

Toward a Better Understanding of Open Ecosystems: Implications for Policymakers*

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Executive Summary

The digital realm is undergoing a significant transformation, marked by the emergence of platform business models and the concept of open ecosystems. This paper delves into the intricate nature of ecosystem openness, underscoring the point that the openness of ecosystems must be understood more as a spectrum than a mere binary state. We then discuss the benefits and challenges associated with open ecosystems. The discussion also highlights the role of centralized governance to ensure ecosystems' sustainable and effective functioning. Furthermore, we discuss our study's implications in the context of emerging technologies such as large language models, XR, and quantum computing. We conclude by discussing the implications for policymakers.

Point 1: Embracing Ecosystem Openness as a Spectrum, Not a Binary Dimension

Central to our report is the understanding that **ecosystem openness is not just an “open” or “closed” scenario. Instead, it spans a spectrum**, from wholly proprietary systems to entirely open-source ones. By embracing this dynamic perspective, policymakers can cultivate an environment that strikes the optimal balance between open and controlled governance structures.

Point 2: Unveiling the Multifaceted Benefits and Challenges of Open Ecosystems

Our analysis has unveiled that **open ecosystems generate substantial value** to third-party developers, consumers and our economy. Conversely, we highlight the challenges intrinsic to openness, like heightened coordination costs, potential ecosystem fragmentation, and difficulties with quality control. Grasping these nuances is pivotal for policymakers aiming to amplify open ecosystems' positive effects while curbing potential pitfalls.

Point 3: Understanding the Role of Centralized Governance for Maintaining a Healthy Ecosystem

As we delve into the complex nature of open ecosystems, this report underscores the **need for control and centralized governance**. These measures are vital **to counteract the potential pitfalls of open ecosystems and ensure their overall health**. Considering the inherent trade-offs of open ecosystems, policymakers should exercise caution in pushing ecosystems toward greater openness. Instead of dictating the degree of openness, it might be more beneficial to allow firms to experiment with varying levels of openness. This approach would let the market determine if multiple ecosystems, each with its own openness level, can coexist and cater to different consumer preferences. Throughout this process, policymakers should remain alert to potential negative externalities.

Introduction

Fueled by rapid advancements in network connectivity and computing power, ecosystems have emerged as a significant aspect of today's economy. From personal computers and smartphones to gaming systems and streaming services, an increasing number of firms are developing their own "ecosystems" (Jacobides, Cennamo, & Gawer, 2018). These ecosystems serve as platforms where other companies can create "applications" that complement the core offerings.

An organization's ecosystem encompasses all entities and individuals linked to its core technology or assets. These stakeholders can both influence and be influenced by the company's operations. Ecosystem sponsors provide inter-organizational frameworks that structure relationships among complementors, defining the roles and rules for collaboration. As Jacobides, Cennamo, and Gawer (2023) elaborate, ecosystems "minimize the costs of coordination and cooperation, allowing firms to leverage comparative advantages in innovation while ensuring system-level integration of modules into a coherent set of value options for customers."

The term "open ecosystems" has gained prominence in recent discussions about digital ecosystems. At times, as often is the case in antitrust reports, it is used normatively to describe the state ecosystems *should* tend to and guarantee participation and fair competition to all business users. This report addresses several key questions:

- What are open digital ecosystems?
- What are the benefits and drawbacks of open digital ecosystems?
- How can policymakers balance these benefits and drawbacks?
- What are the implications for emerging technologies like large language models (LLM), extended reality (XR)¹, and quantum computing?

