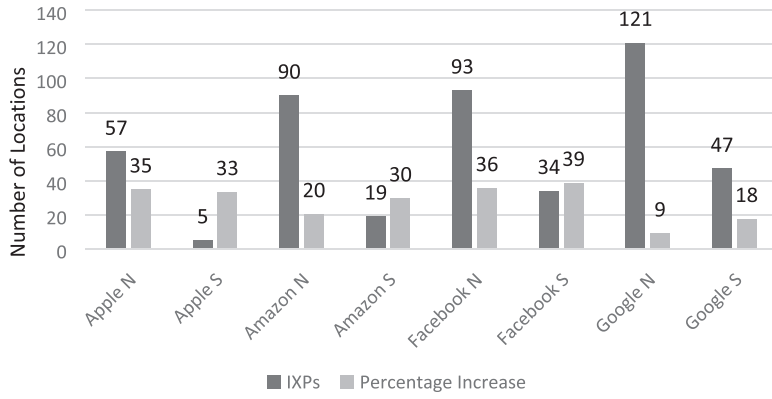
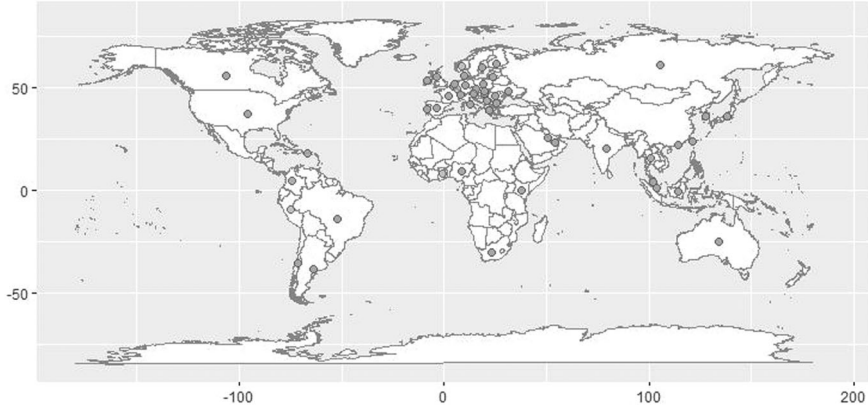
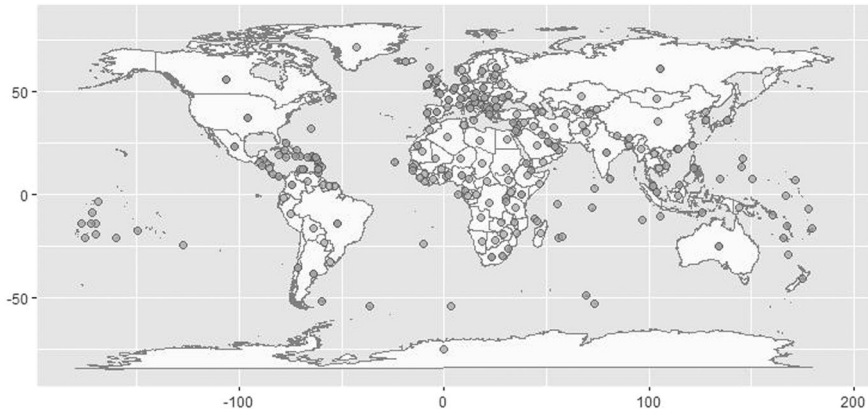


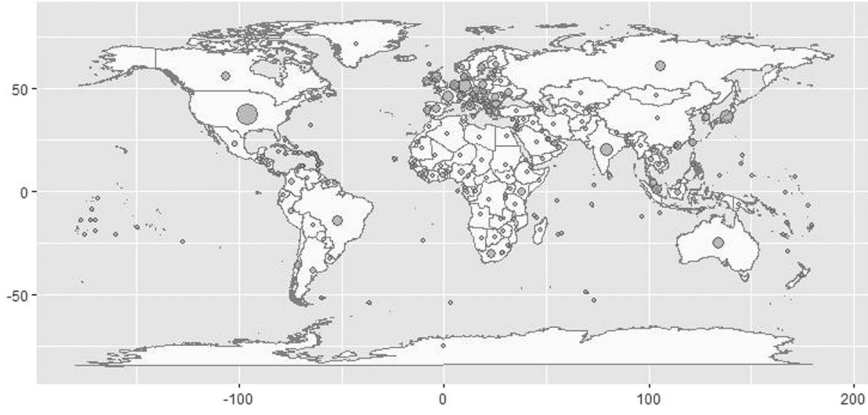
FIGURE 3 GAFA by North and South, with percentage increase for multiple ports. GAFA, Google, Amazon, Facebook, and Apple



MAP 1 Location of GAFA Presence at IXPs. GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points



MAP 2 Location of GAFA Presence at Private Facilities. GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points.



MAP 3 GAFA presence with duplication of ports. GAFA, Google, Amazon, Facebook, and Apple

$$Duplicate_i = \beta_0 + \beta_1 Global \quad North_i + \beta_2 Google_i + \beta_3 Amazon_i + \beta_4 Facebook_i + \varepsilon_i.$$

Duplicate takes a value of 1 if port "i" is a duplicate and 0 otherwise. *Global North* is an indicator variable that takes the value 1 if the port is global North and 0 otherwise. *Google, Amazon*, and *Facebook* are indicator variables that take the value of 1 if a port is accessed by the respective GAFA company, or are jointly zero if a port belongs to Apple in the reference group. The results are given in Table 2, which shows that there exist statistically significant differences in the probability a point of interconnection will have duplicate presence based on global North classification and company.

