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Invasive Species of the App Ecosystem: Exploring the Political Economy of Mobile Communication

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The mobile market is frequently described as an ecosystem where powerful companies generate value from continuously harvesting and distributing data. In this article, we advance the ecological metaphor through both theoretical conceptualizations and empirical explorations of the contemporary app ecosystem. We thereby contribute to the emergent field of app studies by critically scrutinizing the political economy of mobile communication. The article identifies the prime infrastructural resources that ground app-based communication (devices, operating systems, app stores, apps, third-party services, and data accesses) and their ownership structures to discuss how power is obtained, exercised, and amplified in the app ecosystem. To illustrate the value of the theoretical approach, we provide a critical asset analysis of Google LLC (Alphabet, Inc.) and discuss its position as an invasive species in the app ecosystem.

Keywords: mobile applications, apps, media ecology, mobile communication, ecosystems, political economy, digital infrastructure, Alphabet, Google, data economy

On October 21, 2020, the U.S. Justice Department filed a landmark lawsuit against Google LLC, a subsidiary of Alphabet, Inc., claiming that Google violates antitrust laws by killing off competition to protect its monopoly status in Web searches (United States Department of Justice, 2020). The lawsuit follows in the wake of a range of fines and litigations issued by, among others, the European Commission, regarding Google's alleged abuse of market power (European Commission, 2017, 2018). Taken together, the recent cases testify to the company's control, not just over the search market, but across the digital economy. Google is one among a few global tech companies that play central roles in the construction and governance of the critical infrastructure of the Internet, and thereby constitute powerful institutions in society.

In this article, we set out to critically discuss how power is obtained, exercised, and amplified in the digital economy, and more specifically, in the increasingly central market for mobile apps. As users gradually,

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but surely, move from Web platforms to mobile apps, so do ad revenues, which made 2020 a monumental year for mobile advertising: Up 26% since 2019, advertisers were pouring more than 240 billion U.S. dollars into mobile ad spend in 2020 (App Annie, 2020). Yet analyses of the burgeoning app market continue to be few and far apart. Contributing to the emergent field of app studies, the article scrutinizes the political economy of mobile communication by mapping out critical infrastructural resources and control mechanisms that ground power over the app market, and so, the future of digital communication.

To understand the central position of Google as well as other large tech companies, the article advances the metaphor of a biological ecosystem, where powerful actors figure as invasive species that grow quickly and spread aggressively, curb diversity, and alter the basic living conditions for other species. The goal of the article is to understand and explain these invasive processes through theoretical discussions as well as empirical explorations. This is done across two main sections: In the first, we advance the notion of an ecosystem as a valuable conceptual lens for studying the political economy of mobile communication and outline how value is generated and control is exerted through the ownership of six types of critical infrastructural resources that support app-based communication, namely (1) devices, (2) operating systems, (3) app stores, (4) apps, (5) third-party trackers, and (6) data accesses. In the second section, we conduct an explorative analysis and discuss the contemporary app ecosystem, providing empirical examples of current market dynamics and power relations. We do this through three analytical entry points: We first describe the app ecosystem as it appears *on the surface* by mapping the most prominent services and products across the six infrastructural resources; we then take *a deeper dive* into the app ecosystem by uncovering ownership structures and identifying the dominant market actors through the assets they control; and lastly we place the most prominent market actor—namely, Google—*under the microscope*, and discuss the company's position as an invasive species in the app ecosystem.

Conceptualizing Mobile Apps

The emergent field of app studies is home to a loosely connected pool of research dedicated to mobile apps in particular. Despite the novelty of this field, there are multiple strands of research that engage with apps from different vantage points, including studies of mobile media and communications (Ling, 2008), mobile markets and business models (Nieborg, Young, & Joseph, 2020), and mobile app infrastructures (Gerlitz, Helmond, Nieborg, & van der Vlist, 2019) and platforms (Poell, Nieborg, & van Dijck, 2019). Much of the research engaging with apps consists of case studies that center on particular apps or genres of apps like social media, dating, mindfulness, fitness, and so forth (Morris & Murray, 2018), thereby providing valuable in-depth knowledge on the app or app genre in question, but not on the larger ecosystem of mobile apps. Exceptions can, for instance, be found in the work by Gerlitz and colleagues (2019), who offer a valuable research agenda for empirical app studies, as well as in Dieter and colleagues' (2019) discussion of methodological approaches to multisited app studies. Also, studies that chart the prominence of commercial tracking in apps are occasionally surfacing, showing how power structures are distributed across the digital economy at large (Atkinson et al., 2015; Binns et al., 2018; Vallina-Rodriguez et al., 2016). While studies in this vein often call on the analogy of an ecosystem when describing the process whereby data from mobile apps are harvested and distributed to third parties, they tend to focus on particular aspects of that system (e.g., third-party services or mobile permissions) and do not engage in discussions of how to define and operationalize app ecosystems as broader objects of study. Before engaging in a characterization

of the contemporary app ecosystem, it is therefore necessary to define and elaborate on what we mean by an app ecosystem.