The key findings and policy implications of our report are:

- **Embracing Ecosystem Openness as a Spectrum:** Policymakers should understand that ecosystem openness is not binary but exists along a continuum.
- **Unveiling the Multifaceted Benefits and Challenges of Open Ecosystems:** Open ecosystems offer significant value to third-party developers, consumers, and the economy. However, they also face challenges intrinsic to openness, such as increased coordination costs, potential fragmentation, and quality control issues.
- **Necessity of Centralized Governance:** To mitigate the drawbacks of open ecosystems, centralized governance is essential for maintaining their overall health.
- **Implications for Policymakers:** Given the inherent trade-offs, policymakers should exercise caution in advocating for greater openness. Rather than prescribing a specific level of openness, it may be more beneficial to allow firms to experiment with different degrees of openness. This approach would enable the market to determine if multiple ecosystems, each with its own level of openness, can coexist and meet diverse consumer needs. Policymakers should remain vigilant to potential negative externalities throughout this process.

¹ XR refers to the concept of using technology to create immersive environments, experiences, and interactions. It is an umbrella term for virtual reality (VR), augmented reality (AR), and mixed reality (MR).

Defining Open Ecosystems

Digital Ecosystems

Digital ecosystems differ significantly from traditional, physical business ecosystems (Yoo et al., 2010). A comprehensive understanding of digital ecosystems requires an integration of both technical components—namely, the architecture of digital technologies—and organizational components, which include governance rules that facilitate value-creating interactions between the core platform and external participants (Tilson et al., 2012; Ghazawneh & Henfridsson, 2013; Eaton et al., 2015; Tiwana, 2015; Parker et al., 2016; Adner, 2017; Constantinides, Henfridsson, & Parker, 2018; de Reuver et al., 2018; Kapoor, 2018).

In architectural terms, digital ecosystems are often categorized as either “platform-mediated networks” (Rochet & Tirole, 2003; Eisenmann, Parker, & Van Alstyne, 2006; Evans & Schmalensee, 2007) or as having a “layered modular architecture” that includes a service layer and a content layer (Yoo et al., 2010; Parker et al., 2016). However, these classifications capture only some of the essential features. A more nuanced definition, later proposed in the literature, describes a digital ecosystem as an extensible codebase (the platform) complemented by third-party modules (applications) and interfaces, such as APIs, SDKs, and templates, that enable interoperability (Tiwana et al., 2010; Boudreau, 2012; Tiwana, 2013; Anderson et al., 2014; Gawer, 2014; Ghazawneh & Henfridsson, 2015; Cennamo et al., 2018). These interfaces, often termed “boundary resources,” facilitate arm’s-length relationships between the platform and its participants and serve as the core unit of analysis for understanding digital ecosystem dynamics (Eisenmann et al., 2011; Henfridsson & Bygstad, 2013; Eaton et al., 2015).

From an organizational standpoint, the ecosystem includes both the governance model—comprising rules of participation and incentives set by the platform owner to encourage innovation (Tiwana, 2013; Parker & van Alstyne, 2014)—and the roles of platform participants, who autonomously and collaboratively act as complementors, contributing to the platform’s value proposition (Iansiti & Levien, 2004a, b; Lucas & Goh, 2009; Alt et al., 2010; Eaton et al., 2015; Teece, 2018). The latter becomes especially crucial when control is devolved to communities of app developers, a common occurrence in open-source software or open standards organizations (Hauge et al., 2010; Krogstie, 2012). In essence, a broader perspective is needed to examine the intricate web of interdependencies between the platform and all its participants. Digital ecosystems are uniquely characterized by these structured, multilateral relationships, forming a distinct collective organization that is not the traditional linear value chain (Jansen et al., 2009; Adner & Kapoor, 2010; Jacobides et al., 2018; Kapoor & Lee, 2013).

Jacobides et al. (2018, p. 2264) define an ecosystem as “a set of actors with varying degrees of multilateral, non-generic complementarities that are not fully hierarchically controlled.” While ecosystems are bound by specific types of complementarities and exhibit significant interdependence among providers of complementary innovations, products, or services, their value creation is not solely dependent on customized contractual agreements. Instead, it arises through the coordination of these interrelated, yet significantly autonomous, organizations.