The computed marginal effects indicate that the predicted probability of a port having duplicate presence was 32% higher when the port was located in the global South. This finding supports our initial descriptive finding that GAFA companies are more likely to have multiple ports at their chosen IXPs in the global South than multiple ports at their chosen IXPs in the global North. Also, Google was least likely to have multiple ports at any given IXP, followed by Amazon, and then Apple.

In addition to having multiple ports at IXPs, as clients of public facilities, content providers may pay for ports of different sizes to transmit their data in these facilities (e.g., speeds of 1, 10, and 100 Gb/s). Table 3 shows the average speed of GAFA's ports in the global North and South; we use this speed as a proxy for the maximum amount of data that can circulate, summing all ports listed at PeeringDB for GAFA companies. Map 4 adds reported speeds to interconnection points globally (note that not all private facilities reported average speed, leaving fewer observations to be included in Map 4).

The port speeds support the notion that Apple and Amazon focus on the information infrastructure in the global North, as their speed is faster on average there than in the global South. Consistent with their higher presence in the global South than their peers, Facebook and Google present a different pattern, with greater speed in the global South (Maps 5 and 6).

Next, we consider GAFA location by continent. Figure 4 illustrates that GAFA's points of interconnection are mostly in Europe, and then in North America and Asia. Africa, Oceania, and South America have far fewer GAFA interconnection points.

Taking population into account yields more striking results. Figure 5 charts the presence of GAFA by continent, and Table 4 provides detailed data.

The totals indicate that while approximately 72% of the population is served in the global North, approximately 34.4% is served in the global South. More than twice as many countries in the global South have no GAFA presence than countries in the global North.

Next, we focused on the five countries in the global North and the five countries in the global South that have the largest GAFA presence (Table 5 and Figure 6). The top number of each cell indicates the total number of IXP and private interconnection points in a given

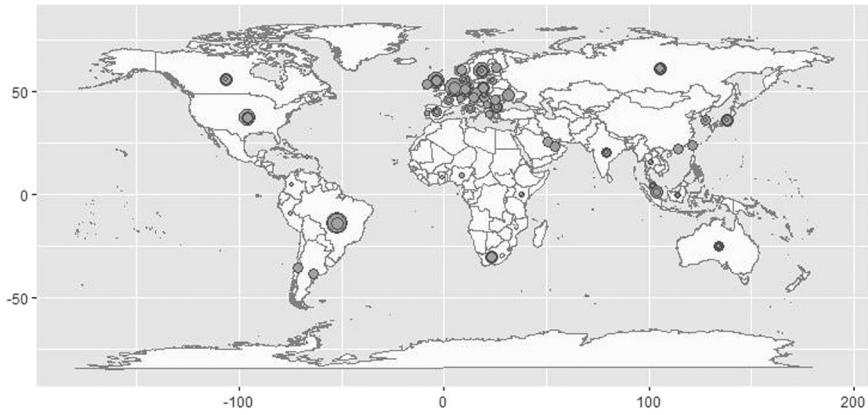
TABLE 2 Probit Model—GAFA use of multiple ports

		Number of Obs.		839
Log-likelihood	**463.306**	**LR chi^2(4)**		**123.03**
		Prob > chi^2		**0.0000**
Duplicates	**Coef.**	**Std. Err**	**z**	***P*>|z|**
Global North	−0.2553	0.1101	−2.16	0.031
Amazon	−0.6234	0.1468	0.00	0.000
Facebook	0.1905	0.1443	0.187	0.187
Google	−1.0609	0.1494	0.00	0.000
Constant	0.1448	0.1022	0.358	0.358

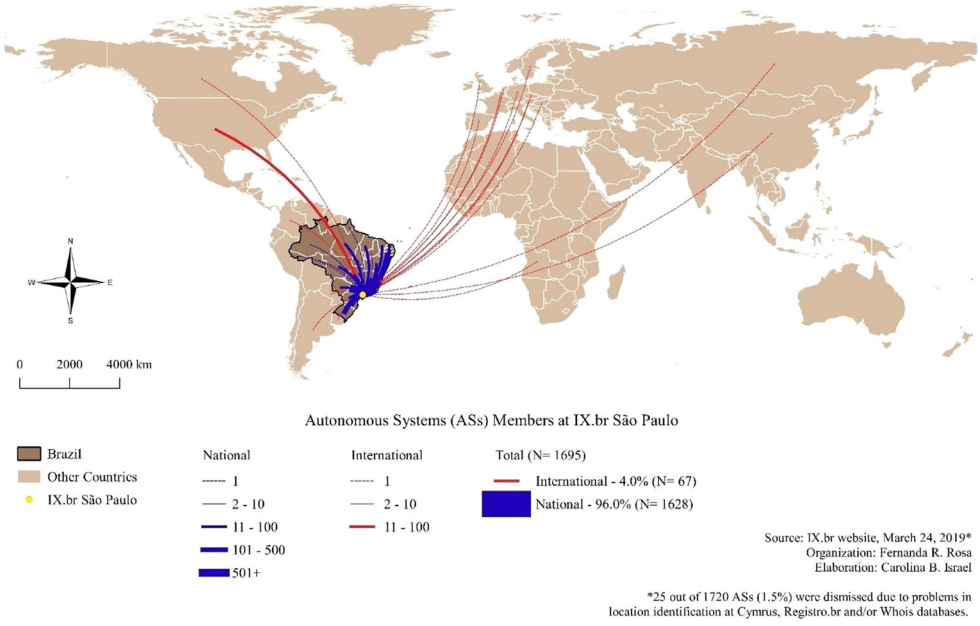
TABLE 3 GAFA average port speeds in the global North and global South

GAFA	Global North average IXP port speeds (Gbps)	Global South average IXP port speeds (Gbps)	Difference
Amazon	93.75	64	N 19% faster
Apple	122.2	64	N 31% faster
Facebook	72.76	88.05	N 10% slower
Google	56.34	81.34	N 18% slower
Average	*83.36*	79.95	

Abbreviations: GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points.