Apps as Ecologies

In the natural sciences, an ecosystem is defined as "a complex of living organisms, their physical environment, and all their interrelationships" ("Ecosystem," 2020, para. 1). Ecosystems can be characterized by different degrees of biodiversity, understood as a richness of species, a genetic variety within species, as well as the coexistence of different ecosystems. A common threat to biodiversity stems from invasive species: In the United States, the Asian carp has outcompeted native fish species of food and habitat; in Northern Europe, the Spanish slug haunts gardeners by invading cultivated areas and destroying crops; and in Africa and South America, eucalyptus plantations are creating extensive monocultures that suppress other plants and wildlife.

In communication research, the ecology metaphor is frequently used as an entry point to studies of media as environments that "structure what we can see, say, and do" (Scolari, 2012, p. 205). Media ecosystems are, similar to natural ecosystems, defined by their material conditions as well as by the activities and strategies of the actors who inhabit them. As Scolari (2012) puts it with reference to Marshall McLuhan's work: "Media are like 'species' that live in the same ecosystem and establish relationships between each other" (p. 209). While recent studies often focus on the cultural implications of different communication technologies (e.g., Lum, 2014), earlier media ecologists, most prominently Harold Innis (1991), combine media ecology and political economy. These studies generally seek to explore the basic power structures that are built into physical communication environments, and to understand how these environments are, in turn, shaped by the actors in control. Though it is rarely theoretically elaborated, the ecological terminology is also often applied in empirical research on political and economic media structures that, for instance, study and compare media diversity in different societal settings (Dimmick, 2003; Winseck, 2008). Like biodiversity, media diversity is typically measured in terms of ownership concentration, media and content pluralism, and competition enforcement (e.g., Brogi, Carlini, Nenadic, Parcu, & de Azevedo Cunha, 2020). Building on, but also developing, the notion of media ecosystems, the remainder of this article advances the ecological approach as a theoretical and analytical point of departure that can enhance our understanding of mobile apps and their increasingly important role in the digital communication environment.

The ecological metaphor has two important conceptual implications for the study of apps: First, it draws attention to the material aspects of communication and emphasizes the need to understand the technological features of mobile apps as structuring conditions for how they can be used, commodified, and controlled; secondly, it takes into consideration the various functions that different apps have, their co-dependencies as well as apps' position in the greater digital ecology (see also van Dijck, 2020, for the use of the metaphor of tree for conceptualizing contemporary power structures and dependencies in the digital ecology). While legacy media studies often focus on diversity alone, we develop the metaphor to also include invasiveness as a key concept for understanding and assessing the state of contemporary app ecosystems. Invasiveness refers both to the process whereby large tech companies invade our everyday lives and societies through extensive data harvesting and surveillance (Zuboff, 2019), *and* to the process through

which single powerful companies gain dominant market positions, from where they are able to dictate the activities of their competitors and to undermine the diversity of entire ecosystems.

Apps as Political Economies

Our approach to studying app ecosystems is, as mentioned above, inspired by classic studies of the political economy of communication and it is, as such, concerned with the distribution of goods in society. This includes how critical communication resources—like "the Internet as one of today's most important forms of world property" (Mazepa & Mosco, 2016, p. 163)—are organized and controlled, how the organization reflects and sustains existing and emergent power structures in society, and how these power structures are naturalized and institutionalized over time (Mansell, 2017). Political economy analyses provide insights into the machinery of how contemporary power structures and control mechanisms are shaped through examining value generation processes and exchanges, identifying the actors involved, their incentives to be so, and the effects of these power configurations (see, e.g., Hardy, 2014; Mosco, 2009). Recently, researchers have engaged specifically with the institutionalization of digital power. Laura DeNardis (2012), for instance, directs attention toward core governance functions "carried out via arrangements of technical architecture and through policy decisions of private industry" (p. 721). Emphasizing the value of digital data and meta-data as important assets in the digital economy, Robin Mansell (2017) argues that the data flows of, for instance, mobile apps, can be seen as "bits of power": "a reminder of the significance of power relations in the changing technological and institutional environment in which information is produced, circulated and applied" (p. 3).

Despite these important critical efforts, the political economy perspective has not yet been fully applied to and developed for the study of app ecosystems. The examples of app studies mentioned above deal, in some instances, with business models and market incentives of particular apps (Nieborg & Helmond, 2018) or, on a rather descriptive level, with ownership structures (Binns et al., 2018). Yet they do not discuss the distribution of assets across the app ecosystem that ground larger power structures (for an exception, see Nieborg et al., 2020). Hence, in approaching the political economy of mobile communication, we first need to identify the main resources in the app market, uncover their ownership, and scrutinize the ways they are organized and controlled. To do so, we follow the recent "turn to infrastructure" (Musiani, Cogburn, Denardis, & Levinson, 2016, p. 1) in Internet studies and zoom in on the infrastructural components that serve as the material foundation under the app ecosystem, and thereby the mobile market.