Open vs. Closed Systems

All ecosystems exhibit some degree of “openness,” but the extent varies. In many digital ecosystems, openness is characterized by a system that grants third-party actors access for developing complementary products. This often involves providing APIs, software developer kits, and documentation. Firms shift from developing applications in-house to supporting third-party developers (Prügl & Schreier, 2006; Ghazawneh & Henfridsson, 2013). However, this level of openness still maintains the concept of ownership, allowing parties to modify rights and obligations through contracts or other rule-setting mechanisms (Boudreau & Hagiu, 2009).

Many PC and mobile operating systems (OSs), serving as infrastructures for innovation, fall into this category of openness.² For instance, Apple tightly controls its iOS operating system and associated devices like iPhones and iPads but allows external development of apps and media to complement its services (Boudreau, 2010).

Greater openness often involves ceding platform control to a developer community, commonly seen in open-source projects like Android, Chromium, Linux, and Apache. These communities, shaped by norms and nonpecuniary interests, can be more cooperative than a single platform owner (Lerner & Tirole, 2002; Feller et al., 2005; Roberts et al., 2006; Boudreau & Lakhani, 2009). For example, Linux is considered more open than Microsoft Windows, although both enable third-party innovations. Android’s open-source nature allows anyone to access and modify its source code, whereas Apple retains full control over iOS. In addition, Android allows software packages to be either distributed through application stores like Google Play Store or installed directly by users, while on Apple’s iOS, all software packages must be vetted by and distributed through Apple’s App Store. Scholars have also examined varying openness levels in digital marketplaces (Ghazawneh & Henfridsson, 2015) and payment platforms (Ondrus et al., 2015).

Products with different openness levels can coexist within a single ecosystem. For example, while Android is typically regarded as an open-source project, there are different layers of openness for different Android implementations. The most open level is the Android Open-Source Project (AOSP), which is the fundamental set of publicly available source codes. The usage of AOSP does not require permission from Google or any other parties. Then, there is a version of Android used on Google’s own devices such as Pixel, which comes with Google Mobile Services (GMS) including Google Search,

² For a discussion of these platform typologies and what specific economic problems and benefits each type delivers, see Jacobides, Cennamo, & Gawer (2023). They argue that transactional multi-sided platforms are new (inter)organizational structures of economic relations addressing market failure problems: Lack of or limited individual actors’ incentives to engage in a transaction due to failures to coordinate with other actors for exchange. Open platforms of this kind can deliver different benefits in the form of 1) better searching and matching of product/service providers with consumers; 2) lower transaction costs; and 3) lower information asymmetry problems. They define innovation platforms as (inter)organizational value architectures based on modular technological architectures that address innovation system failures: Limited individual actors’ incentives to invest in needed components and complements for an innovation system to work effectively due to failures to exchange knowledge and converge on a technological standard. Open innovation platforms bring benefits in the form of 1) greater interoperable complements and components; 2) components integration and extension into a technological system; 3) convergence over technological standards; 4) knowledge exchange for the development of compatible complements.

Google Play, YouTube, Google Maps, etc. Finally, Original Equipment Manufacturers (OEMs), such as Samsung, OPPO and VIVO, often carry customized Android implementations on their own devices, which are built upon AOSP and may or may not have the GMS pre-installed.

The academic literature presents multiple definitions of open ecosystems to capture varying degrees of openness. Two key aspects frequently mentioned are access, which refers to “*who*” is allowed to use the platform, and authority, which pertains to “*what*” actions are permitted on the platform.

Focusing on the aspect of access, Tiwana (2013), building on Evans et al. (2006), defines platform openness as “whether outsiders require permission from the platform owner to build on it.” De Reuver et al. (2022) argue that platform openness involves “allowing third parties to access platform resources, either by adopting open-source models or by making specific interfaces, such as APIs, available.”