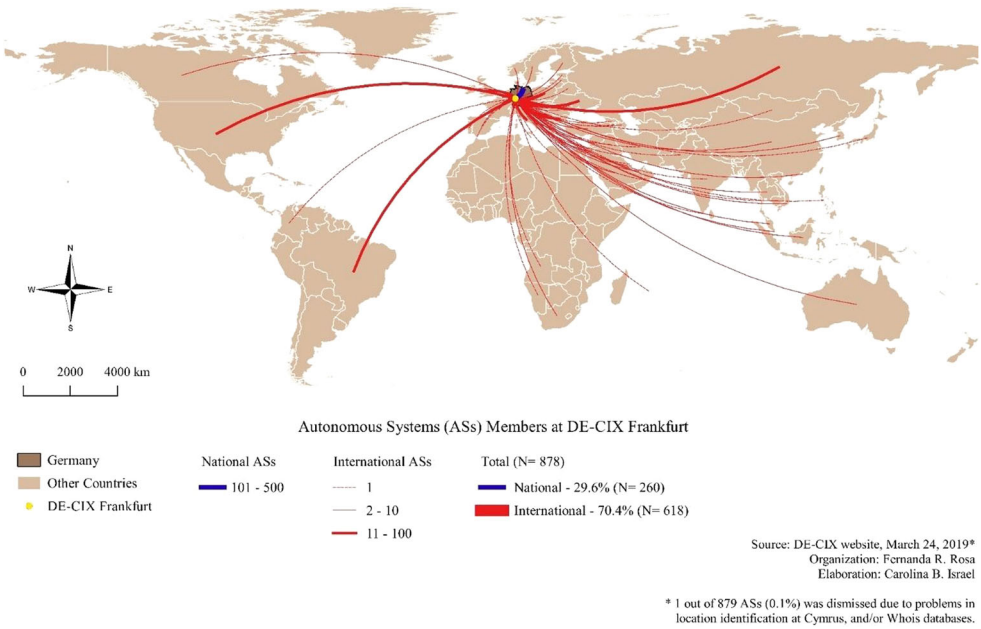
MAP 4 GAFA presence by average speed. GAFA, Google, Amazon, Facebook, and Apple



MAP 5 Connected networks per Region and Brazil. GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points

country; the bottom numbers indicate the division between IXP and private, with IXP being the first number in parentheses and private being the second (Figure 7).

In the global South, four of the five major national economies are among the countries with the largest GAFA presence; the exception is the inclusion of Bulgaria in lieu of China.[12] The global North has more than three times the GAFA presence than the global South. Particularly, the top global North country (the United States) has more than four times the number of points of interconnection than the top global South country (India). The lack of Apple's presence in Brazil, which is the most populous country in South America, also stands out. Brazil has more than 30 IXPs, and as of the time of writing, Apple is not connected at any of them. This suggests that GAFA's absence in the global South cannot be fully explained by the lack of available



MAP 6 Connected networks per Region and Germany. GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points

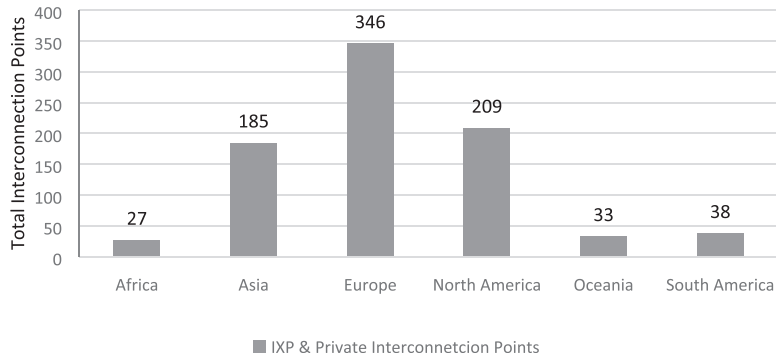


FIGURE 4 GAFA presence by continent. GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points

infrastructure.[13] If absent in their countries, ISPs need to pay for international transit to reach GAFA, increasing the cost of the internet in that locality.

To further illustrate this unequal condition, Maps 5 and 6 show the IXP connections in Brazil and Germany, respectively.[14] Brazil's connections at Sao Paulo, the largest IXP in the global South, are primarily national, with relatively fewer connections to regions classified as global North. By contrast, Germany's connections at Frankfurt, the largest IXP in the global North, is primarily international, with connections throughout the global North and global South. This illustrates the considerable discrepancies between large IXPs across the global North and global South, in part due to the presence or absence of GAFA. While the largest IXP in the global North (Deutscher Commercial Internet Exchange Frankfurt—DE-CIX) has 23.2% of its members coming from the global South and 70.4% from abroad, the largest IXP in the global South (IX.br