Apps as Infrastructures

The infrastructural perspective entails "turning away from the symbolic and investigating the structural—this is the Internet not as 'what people say with it' but as 'how it works'" (Sandvig, 2013, p. 90). In other words, infrastructure studies pivot the perspective from the common focus on digital content and social practices to material structures that enable and constrain (mobile) communications. Understanding the basic details of mobile communication is a valuable starting point for studying not only the conditions for developing or using apps but also the business models of and dependencies between various actors in the mobile markets. The material components of the systems that support the functionality, and commodification, of mobile apps are gateways to identifying the resources that app providers and other

digital market actors own, depend on, and profit from. Inspired by previous research that establishes a number of methodological entry points for app studies and distinguishes between different levels of analysis when engaging with apps as infrastructures (Dieter et al., 2019; Gerlitz et al., 2019), we identify six critical infrastructural resources by which to obtain power in the app ecosystem, namely: mobile devices, operating systems, app stores, apps, third-party services, and data accesses (see Figure 1).

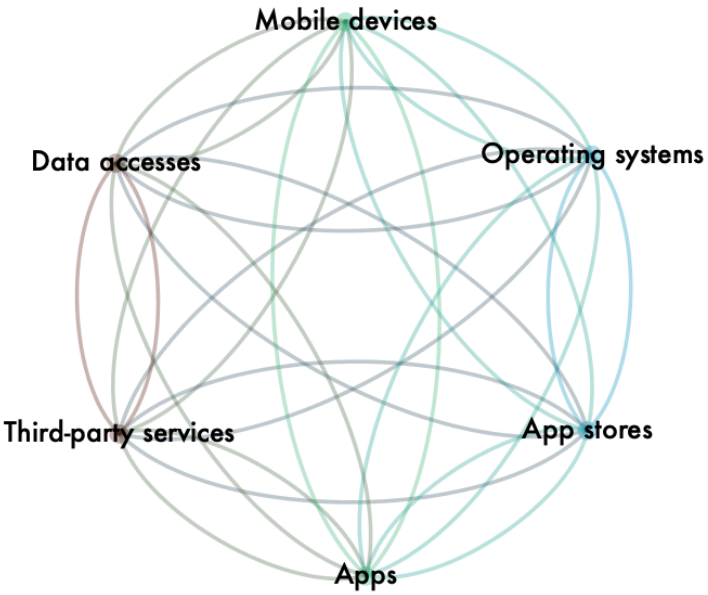

Figure 1. The app ecosystem.

These resources are far from exhaustive, and we might have included others such as developer studios, advertising platforms, and so forth. However, we choose these six infrastructural components because they constitute relatively fixed features that app-based communication is dependent on, regardless of the particular functions and uses of individual apps: To run and use a mobile app, users have to have an operating system installed on their devices; if they are to download an app that is not preinstalled, users have to access an app store; the app in question must, obviously, be developed and available for download; in most cases, the apps are dependent on embedding a range of third-party services to, for instance, store and distribute content, monitor and analyze user behaviors, and deliver targeted ads; and finally, all apps collect data and meta-data that travels through in- and out-bound data flows, both to secure the functionality of the apps but also to sustain the dominant business model behind commercial free-to-use apps: data mining and reselling. Moreover, inasmuch as these are key resources, they are also chosen because they co-depend, interact, and can be employed analytically in a strive toward understanding one in light of the other. For instance, a user's inclination to download a certain app is closely tied to the app store and the type of operating system that is installed her device, which, in turn, has implications for the kinds of data accesses requested by the app. Or, as exemplified by the recent updates from Apple, operating systems and proprietary and preinstalled apps, like Web browsers, set up boundaries for third-party services used for serving ads or trading in user data. By identifying the actors that own and control assets across

the different types of resources, we are thereby able to explore the distribution of power across the app ecosystem and to understand the foundational business models.

Empirical Examples and Materials

The conceptualization of the app ecosystem as illustrated in Figure 1 enables mappings and analyses of infrastructural resources and contemporary market structures that can be studied using various types of empirical sources. For research on the first three infrastructural resources—mobile devices, operating systems, and app stores—reports provided by different businesses and government bodies offer secondary data on market developments, ownership structures, and so forth. In the analyses below, we rely on StatCounter's (n.d.) statistics on the distribution of and market shares in devices and operating systems, and Statista's (n.d.) statistics on app stores. The markets for app development and provision, in-app third-party services, and mobile data harvesting are, by all comparison, less monitored and transparent. Hence, when exploring the final three infrastructural resources—apps, third-party services, and data accesses—research depends on generating primary data. In the analyses below, we draw on various studies of third-party tracker markets and data accesses that we supplement with information collected through the Google Play store on the 500 most downloaded Android apps (AndroidRank, n.d.-b) as of November 2020. Google Play store has become the default platform for scholars, as it allows for research interventions that other app stores do not. This does, however, constitute a methodological challenge, as existing studies of apps, third-party trackers, and data accesses that take Google Play as an outset thereby potentially overestimate the position of Android apps, and thereby the power of Google, in the app ecosystem, while underestimating the influence of other players, most importantly, Apple. As Google Play does not include Apple's preinstalled and proprietary apps for messaging, navigation, calls, and so forth, Apple and other app providers distributing their products through other app stores are most likely more prominent than they appear when taking Google Play alone as an outset for research.