On the authority side, Nachira, Dini, & Nicolai (2007) claim that digital ecosystem openness means “fewer intellectual property rights restrictions in the private sector, along with initiatives like Open Access Publishing or Creative Commons in academia.” De Reuver et al. (2018) define platform openness as “the degree to which platform boundary resources support complementary offerings.”

Some definitions blend both aspects. Eisenmann, Parker, & van Alstynne (2009) describe platform openness as “the extent to which the platform imposes fewer restrictions on participation, development, or usage across its various roles, whether for developers or end-users.” Boudreau (2010) argues that system openness relates to “easing restrictions on the use, development, and commercialization of technology,” contrasting this with closed systems, which are “wholly owned, proprietary, vertically integrated, and controlled by a single entity.”

Additionally, Broekhuizen et al. (2021) propose that platforms must also decide on the level of openness concerning product categories (“*what*”) and communication and distribution channels (“*where*”).

These studies indicate that most digital systems are neither purely open nor closed; rather, openness exists on a spectrum (West, 2003; Schaarschmidt et al., 2015). Optimal openness levels are crucial for platform sustainability (Gawer & Cusumano, 2002; West, 2003; Gawer & Henderson, 2007; Eisenmann, 2008; Parker & Van Alstynne, 2008; Boudreau, 2010). Van Alstynne, Parker, and Choudary (2016) argue that platforms can fail if they are either too closed, stifling network effects, or too open, inviting poor-quality contributions.

Impact of Open Ecosystems

Benefits of Open Ecosystems

We categorize the benefits of open ecosystems into three primary beneficiaries: 1) complementors or developers, 2) consumers, and 3) the economy at large. It’s important to note that these categories are not mutually exclusive; benefits to one group often spill over to others. For instance, increased productivity and reduced development costs can attract more developers to the ecosystem, thereby stimulating innovation and intra-platform competition. This, in turn, offers consumers more choices at lower prices and contributes to overall economic growth.

1) Value Creation for Developers

Increased Autonomy

Open ecosystems typically grant developers greater autonomy, which is vital for their productivity and performance. Research has shown that openness is instrumental in fostering intrinsic motivation by providing greater work autonomy (Barrick & Mount, 1993; Dewett, 2007; Wu et al., 2007). This encourages developers to work longer hours and engage in risk-taking and creative behaviors (Oldham & Cummings, 1996).

Studies also indicate that individual developers are more likely to invest in a software project when it is open-source and offers strong reputational benefits (Economides & Katsamakos, 2006; Hagi, 2007; Belleflamme & Peitz, 2010; Zhao, 2010; Lin et al., 2011). Scacchi (2007) observed that the shared beliefs and practices around freedom of expression and choice form part of the virtual organizational culture that characterizes open-source projects (see also Elliott & Scacchi, 2005; Benkler, 2006). Hilbert et al. (2011) found that app developers are more satisfied when granted greater authority, as it allows them to co-create value with end-users and differentiate themselves from competitors (Benlian, Hilbert, & Hess, 2015).

In a related study, Schaarschmidt, Homscheid, & Kilian (2019) explored the relationship between platform openness and developer engagement, measured by the number of projects and hours worked. They concluded that various aspects of openness—such as contribution, development, and commercialization—positively influence developers’ sense of autonomy and work motivations, leading to increased productivity.

Developers’ increased autonomy is evident in their distribution choices. For instance, Android app developers have multiple avenues to reach users, including various app stores beyond the Google Play Store. They can also bypass these stores by offering web apps—applications crafted with web technologies that run in browsers, contrasting with native apps—or by directly providing the installation package. In contrast, Apple’s iOS platform has a single app store: the App Store. Direct app installations on iOS are only possible if users “jailbreak” their devices. Web apps face challenges competing with the iOS App Store because Apple mandates all browser providers on iOS to utilize the WebKit framework, which lacks essential features and often presents glitches when running web apps.³

This distribution diversity is advantageous for developers. With web apps, for instance, companies enjoy greater design, functionality, and technological flexibility. They can also expedite app launches. For example, the creator of HypeDocs initially released the app on a website, finding it simpler to instantly test new concepts without navigating the approval process required by app stores.⁴ Moreover, by directly reaching users (although developers will lose the benefits that app stores offer such as the easy reach to phone users, the ease of purchase, and the integrated rating system) they can avoid the 15% to 30% fees imposed by app store proprietors, significantly reducing development costs.