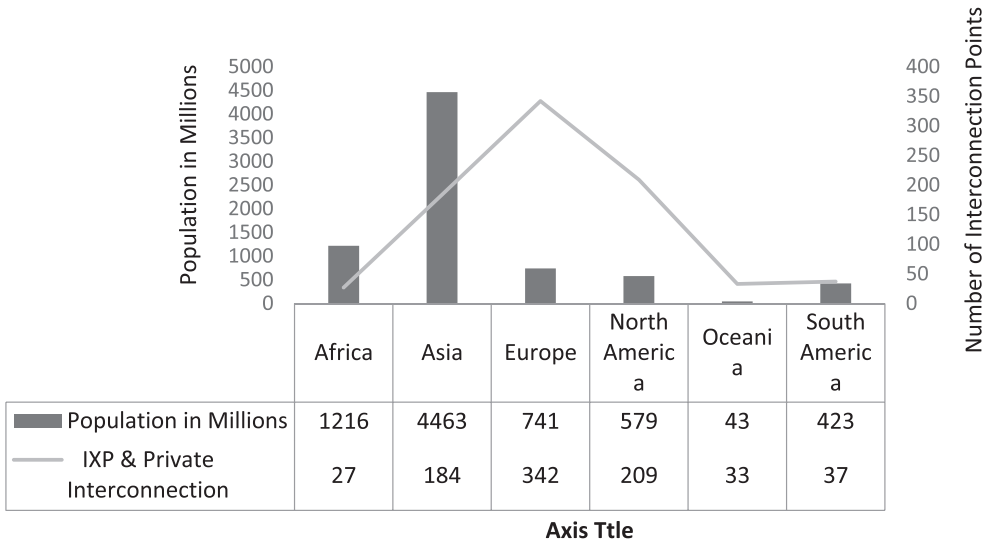


FIGURE 5 Population by GAFA presence, IXP and private interconnection points. GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points

São Paulo) attracts only 3.3% of members from the global North and 4.0% from abroad (ROSA, 2019). If DE-CIX numbers seem aligned with the EU single market strategy of leveraging the flow of people, goods, and services in the region, the comparison with IX.br suggests an unequal flow of information between the global North and the glob al South. This prompts the historical debate in global communication regarding how the paradigm of "free flow of information" tends to benefit the predominance of a few global North companies and countries over content and technology circulated worldwide (UNESCO, 1980).

We also investigated GAFA's presence in relation to population. Low population density does not seem to be a reason for the absence of content providers' presence in the global North. In fact, the data indicates that a country's per capita GNI is more relevant to predict GAFA's points of interconnection than population. The exception in our data is Oceania, which includes relatively affluent countries of Australia and New Zealand that have a relatively lower population; this results in Oceania having fewer GAFA points of interconnection than other countries classified as global North. Despite that, Oceania offers a striking example. Even with its relatively small population (less than 43 million) it has more GAFA points of interconnection than Africa, whose population is approximately 26 times larger.

Our final consideration is the degree to which GAFA companies locate at the same facility. Table 6 shows the multiple presence of GAFA at locations in the global North and global South.

GAFA Presence of 4 means Amazon, Apple, Facebook, and Google all are located at a common interconnection point. Note that in each instance in which all four are together, they are in the global North and this pattern continues. In locations in which three GAFA are present, 84% are in the global North; two GAFA present have 78% in the global North, and where only one of the GAFA companies is present, 73% of the time this is in the global North. Summarizing the number of data centers by city shows that the average global North city has 2.4 more GAFA copresence than the average global South city, with cities classified as global North having on average 7.97 observations of copresence and cities classified as global South having 5.67 observations of copresence.[15] Note that there are 200 countries or territories that do not have any GAFA public presence; all GAFA's points of interconnection are located within 49 countries.

TABLE 4 GAFA presence in global North and global South, by population

		Total population	Countries without GAFA presence	Population without GAFA	Countries with GAFA presence	Population with GAFA	Percent of population served
North	Africa	98,347	1	98,347	0	0	0.00%
	Antarctica	0	1	0	0	0	NA
	Asia	200,853,795	10	56,935,015	7	143,918,780	71.65%
	Europe	484,473,467	19	10,661,678	22	473,811,789	97.80%
	North America	378,026,984	15	6,421,326	3	371,605,658	98.30%
	Oceania	31,132,951	7	5,633,067	1	25,499,884	81.91%
	South America	22,754,024	3	3,637,823	1	19,116,201	84.01%
Total		1,117,339,568	56	83,387,256	34	1,033,952,312	72.28%
South	Africa	1,139,289,915	53	788,997,400	4	350,292,515	30.75%
	Antarctica	0	4	NA	0	NA	NA
	Asia	4,096,192,602	33	2,340,498,625	4	1,755,693,977	42.86%
	Europe	183,266,304	8	104,609,035	5	78,657,269	42.92%
	North America	213,057,174	20	213,057,174	0	0	0.00%
	Oceania	11,418,600	17	11,418,600	0	0	0.00%
	South America	379,730,415	9	38,120,479	4	341,609,936	89.96%
Total		6,022,955,010	144	3,496,701,313	17	2,526,253,697	34.41%

Abbreviation: GAFA, Google, Amazon, Facebook, and Apple.

TABLE 5 GAFA's points of interconnection (IXP and private), five most connected countries global North and global South

	Amazon	Apple	Facebook	Google	Total
Global North	**99 (55/44)**	**79 (41/38)**	**75 (44/31)**	**115 (64/51)**	**368 (204/164)**
United States	54 (31/23)	38 (18/20)	37 (22/15)	61 (37/24)	190 (108/82)
Germany	9 (3/6)	11 (7/4)	18 (11/7)	20 (11/9)	58 (32/26)
Japan	11 (8/3)	15 (7/8)	10 (6/4)	16 (9/7)	52 (30/22)
United Kingdom	11 (3/8)	9 (5/4)	5 (2/3)	10 (3/7)	35 (13/22)
Australia	14 (10/4)	6 (4/2)	5 (3/2)	8 (4/4)	33 (21/12)
Global South	**26 (14/12)**	**8 (5/3)**	**28 (18/10)**	**48 (32/16)**	**110 (69/41)**
India	12 (6/6)	4 (2/2)	11 (7/4)	15 (8/7)	42 (23/19)
Russia	2 (2/0)	3 (2/1)	1 (1/0)	18 (14/4)	24 (19/5)
Brazil	4 (2/2)	0	8 (4/4)	6 (3/3)	18 (9/9)
Bulgaria	2 (1/1)	0	6 (5/1)	6 (3/3)	14 (11/3)
South Africa	6 (3/3)	1 (1/0)	2 (1/1)	3 (2/1)	12 (7/5)

Abbreviation: GAFA, Google, Amazon, Facebook, and Apple.