The Contemporary App Ecosystem

In much the same way as the biodiversity of natural ecosystems is studied through investigations of individual species, relationships among species, as well as coexistences among different ecosystems, the diversity, or lack thereof, in app ecosystems can be studied from various perspectives: Through zooming in on particular market actors, looking at competition structures and market dynamics, or studying the app ecosystem's prominence and position in the greater environment of (digital) communication. The latter perspective entails tracing the origins of the app ecosystem as it has challenged the Web ecosystem, which dominated the digital communication environment in the past (see also Blanke & Pybus, 2020): A decade ago, most Internet-based communication activities relied on websites and cookie scripts installed in browsers, which were, in turn, an integral part of desktop operating systems. These infrastructural arrangements grounded the establishment of market structures where individual companies (such as Microsoft) gained significant power as providers of, among other services, operating systems (e.g., the Windows systems) and browsers (e.g., Internet Explorer) that served as gatekeepers for all Web-based activities. Or where a company such as Facebook gained a key position through its social network site as well as through the integration of its services across the Web in the form of like buttons, logins, and other plug-ins that other websites depend on. These processes, which have been referred as the *platformization*

of the Web (Helmond, 2015), means that a handful of companies own and control critical infrastructures that other market actors become increasingly, and critically, reliant on (Plantin, Lagoze, Edwards, & Sandvig, 2018; van Dijck, Poell, & de Waal, 2018).

Since the introduction and spread of smartphones and other mobile devices, the former prominence of Web-based services and market actors has been challenged by the surging use of mobile apps. The app ecosystem described in the previous section resembles that of the Web, and market actors such as Microsoft, Amazon, and Facebook have strong positions in both ecosystems. However, the app ecosystem is also distinct in important ways tied to the infrastructural features of apps: For one thing, the mobility of apps increases the ubiquitous presence of the Internet across everyday life, and provides fine-grained data on users' activities, whereabouts, and so on. For another, while browsers are key gatekeepers for Web-based activities, they are one (albeit important) app among many on mobile devices, where app stores are the main gatekeepers (Poell et al., 2019). The Web has thus, in some ways, become a subsystem in the app ecosystem. By following the six infrastructural resources of the app ecosystem established above, and mapping how they are organized and controlled, we can begin to understand this historical restructuring of the digital ecology.

Over the following sections, we argue that the contemporary app ecosystem should be studied broadly as well as in depth. That micro processes should be understood in light the ecosystem's macro structures, yet without underestimating the power of individual species in shaping the greater digital ecology. In other words, we need to study the app ecosystem as it appears *on the surface*, through *a deeper dive*, and *under the microscope*.

On the Surface

At first sight, the global app ecosystem is enormous and remarkably complex: smartphone and tablet users can choose between various products and brands in different price ranges and with unique features. They can also select between millions of different apps, offering a multitude of services that are provided by a mass of developers based on various business models characterized by distinct terms and conditions. In other words, to grasp this system in all its complexity, we need to map out its many assets and actors as they relate to the six infrastructural resources of the app ecosystem.

In the market for *mobile device*, iPhones and iPads as well as Samsung Galaxy phones and tablets are the most notable in terms of sales and uses, though regional differences exist (StatCounter, n.d.). All mobile devices come with preinstalled *operating systems* that provide a range of basic apps (e.g., browser apps, camera apps). The most prominent one, Android, is branded as an open source software (although this branding is highly debatable; see Spreeuwenberg & Poell, 2012), used by a wide range of device manufactures (e.g., Samsung, Huawei), followed by the proprietary iOS, which is exclusive to Apple devices (StatCounter, n.d.). Alternative operating systems include Linux and HarmonyOS, of which the latter might see rapid growth in 2021 if Huawei starts shipping it on its smartphones and other smart devices. The prominence of Android and iOS is also reflected in the *app store* market, where the Google Play store (2.9 million apps) followed by Apple's App Store (2 million) are the largest in terms of available apps (Statista, n.d.). Similar to the operating system market structures, alternative app stores such as Amazon App Store and Tencent's MyApp exist, yet

they offer only a fourth or less of the apps available on Google Play and App Store. As gatekeepers, app stores differ significantly from Web browser insofar as any browser gives indefinite access to the World Wide Web, whereas app stores host varying quantities of a limited resource—namely apps.