³ <https://open-web-advocacy.org/files/OWA%20-%20Bringing%20Competition%20to%20Walled%20Gardens%20-%20v1.0.pdf>

⁴ <https://www.fastcompany.com/90623905/ios-web-apps>

Different channels also enable developers to cater to a broader user base with varied preferences. Consider web apps: half of smartphone users prefer using a company's mobile site for browsing or shopping and are reluctant to download an app.⁵ Furthermore, limited storage is a primary reason for app deletions, yet an installed web app typically consumes less than 1MB.⁶ This indicates that by transitioning from native to web apps, developers can engage certain user segments more effectively, leading to higher conversion rates. For example, users on older devices engage 11% more with Lyft's Progressive Web App (PWA) than with its native app and are 40% more likely to click "install PWA" than "Download App."⁷

Reduced Development Costs

Open ecosystems offer a range of benefits that lower the barriers to entry for developers. These ecosystems provide diverse tools and technologies that mitigate technological uncertainty and the costs associated with hold-up problems (Cennamo et al., 2018). Low upfront costs and publicly available specifications and documentation make it easier for less-experienced developers to join a software platform (West, 2003). Additionally, these ecosystems often offer abundant resources and collaborative opportunities, fostering learning and innovation (Foerderer et al., 2018; Özalp et al., 2018). Developers can share knowledge to generate value-added complements, thereby enhancing the ecosystem's generativity (Boudreau, 2012; Dokko et al., 2014).

In the realm of open-source software (e.g., Lakhani & Wolf, 2005; Lakhani & von Hippel, 2003), studies have shown that resource sharing and communication among programmers from diverse backgrounds (Aksulu & Wade, 2010; Krogh et al., 2012) expedite the development of innovative software modules and eliminate intellectual property negotiation hassles (Nagle, 2019; Wen, Ceccagnoli, & Forman, 2016). Eilhard & Ménière (2009) examined open-source projects on SourceForge and found that developer productivity significantly increased with access to code libraries, showing non-decreasing returns to scale.

When smartphones first entered the market, device makers faced a dilemma: they could either pay a licensing fee to use an existing operating system (OS) or shoulder the cost of developing their own. Both options resulted in substantial fixed costs and extended development cycles. However, the landscape changed in 2007 when Google collaborated with the mobile industry to form the Open Handset Alliance. The alliance aimed to establish Android as an open-source OS, allowing anyone to access, download, and modify its source code without charge. This shift enabled device manufacturers to install Android on their products without the need for licensing or developing a proprietary OS. As a result, manufacturers significantly reduced development costs. For example, Gigaset, a German hardware manufacturer, cut its production costs by 30% with the aid of Android and launched its first Android

⁵ <https://www.thinkwithgoogle.com/data/smartphone-user-mobile-shopping-preferences/>

⁶ <https://www.thinkwithgoogle.com/data/why-users-uninstall-travel-apps/>

⁷ <https://twitter.com/ebidel/status/1445425210119704578>

smartphone in September 2015.⁸ This reduction in development costs also had a broader impact: between 2011 and 2013, the average price of smartphones worldwide fell by 25%.⁹

Open ecosystems have also reduced development costs in the field of quantum computing, which leverages quantum physics to solve problems at speeds unattainable with classical computers. Given the specialized equipment required, installing a quantum computer on every desk is impractical. Instead, “quantum-as-a-service” allows researchers to access quantum computing capabilities via the internet, eliminating the need for physical access.¹⁰ Among others, IBM Quantum is an open platform that makes real quantum hardware available to hundreds of thousands of developers. These quantum computers are programmed using Qiskit, an open-source quantum software development kit (SDK) with modules for applications in finance, chemistry, optimization, and machine learning.¹¹ Similarly, Google has developed Cirq, its own open-source framework for programming quantum computers.¹²