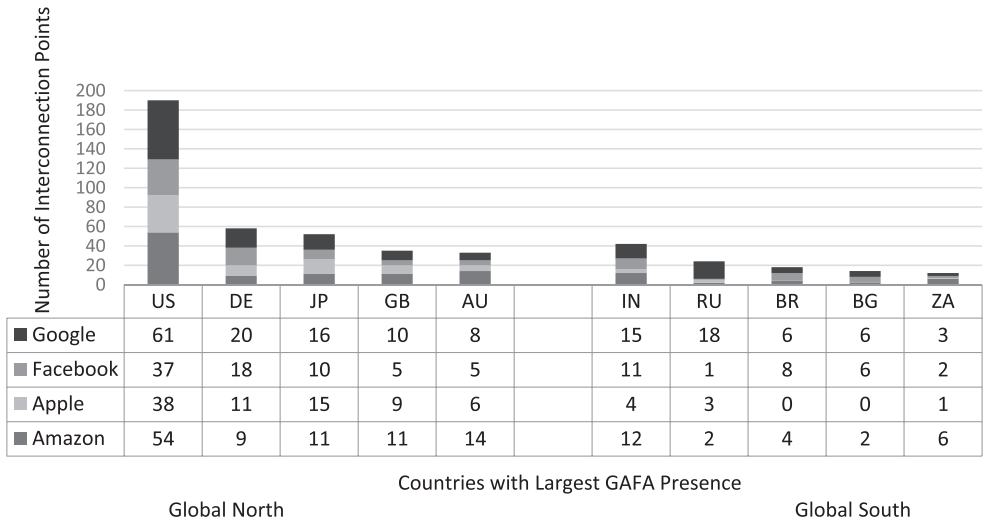


FIGURE 6 GAFA Presence (IXP and private interconnection points): top five countries by global North and global South. GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points

EMPIRICAL ANALYSIS

The preponderance of GAFA's points of interconnection at IXPs and private interconnection points are located in the global North (77.9%). Next, we conduct empirical analyses to better understand GAFA's interconnection choices. Our goals are to determine the location characteristics that are correlated with GAFA's presence, and to predict the likelihood of GAFA points of interconnection being located in the global North versus the global South.

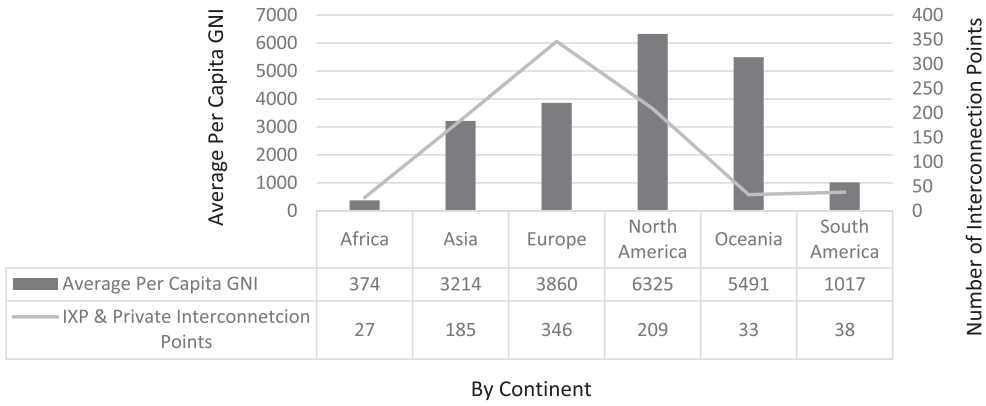


FIGURE 7 GAFA presence by continent, with per capita GNI. GAFA, Google, Amazon, Facebook, and Apple; GNI, gross national income

TABLE 6 Number of GAFA located by global North and global South, IXP and private interconnection points

GAFA presence		Private	IXPs	Total	% North	% Public
4	North	68	0	68	100%	0%
	South	0	0			
3	North	75	109	219	84%	50%
	South	18	17			
2	North	72	141	273	78%	52%
	South	14	46			
1	North	91	111	278	73%	40%
	South	34	42			
Total	North	306	361	838	80%	56%
	South	66	105			

Abbreviations: GAFA, Google, Amazon, Facebook, and Apple; IXP, internet exchange points.

Our data includes 1357 observations of GAFA presence and/or lack of presence in every country and territory. Table 7 provides the summary statistics of the subset of data shown to be statistically valid and appropriate for inclusion in our empirical analysis.