The market for *apps* consists of a multitude of different developers since anyone, in principle, is able to launch an app and make it available (so long as it conforms to the terms and conditions of a given app store). Taking the top 500 most downloaded apps in the Google Play store as an example, they are all free-to-download apps, developed and offered by various different companies from around the globe. The top apps are Google Play, YouTube, Google Maps, and the Google search app that are each downloaded more than 5 billion times. Despite the abundance of apps available for download, analyses of Google Play show that the top apps account for the majority of downloads in the app store suggesting that "although it matches the criteria of being a Long-tail market, the mobile market is found to be a Superstar market" (Zhong & Michahelles, 2013, p. 503).

The market for *third-party services* is closely tied to the app market insofar as the most prominent third-party services are the ones that are built into many apps as well as into the most downloaded apps. Third-party services come in the form of small pieces of software, called software development kits (SDKs), such as crash reporters, analytics, content delivery networks, and ad trackers, that support the basic functionalities and business models of apps. Previous analyses show that the most prominent third-party services include Google AdMob, Google Firebase, and Facebook Ads (Binns et al., 2018, p. 27). However, there are also a multitude of small and medium-sized businesses that profit from the functions of perhaps just a single or a few lesser known third-party services.

The control over *data accesses* similarly follows the app market as permissions to access data are obtained once a user installs an app on her device. Google Play conveys information on what accesses and permissions are coded in the software of different apps, and can thereby be used for comparative analyses of the amounts and types of data that different apps can be expected to harvest. Previous analyses (Atkinson et al., 2015) show that apps in Google Play request hundreds of different permissions (e.g., *precise location*, *read call log*, *find accounts on the device*), offering various accesses to data residing on mobile devices (e.g., to *location, phone, contacts*; p. 4). As infrastructural aspects of apps, these data accesses constitute valuable assets in the app ecosystem: They both support the very functionality of an app (like a photography app accessing the *camera* with the permission to *take pictures and videos*), and ground commercial collection, mining, and reselling of user data that can be fed back into the system in the form of targeted ads, curated feeds, and user profiling, thereby supporting the business models of most free-to-download apps.

Compared with other communication technologies (e.g., landline telephony and broadcasting), the market for providing mobile app services seems highly diverse and characterized by low barriers to entry. If a user wants to make a voice call, she can choose between various different apps (Viber, Skype, Zoom, etc.). These apps can, in turn, select between a multitude of third-party services for storing and distributing their content, collecting and analyzing user data, serving ads, and so forth. App owners have a range of options in terms of developing their business model. These markets are, thus, from a surface glance, not subject to significant risks of monopolization nor in urgent need of regulation. However, this impression

changes once we take *a deeper dive* into the political economy of mobile communication by uncovering the ownership structures of the app ecosystem.

A Deeper Dive

Based on the initial mapping of the app ecosystem as it appears on the surface, the following section explores the ownership structures underlying the multitude of different products and brands identified above. In the markets for devices, operating systems, and app stores, the ownership structures are relatively straightforward due to monitoring practices on the part of governments and private corporations. In the global market for *mobile devices*, South Korean-based Samsung and U.S.-based Apple dominate with shares around 30% each on smartphones (and for Apple, even more so on tablets), while Huawei and Xiaomi, as particularly important device manufacturers in the Chinese market, hold market shares at 10% (StatCounter, n.d.). Related to this, Apple's share in the *mobile operating system* market amounts to 27% worldwide as of January 2021, while Google, through its acquisition of Android in 2005, holds a market share of 72% (StatCounter, n.d.). Following two contrasting business strategies, Apple's proprietary operating system supports and protects the company's position in the device market, while Google has leveraged its power in the app ecosystem by making the Android system available to all mobile manufacturers (e.g., Samsung). The duopolistic nature of the operating system market (Poell et al., 2019) has important repercussions for competition and power structures across the app ecosystem. This is especially apparent when looking at the *app store* market, where alternative providers, despite recent efforts, are struggling to compete with Apple's and especially Google's products. An obvious reason for this is that Google Play is the default app store on Android devices and, thus, comes preinstalled on many smartphones and tablets worldwide.

Looking to the market for *apps*, the seeming diversity also somewhat fades once we inquire into the ownership structures: For instance, just one company, Google, owns 10% (50 apps) of the entire top 500 most downloaded apps in Google Play as well as all apps in the top 10 (AndroidRank, n.d.-b). Google's apps are downloaded 2.7 billion times in average, which is four times more than the remaining 450 apps in the top 500. The second and third largest app owners are Samsung, with 19 apps, and the Chinese company Zhejiang Jinke Entertainment Culture, with 15 apps in the top 500. Facebook's 13 apps, however, account for the second highest number of downloads (1.8 billion). The top 50 most downloaded apps are owned by 10 companies, among which Google own 24 apps, Samsung owns 10 apps, and Microsoft and Facebook each own five. An explanation for this can be found in the large tech companies' aggressive acquisition strategies illustrated in, for instance, Facebook's acquisition of Instagram and WhatsApp and Google's acquisition of YouTube (all of which appear in the top 50).