Open ecosystems can further reduce development costs by offering standardized environments. For instance, when Microsoft replaced Internet Explorer with Edge, based on the open-source Chromium project, they claimed that developers could now have a high level of confidence that any toolset or framework they wished to use would be compatible with Edge.¹³

Boosting Transparency

Open ecosystems often provide developers with enhanced transparency, enabling them to better understand both architectural and organizational rules. This transparency extends to technical documentation, end-user communication, and market mechanisms. As a result, developers can more effectively create and distribute third-party applications on the platform and stay informed about governance decisions (West & O’Mahony, 2009; Anvaari & Jansen, 2010; Hilkert et al., 2011; Setzke, Böhm, & Krcmar, 2019). These transparency features significantly influence platform adoption among developers (Robillard & DeLine, 2010; Jansen, 2013; Puvvala et al., 2016).

Moreover, a higher level of openness acts as a commitment device, reassuring developers that the ecosystem they invest in will continue to exist and thrive. For example, once Google had released Android as open source, the OEMs building their customized OS on these codes can now trust that Google will not pull the rug and their relationship-specific investments will not go under. This, in turn, further encourages innovation, collaboration, differentiation, and interoperability.

⁸ <https://www.android.com/everyone/enabling-opportunity/>

⁹ [BCG - The Growth of the Global Mobile Internet Economy \(PDF\) - February 2015](#) (page 7)

¹⁰ James Andrew Lewis and Georgia Wood, “Quantum technology: Applications and implications” <https://www.csis.org/analysis/quantum-technology-applications-and-implications> [May 25, 2023]

¹¹ IBM, “What is quantum computing?” <https://www.ibm.com/topics/quantum-computing>

¹² Cirq, <https://quantumai.google/cirq>

¹³ <https://query.prod.cms.rt.microsoft.com/cms/api/am/binary/RWEs2U>

Enhancing Security

Open ecosystems, particularly those based on open-source platforms, offer an additional layer of transparency. This transparency in code not only allows for a broader examination by multiple individuals but also provides developers with the flexibility to verify the code independently or through external audits, as well as contribute to the codebase (Payne, 2002; Almeida, Oliveira, & Cruz, 2011). This openness enables a large community of contributors to swiftly identify and fix vulnerabilities, a phenomenon known as Linus' Law, often summarized as "Given enough eyeballs, all bugs are shallow" (Raymond, 1999, p. 23).

Research suggests that the collective wisdom of an open ecosystem often yields better security outcomes than a closed system reliant solely on experts (Shankland, 2003; Giles, 2005; Hoepman & Jacobs, 2007; Greenstein & Zhu, 2016, 2018; Greenstein, Gu, & Zhu, 2021). This is achieved through several mechanisms:

- Users with diverse skill sets are likely to complement one another, identifying different vulnerabilities.
- Unlike closed systems, where only the producers can issue patches, open systems encourage community engagement in resolving issues.
- Open-source communities facilitate more efficient communication about bugs between developers and users.
- Knowing their work will be scrutinized, open-source developers tend to exercise greater caution and employ the best available tools to secure their systems.