The World Bank and the United Nations criteria for categorization of countries by global North or global South based on per capita GNI is appropriate with our data, as confirmed by the correlation coefficient for global North and per capita GNI of 0.84. High income, lending category, per capita GDP, fixed broadband per 100 persons, and a composite variable called "obstacles to access" all have a strong correlation with global North. The most appropriate model specification was determined through sequential modeling techniques to identify consistently predictive characteristics of global North.[16] Company and per capita GNI remained the most significant independent variables, with wealth, and development variables appropriate to include. Estimation of the full variance-covariance matrix confirmed that GNI and GDP per capita had the strongest correlation with other relevant regressors. GNI per capita was more consistently predictive than GDP and therefore determined it to be

TABLE 7 Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
IXP	1357	0.57775	0.4941	0	1
Private Interconnection	1357	0.27413	0.44624	0	1
Per Capita GNI	1260	37841.9	23751.9	280	85500
Port Speed in Gs	784	82.5383	92.0051	10	800
North = 1	1357	1.29425	0.45587	1	2
Fixed Broadband/100	1098	28.5972	13.4394	0.00979	73.895
Land in km^2	1339	3122192	4350927	0	1.64E+07
Apple = 1	1357	0.13854	0.34559	0	1
Amazon = 1	1357	0.20781	0.40589	0	1
Facebook = 1	1357	0.26234	0.44007	0	1
Google = 1	1357	0.24318	0.42916	0	1

Abbreviation: IXP, internet exchange points.

TABLE 8 Probit model—Presence in global North

		Number of Obs.		1260
Log-likelihood	–8.8998	LR chi^2 (4)		1482.45
		Prob > chi^2		0.0000
Global North	Coef.	Std. Err	z	$p>\|z\|$
GNI per cap.	0.0013	0.0002	5.31	0.000
Google	2.0801	1.0234	2.03	0.042
Facebook	1.8988	0.8566	2.22	0.027
Amazon	2.2703	1.1857	1.91	0.056
Intercept	–20.4079	3.9943	–5.11	0.000

a sacred regressor along with company code. The resultant probit model estimates for predicting GAFA location in the global North is:

$$Global\ North_i = \beta_0 + \beta_1 GNI\ per\ capita + \beta_2 Google + \beta_3 Facebook + \beta_4 Amazon + \varepsilon.$$

Global North takes the value of 1 if port "i" is classified as such, and 0 otherwise. *GNI per capita* represents the per capita GNI in US dollars of the country in which port "i" is located. Company indicator variables are included to measure differences in GAFA preferences to locate in the global North, with Apple the reference group. Results of the model are presented in Table 8.

The nonlinear nature of the probit model results in the regressors affecting the probability of global North in a nonconstant way; therefore, the marginal effects of GNI on the probability that a site is located in the global North require specification of a company and level of GNI.[17] To provide appropriate context, we consider the likelihood of GAFA to interconnect to an IXP or private facility in a country with exactly $12,375 GNI per capita (the richest upper-middle-income country according to the World Bank; by comparison, US GNI per capita was $65,760 in 2019). The model

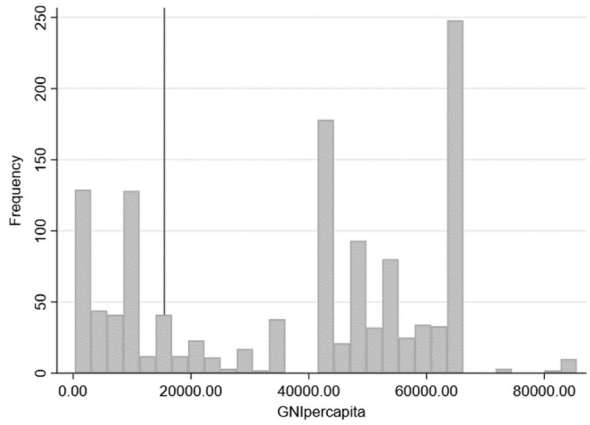


FIGURE 8 Frequency of per capita GNI. GNI, gross national income

predicts the probability of GAFA interconnecting at such a point is about 5% (7% for Amazon, 3% for Facebook, and 5% for Google). In other words, a country with GNI at this level can expect very little GAFA presence. However, once per capita GNI reaches $13,640, GAFA is more likely to have interconnection points than not (51% average predicted probability; 59% if Amazon, 44% if Facebook, and 52% if Google). After $15,500 of GNI per capita, our model predicts GAFA presence to approach certainty (99%). Of all GAFA companies, Apple is most sensitive to GNI per capita. Google, Amazon, and Facebook are virtually identical in their relationship of global North interconnection to GNI.

This near certainty of GAFA interconnection in the global North occurs very low in the range of GNIs observed. The highest per capita GNI is $85,500, and yet our model is nearly certain at least one GAFA interconnection will exist in a given country that reaches at least $15,500 of GNI per capita, as indicated by the vertical line in Figure 8. This indicates how strongly the propensity to interconnect to sites in locations classified as global North, or more precisely, to locate at higher levels of GNI, is actually a propensity to locate in places with higher baseline wealth.

Based on our data and statistical analyses, we assert that GNI is the most significant predictor of GAFA location worldwide.

LIMITATIONS

As noted in the introduction, PeeringDB is based on voluntary information; the data depends on the willingness of its users to keep the database current. Specifically with respect to GAFA, although the companies have incentives to update their information to allow their content to be distributed worldwide, they may choose not to publicize some information for business reasons (e.g., they may want to avoid peering at a particular location). Also, data from the same company may be differently administered (e.g., personnel differ regionally), generating different data treatment and update patterns. This is a limitation that both motivates the study, and is acknowledged and addressed in our analyses.

We use the points of interconnection distribution as a proxy for GAFA's CDN distribution, given that this is the most broadly-available public data. Nevertheless, the universe of CDNs where these companies' content is available reach beyond these points, given that there exist private agreements with third-party networks as well, including traditional CDN operators (e.g., Akamai and Cloudflare). For example, Google operates Google Global Cache (GGC),(Google, n.d.) where they cache popular content and place the server in third-party networks to facilitate access

to its content for the clients of such third-party partners. The distribution of GGC is not captured by PeeringDB data, and is ruled by confidentiality agreements. Information infrastructure for global platforms respond to business dynamics in ways that currently are beyond public scrutiny. This has implications for discussions of competition and antitrust policies.