Though the ownership over some of the most prominent *third-party services* can be glanced off of the name of the third-party service (e.g., Google Firebase and Facebook Ads), there are also many third-party services whose ownership structures are far more opaque. This is more due to either household brands using unfamiliar names for their third-party services or different acquisition processes over the past years where services, just like apps, have been collected under the same parent company. As we start examining the ownership structures covering the vast forest of services solicited by third-partiers, it becomes clear that there is a small elite consisting of most prominently Google (present on 88% of the 1 million most

popular Android apps in Google Play) and Facebook (43%; Binns et al., 2018). A more diverse bulk of actors supply third-party services to fewer apps and count companies such as Oracle, Verizon, Tencent, and Unity—most of which are also app developers. A third category of third-party services are owned by companies such as AppLovin, Adjust, and Yandex, who have made a business out of trading in, hosting, and analyzing data obtained through the individual data accesses of apps.

The control over *data accesses* naturally reflects that of apps as the mobile permissions are coded in the software of any app, and thus requested by and granted to the app owners. In other words, as a result of owning a large number of apps that also top the charts in terms of worldwide downloads, the largest app owners will typically obtain the most accesses to user data. However, mapping the particular accesses and permissions for each app and app owner also shows that there are significant differences in terms of the types of accesses they request as well as the volume (Lai & Flensburg, 2020). Some companies distribute one or a few apps and ask for only a little or no permissions to access data. Others, as outlined above, distribute a suite of apps, and through these they request a multitude of accesses, just as many of them, simultaneously act as third-party services and harvest data from other apps through various types of trackers. This includes Google, which, through its many different apps, obtains a range of data accesses across more than 150 distinct permissions, including permission to *read your text messages (SMS or MMS)* through, for instance, the Google search app, Hangouts, and Google Pay; and permission to *record audio* by accessing the microphone through apps like Google Maps, Google Keep, or Google Chrome (p. 8). Unlike Google, other companies acquire a suite of data accesses through distributing just one app that appears in the top 500—for instance, the China-based Ludashi Holdings, which requests a total of 102 permissions through its app Dual Space, enabling users to stay logged in to several different accounts on the same platforms. These permissions include *read your Web bookmarks and history* and *read sensitive data log* by accessing *device and app history* and *read instant messages*.

Taken together, the empirical examples of ownership structures and control mechanisms across the app ecosystem provide a clear indication of who the most powerful species are and of the importance of owning and controlling key infrastructural resources. Across five of the six resources overviewed in Figure 1, Google holds a dominant position through its ownership of the Android operating system and the Google Play store, as well as a suite of highly used apps, third-party services, and data accesses, rendering it both a critical and an extreme case (Flyvbjerg, 2006) for closer scrutiny *under the microscope*.

Under the Microscope

If we are to understand the dominant position of Google in the app ecosystem as well as the greater digital ecology, we need to take a closer look at the company's assets as they cut across—and beyond—the mobile markets. That is, in this section, we outline Google's role as a device manufacturer, operating system provisioner, app store provider, app developer, third-party service, and as a data harvester and broker, emphasizing how these market activities intersect and mutually amplify each other. In doing this, we discuss not only Google's assets and how the company profits from them, but also its market strategies including incentives to develop and launch new products, and to take over and potentially extinguish competitors.

Of the six key infrastructural resources, Google holds the least significant position in the market for *mobile devices*. Although the company offers various smart devices such as Chromecast and smart TVs, Chromebooks, watches, and so on, its shares in the markets for smartphones and tablets is less than 1% (StatCounter, n.d.). In contrast with Apple, which largely built its business on offering devices with proprietary operating systems and preinstalled apps, Google instead profits from the many devices that employ Android and its default suite of other Google products.

What Google lacks in mobile devices, the company gains when it comes to *operating systems*. In the global mobile operating system market, Google's Android system, as of January 2021, holds a market share of 72% compared with Apple's iOS's 27%, whereas Google's share in the tablet operating system market is 44% compared with Apple's 56% (StatCounter, n.d.). As mentioned, Google has previously been fined by the EU Commission for breaking antitrust laws and imposing illegal restrictions on device manufactures using Android. Specifically, Google has been penalized for, for instance, requiring Android manufactures to preinstall their Search app and browser (Chrome) as a condition for licensing Google Play and for making payments to specific large manufacturers and mobile operators for exclusively preinstalling Google Search on their devices (European Commission, 2018). Though Google promotes Android as an open-source product, the examples above testify to the power of mobile operating systems as a foundational resource that can be used to influence and control the conditions in other parts of the ecosystem. Examples from other ecosystems testify to the power of the kind of integration that Google enjoys in the app ecosystem. One would be Google's recent announcement that it will ban Web cookies from the Chrome browser as of 2022 (Schuh, 2020), leaving a multitude of smaller Web market actors that have built their business on top of the cookie technology in a bad position; another would be Facebook closing its application programming interface (API), rendering companies that relied on access to the Facebook data hose out of business.