Finally, we clarify that a given point of interconnection may not give access to all services of a company (e.g., Amazon may give access to its streaming services, but not to their cloud services in a certain location). Also, companies' CDNs and devices may not be located at the points of interconnection themselves, but in other locations connected to them by a link, as per the company's own decision. How companies design their networks and distribute their content is not public information, which is among the most significant challenges for researchers on platforms' infrastructure.[18] As such, we assert that those analyzing competition policy and proscribing regulatory policy take into account global implications of those policies to better serve ISPs, and ultimately, people worldwide.

CONCLUSION

Internet interconnection is a crucial element of market competition, and decisions at the level of infrastructure affect how ISPs compete in global and local markets. This study shows that GAFA's public points of interconnection in public and private facilities are unequally distributed across the global North and the global South. Countries with higher GNI have greater propensity to have GAFA's presence than countries with lower GNI. Population density does not explain such differences, nor does lack of infrastructure, as shown by evidence of the existence of stable internet exchange points in countries where GAFA companies are absent.

Considering that the data analyzed is one of the main sources to support ISPs' interconnection decisions worldwide with respect to GAFA's infrastructure, we expect these results to inform policy in two ways. (1) Given that the location of content providers' CDNs matters for the cost of ISPs to geographically reach them, GAFA's commercial strategies may have an impact in local markets, in the competition between tier-2 and tier-3 ISPs, as well as in global markets, in the competition between ISPs from the global North and the global South. We suggest that GAFA's interconnection distribution data is analyzed with antitrust lenses at national and global levels to understand the effects of their interconnection infrastructure worldwide. (2) The limits to draw conclusions about GAFA's current commercial behavior in internet interconnection comes from the partial coverage of data publicly available. The reflections proposed in this paper indicate the need for internet interconnection information of digital platforms to be considered in the public interest to subsidize further research and policy debates. For instance, if GAFA are more widely present in the global South than our data captures, as they likely are for their interest in optimizing their services, it matters for competition in local markets if this presence is based on private interconnection agreements mostly with telecommunications incumbents and large ISPs.

GAFA has had a tremendous impact on the flow of information online. Further research should address the international flows generated by digital platforms infrastructure. Disparities in the flows of communication between North and South have been a focus of debate in public fora for years. We assert that the conversation should be reconfigured to account for the complexities of privatized digital information infrastructure and the extraterritorial effects of the design of digital platforms.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

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ENDNOTES

[1] Economists define economic welfare as the sum of consumer and producer surplus, and use estimates of such surplus to evaluate the effects of changes in market structure.

[2] The acronym GAFA has been used to identify the four companies as an oligopoly controlling much of the tech industry market. Adding Microsoft to these companies (GAFAM) is a variation used in related discussions.

[3] For instance, Khan (2018) shows how Amazon's commercial strategies embracing different vertical business lines allow it to compete with its own clients based on data collected through its platforms.

[4] Special infrastructure can be defined as products that have zero marginal production costs over an appreciable range of demand and whose downstream uses exhibit significant externalities and include a wide range of private, public, and social goods. The idea follows that of technologies that are spread pervasively to most sectors, that improve over time, and thus continue to have improved benefits for uses, and that make it easier to invent and produce new products or processes (Bresnahan & Trajtenberg, 1995).

[5] In 2019 the European Parliament passed a law requiring digital platforms to monitor and remove "terrorist content," while US presidential candidate Warren advocated breaking up digital platforms entirely.

[6] Paid-peering also exists, and is applied especially in situations where there is imbalance of traffic among peers. (Faratin et al., 2008; Metz, 2001). Another situation also referred to as paid-peering is when ISPs charge content providers to take their content to their customers, as is the case between Netflix and Comcast and Verizon. (Gustin, 2014).

[7] To be considered a public facility does not mean to be public in an administrative sense. IXP governance can be private, not-for-profit, multi-stakeholder, or can be held by the government. For instance, in the United States, private governance is the most common, while in Europe and Africa, not-for-profit tends to predominate, and in South America, not-for-profit and multi-stakeholder models coexist.

[8] Tier-1 networks also interconnect to GAFA in both public and private facilities, as they sell transit to smaller ISPs who do not have access to it.

[9] Our data was collected from PeeringDB on March 17, 2020. Amazon: https://www.peeringdb.com/net/1418, Apple: https://www.peeringdb.com/net/3554, Facebook: https://www.peeringdb.com/net/979, Google: https://www.peeringdb.com/net/433.

[10] The AS number listed below the company name is the technical identifier. For example, a company that wants to peer with Amazon AS16509 must request to do so; Amazon then assesses the peering request and responds on an individual basis. GAFA companies maintain a global information infrastructure that enable them to peer with external networks via public peering (IXPs) and private peering (private interconnection).

[11] This is the method used for the World Bank lending policy. For more information, see (World Bank, n.d.)

[12] The major economies known by the acronym BRICS are Brazil, Russia, India, China, and South Africa.

[13] Research on Africa has pointed to challenges to overcome in infrastructure availability, such as data centers, optical fiber, and risks of outage due to political instability (Fanou et al., 2017).

[14] Maps are from prior as of yet unpublished work; citation temporarily withheld for anonymity of review.

[15] City data is too extensive for inclusion here, and is available upon request.

[16] Details available from authors by request.

[17] Table of marginal effects and calculations are available from the authors by request.

[18] This issue now appearing in the literature deserves further study to understand its impact in a transnational context. See (Blendin et al., 2018; Böttger et al., 2018).