Relatedly, Google's ownership of the major *app store*, Google Play, holds an important key to understanding the company's power and position in the app ecosystem. According to Statista's (n.d.) latest reports, 108 billion apps were downloaded from Google Play in 2020, making it the largest app store measured on both the number of available apps and users. This creates obvious network effects as the high availability of apps, on the one hand, attracts users, while the large number of users, on the other hand, makes it particularly appealing for developers to make their products available here. Google profits from their app store in a number of ways: to create an account that allows for the launch of apps, developers have to pay a one-time fee; the app store further requires a service fee for paid apps and in-app purchases. Apart from these revenues, Google Play's role as an intermediary (see also van Dijck, 2020, p. 7) between users and app developers places Google in a gatekeeper position from where it can influence user choices (e.g., which apps are promoted) and establish the terms and conditions that developers have to adhere to, to be located by Android users. Recent cases show that developers and app providers are protesting over the conditions set up by Google—for instance, regarding the cuts of in-app purchases, arguing that the app store exploits its market dominance (Wakabayashi, 2020). One of the main objections to the global power exerted by Google Play concerns its ability to remove apps and determine what is perceived as appropriate content regardless of cultural norms and traditions within particular contexts. Furthermore, Google, through its control of Google Play and the underlying developer tools and instructions, promotes its own third-party services such as AdMob, a suite of SDKs that can be used to monetize apps using targeted advertising.

As described in the previous section, Google also owns a wide range of the most popular apps in Google Play. Aside from its 50 apps in the top 500, Google owns an additional 90 apps (AndroidRank, n.d.-a), thereby providing services that traverse all spheres of life, including e-mail, maps and location, voice and video calls, games, photo editing, banking, education, health, streaming, and so forth. These apps collect vast amounts of data that feed into Google's targeted advertisement business, strengthening its algorithms as well as the basic functionalities of the apps. If we hold up Google's position in the app ecosystem against its dominance in the market for websites, their power crystallizes further. Google's services and functionalities from the Web sphere have been transferred to their apps—apps that the company has then been able to push to mobile device manufacturers as down-payment for licensing the Android operating system and the Google Play store. Just like website developers use Google's third-party services to run, analyze, develop, and profit from their own services, so are app developers encouraged to "built anything with Google" (Google LLC, n.d.-a, para. 1) by using one or several of the staggering 462 different developer products presented in the Google Developers site (Google LLC, n.d.-b).

As described above, Google's *third-party services* are among the most used in the app ecosystem and they thereby tap into the databanks of swarms of other apps. These apps are dependent on Google's services insofar as they solve a long list of challenges faced by app developers both before and after launch of an app. This includes Google Firebase Analytics for app optimizations and userbase growth (present on 19% of the 1 million most popular apps in Google Play) and Google AdMob (15%) for serving in-app ads and thereby financing free apps and increasing revenues (Binns et al., 2018). Though the app providers are using the services to operate and finance apps, the apps also generate value for Google as the company's business model is contingent with harvesting, mining, and reselling data on the online ad exchange, acquired through its own apps as well as its third-party services. In other words, just like the Facebook API and social plug-ins generate value for Facebook (Helmond, 2015), so do Google's services, as they become an infrastructural backbone for a wide range of other businesses while simultaneously figuring as a prominent data broker. The dependency on Google's services across large parts of the app ecosystem gives the company clout over the future of mobile communication and business models.

The last of the infrastructural resources—namely, that of *data accesses*—is perhaps the most crucial for understanding the basic economic foundation for Google. Looking at the company's apps alone, they can, on permissions granted by the users, collect vast amounts of commodifiable data and meta-data through accesses to all parts of any mobile device (camera, microphone, browser, etc.) and permissions to withdraw any type of data (photos, voice recordings, browsing history, etc.). Apart from the data Google collects from its own apps, its third-party services also potentially have access to staggering quantities of meta-data from a wide range of apps that use the services. While it is mandatory for app developers to make their data accesses and permissions publicly available, it is much more difficult to gain insights into the types of data actually harvested by third-party services (Van Kleek et al., 2017), meaning that this part of the data market continues to operate in the shadows. Google's activities in the Web ecosystem, which date back long before it became a prominent actor in the app ecosystem, both served as a foundation (economically as well as technologically) for their mobile app activities and became part of their mobile business. That is, when joining its forces, from the app ecosystem and that of the Web, Google is able to combine data points from Web history with other types of (app-centric) information, for instance, location data and more. Cementing the value inherent in controlling these resources, a recent release from Alphabet

shows how revenues from Google's services ("primarily from advertising") soared to 168 million U.S. dollars in 2020 alone (Alphabet Inc., 2021, p. 9).

To sum up, the case study of Google provides explanations for the power structures of the broader app ecosystem. Google's immense influence on the contemporary mobile markets reflects both its historical position as a key gatekeeper in the Web ecosystem and its ability to gain new territory through product development, aggressive competition strategies, and acquisitions. As indicated above, Google's power starts long before and continues well beyond apps, and despite its peripheral position in the mobile device market, the company is continuously investing in other kinds of hardware—operating, for instance, as a critical actor in cloud computing, fiber-optic submarine cables, and access networks. Hence, Google is constructing technical territories and cementing a strong infrastructural power, that, as voiced by Munn (2020), is often intentionally implicit: "Such influence is powerful precisely because it is not a grand and spectacular strategy but a functional and often invisible reality, anchored in *cables and copper, standards and protocols, switchgear and server racks*." (p. 15, emphasis added).

Conclusions and Perspectives

By advancing the concept of an app ecosystem, this article developed a conceptual lens through which to explore the power configurations and control mechanisms that characterize the contemporary mobile markets. This conceptualization emphasizes the materiality, intermediality, and institutional situatedness of mobile communication and paves the way for empirical studies that look beyond particular apps and genres of apps. Combined with a political economy approach that identifies the dominant market actors through their control over critical infrastructural resources—mobile devices, operating systems, app stores, apps, third-party services, and data accesses—the ecological terminology formed a basis for investigating diversity and invasiveness in the app ecosystem. That is, the ecology metaphor allowed us to see how data-financed businesses are not only *intrusive* in their "pervasiveness, formativity, exploitation, and exclusion" (Ytre-Arne & Das, 2019, p. 186) but also *invasive* in the ways they dictate and control the ecosystems they inhabit.

Similar to other ecological investigations, we have argued that analyses of app ecosystems can be conducted by applying a bird's eye view and studying the ecosystem in its totality and in relation to the broader communication environment; by going below surface to understand the underlying mechanisms and activities of this particular system; and by focusing on individual species. The first part of the explorative analysis showed that, at the surface, the app ecosystem appears to be a complex and diverse environment, enabling users of mobile devices to choose from a multitude of services and allowing app developers to market their products through various channels and by means of various third-party services and business models. It is therefore compelling to conclude that an abundance of different services and products have replaced the scarcity of former communication media, thereby eliminating the need for competition regulation. However, as argued by Winseck (2008), the question of diversity depends on the measures we use: "Whether or not we consider 'numerical diversity' (the number of channels available in any given area) versus 'source diversity' (a measure of the number of media owners in any given area)" (p. 34). In other words, scrutinizing the underlying ownership and power structures allows us to understand the app ecosystem in depth.

The second part of the explorative analysis ventured into ownership structures that cut across the six types of infrastructural resources that support app-based communication. It demonstrates how a political economy perspective can challenge and nuance the notions of the app ecosystem as an open marketplace. The analytical examples show how single market actors dominate the app ecosystem: The largest tech companies hold significant market shares within the individual subsystems of the greater app ecosystem, meaning that the markets for, for instance, operating systems, app stores, or third-party services are highly concentrated. At the same time, these market actors control assets across the value chain, thereby gaining independence while simultaneously making other market actors ever more dependent on them. Power in the app ecosystem is, in other words, established, exercised, and amplified through vertical as well as horizontal alignment strategies, where single companies control the infrastructural backbone that other market actors rely on and, thereby, dictate the structural conditions for mobile communication.

The final part of the explorative analysis placed Google under the microscope and discussed how the company has evolved into an invasive species, not only in the app ecosystem but also across the digital ecology: Google invades the lives of the users who depend on its services for their everyday communications through harvesting, mining, and reselling data about them. It also invades the business models and practices of competing species who rely on Google's infrastructures (be it the company's operating system, app store, third-party services, or other resources), by piggybacking on their products and generating value that feeds back into the Google conglomerate. And finally, Google, similar to dominating plants, animals, or organisms in natural ecosystems, controls large quantities of the app ecosystem, and is thereby able to exterminate, absorb, or significantly harm competing species, and ultimately break down the diversity of the system.

On the basis of the theoretical conceptualization and the empirical explorations of the contemporary app ecosystem, we call for developing and rejuvenating the diversity agenda that is recurrent in media studies as well as in the regulation and monitoring of legacy media structures. For too long, commercial corporations in the tech industry have managed to avoid critical scrutiny by asserting that digital communication markets are inherently diverse and versatile given the abundance of different services that are largely free of charge in a monetary sense. While the lawsuits mentioned in the beginning and throughout the article are signs that the days of the wild, wild Web are over, the ecological approach emphasizes the need to look beyond and across the sectoral boundaries that continue to impact the ways we study and regulate digital markets. Large tech companies do not fit the confines of any past or new categories for legislation, nor do they compete on the terms of them: Amazon is *not* only an online retailer, Facebook is not merely a popular social network site, and Google is *not* just a search engine, but rather an invasive species with immense power over the entire app ecosystem as well as the digital ecology at large.

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