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APPENDIX A

Country Classification: North, by GAFA				Country Classification: South, by GAFA					
Country	No GAFA*	Country	No GAFA*	Country	No GAFA*	Country	No GAFA	Country	No GAFA
Australia		French Polynesia	*	Argentina		Djibouti	*	Morocco	*
Austria		Gibraltar	*	Brazil		Dominica	*	Mozambique	*
Bahrain		Greenland	*	Bulgaria		Dominican Republic	*	Myanmar	*
Belgium		Guam	*	Colombia		Ecuador	*	Namibia	*
Canada		Guernsey	*	Ghana		Egypt, Arab Rep.	*	Nauru	*
Chile		Heard Island and Mc Donald Islands	*	India		El Salvador	*	Nepal	*
Croatia		Holy See	*	Indonesia		Equatorial Guinea	*	Nicaragua	*
Czech Republic		Isle of Man	*	Kenya		Eritrea	*	Niger	*
Denmark		Jersey	*	Malaysia		Ethiopia	*	Niue	*
Finland		Kuwait	*	Mexico		Falkland Islands (Malvinas)	*	Pakistan	*
France		Latvia	*	Nigeria		Fiji	*	Palestine	*
Germany		Liechtenstein	*	Peru		French Guiana	*	Papua New Guinea	*
Greece		Macao SAR, China	*	Romania		French Southern Territories	*	Paraguay	*
Hong Kong SAR, China		Malta	*	Russian Federation		Gabon	*	Philippines	*
Hungary		Monaco	*	Serbia		Gambia, The	*	Pitcairn	*
Iceland		New Caledonia	*	South Africa		Georgia	*	Réunion	*
Ireland		New Zealand	*	Thailand		Grenada	*	Rwanda	*
Israel		Norfolk Island	*	Ukraine		Guadeloupe	*	Saint Barthélemy	*
Italy		Northern Mariana Islands	*	Afghanistan	*	Guatemala	*	Saint Helena	*
Japan		Palau	*	Albania	*	Guinea	*	Saint Lucia	*
Korea, Rep.		Panama	*	Algeria	*	Guinea-Bissau	*	Saint Vincent and the Grenadines	*

Country Classification: North, by GAFA				Country Classification: South, by GAFA					
Country	No GAFA*	Country	No GAFA*	Country	No GAFA*	Country	No GAFA	Country	No GAFA
Lithuania		Qatar	*	American Samoa	*	Guyana	*	Samoa	*
Luxembourg		Saint Kitts and Nevis	*	Angola	*	Haiti	*	São Tomé and Principe	*
Netherlands		Saint Maarten (Dutch part)	*	Anguilla	*	Honduras	*	Senegal	*
Norway		Saint Pierre and Miquelon	*	Antarctica	*	Iran, Islamic Rep.	*	Sierra Leone	*
Oman		San Marino	*	Armenia	*	Iraq	*	Solomon Islands	*
Poland		Sark	*	Azerbaijan	*	Jamaica	*	Somalia	*
Portugal		Saudi Arabia	*	Bangladesh	*	Jordan	*	South Georgia and the South Sandwich Islands	*
Puerto Rico		Seychelles	*	Belarus	*	Kazakhstan	*	South Sudan	*
Singapore		Slovenia	*	Belize	*	Kiribati	*	Sri Lanka	*
Slovak Republic		Svalbard and Jan Mayen Islands	*	Benin	*	Korea, Dem. People's Rep.	*	Sudan	*
Spain		Trinidad and Tobago	*	Bhutan	*	Kosovo	*	Suriname	*
Sweden		Turks and Caicos Islands	*	Bolivia	*	Kyrgyz Republic	*	Swaziland	*
Switzerland		Uruguay	*	Bonaire, Sint Eustatius and Saba	*	Lao PDR	*	Syrian Arab Republic	*
Taiwan, China		Virgin Islands (U.S.)	*	Bosnia and Herze-govina	*	Lebanon	*	Tajikistan	*
United Arab Emirates				Botswana	*	Lesotho	*	Tanzania	*
United Kingdom				Bouvet Island	*	Liberia	*	Timor-Leste	*
United States				British Indian Ocean Territory	*	Libya	*	Togo	*
Andorra	*			Burkina Faso	*	Macedonia, FYR	*	Tokelau	*
Antigua and Barbuda	*			Burundi	*	Madagascar	*	Tonga	*

(Continues)

Country Classification: North, by GAFA				Country Classification: South, by GAFA					
Country	No GAFA*	Country	No GAFA*	Country	No GAFA*	Country	No GAFA	Country	No GAFA
Aruba	*			Cabo Verde	*	Malawi	*	Tunisia	*
Bahamas, The	*			Cambodia	*	Maldives	*	Turkey	*
Barbados	*			Cameroon	*	Mali	*	Turkmenistan	*
Bermuda	*			Central African Republic	*	Marshall Islands	*	Tuvalu	*
British Virgin Islands	*			Chad	*	Martinique	*	Uganda	*
Brunei Darus-salam	*			China	*	Mauritania	*	Uzbekistan	*
Cayman Islands	*			Comoros	*	Mauritius	*	Vanuatu	*
Christmas Island	*			Congo, Dem. Rep.	*	Mayotte	*	Venezuela, RB	*
Cocos (Keeling) Islands	*			Congo, Rep.	*	Micronesia, Fed. Sts.	*	Vietnam	*
Curaçao	*			Cook Islands	*	Moldova	*	Wallis and Futuna Islands	*
Cyprus	*			Costa Rica	*	Mongolia	*	Western Sahara	*
Estonia	*			Côte d'Ivoire	*	Montenegro	*	Yemen, Rep.	*
Faroe Islands	*			Cuba	*	Montserrat	*	Zambia	*
								Zimbabwe	*