Consistent with these findings, a 2022 open-source survey focused on Southeast Asia and India found that 97% of participating organizations cited enhanced security as a significant factor influencing their adoption of open-source software.¹⁴

2) Value Creation to Consumers

Access to a Wide Range of Innovative Complementary Products

By relinquishing control (Katz & Shapiro, 1986; Shapiro & Varian, 1998; Farrell & Katz, 2000; Farrell, 2007), open ecosystems can drive and stimulate external innovation (Economides & Katsamakos, 2006; Boudreau & Lakhani, 2009; Eisenmann et al., 2009; Parker & van Alstyne, 2009; Boudreau, 2010; Gawer, 2014; Schrieck, Wiesche & Krcmar, 2021). These ecosystems are generally more modular than their closed counterparts, as they grant wide access to third-party developers of interoperating, mix-and-matchable components. This in turn fosters vibrant markets with diverse ideas and active experimentations, thereby accelerating the pace of innovation (Farrell et al., 1998; Baldwin & Clark, 2000; Farrell & Weiser, 2003; von Hippel, 2005; MacCormack et al., 2006; Tiwana et al., 2010; Parker et al., 2017; Jacobides, Cennamo, & Gawer, 2023).

Boudreau (2010) studied the development history of handheld computing systems between 1990 and 2004 and found that granting access to independent hardware developers was associated with a dramatic

¹⁴ <http://www.ashnik.com/the-state-of-open-source-trends-2022> (Accessed June 2023)

increase in the rate at which new devices were developed— up to a fivefold acceleration—while platform owners who give up varying degrees of control also experienced accelerated development, but at a smaller order of magnitude. Most of the acceleration can be explained by the liberalness of the licensing approach, followed by lowering entry barriers by sharing hardware designs. When developers of complementary components are granted access to the platform, the intensified competition encourages innovation.

Yoo et al. (2010) observe that, in open digital ecosystems, modules are designed independently from particular product architecture. For instance, when Google introduced the Google Maps APIs, they were not tailored for specific products. However, in a short period, these APIs were integrated with various online resources, such as Craigslist and Facebook, and incorporated into different hardware types, leading to unanticipated innovations. Thus, the potential for innovation in digital ecosystems is limitless.

In 2015, Google announced that TensorFlow, a machine learning and artificial intelligence software library developed by the Google Brain team, would become open-source and free to use. Since then, TensorFlow has been employed in various groundbreaking applications, from planet discovery to medical diagnostics and environmental conservation.¹⁵ For instance, TensorFlow aided in the discovery of the planet Kepler-90i, making the Kepler-90 system the second known system with eight orbiting planets. The library also serves as a cornerstone for other innovative projects like DeepMind’s AlphaGo and OpenAI’s ChatGPT.¹⁶ It is worth noting that ChatGPT also utilizes PyTorch, an open-source machine learning library developed by Facebook, along with Hugging Face’s Transformer and other open-source libraries.¹⁷

Open ecosystems have catalyzed many other innovations. For example, the recent boom of digital payments in Brazil was enabled by the prevalence of point-of-sale (POS) machines, and a majority of these devices use AOSP as their operating system. In the realm of AI-generated art, open-source platforms like Stable Diffusion have outpaced closed-source competitors like Midjourney in technological innovation. This includes the integration of ControlNet, a plug-in that allows users to copy compositions or human poses from a reference image and impose structural and artistic controls on the image, and LoRA (Low-Rank Adaptation), a training method that allows fast fine-tuning of model parameters to generate “slightly different” images with desired styles more efficiently. Both ControlNet and LoRA are considered industry game-changers but they are incompatible with Midjourney due to their closed-source nature.

With the possibility of multihoming, owners of more closed ecosystems may even invest in competing open ecosystems to foster innovation. They can later reap benefits through higher revenues generated by an increased number of applications that become available on their more closed ecosystems (Casadesus-Masanell & Llanes, 2015). This may explain why Microsoft, developer of the proprietary

¹⁵ <https://hackernoon.com/9-things-you-should-know-about-tensorflow-9cf0a05e4995>

¹⁶ Cassie Kozyrkov, “9 Things You Should Know about TensorFlow,” <https://hackernoon.com/9-things-you-should-know-about-tensorflow-9cf0a05e4995>

¹⁷ Steven J. Vaughan-Nichols, “ChatGPT, how did you get here? It was a long journey through open source AI,” <https://www.theregister.com/2023/03/24/column/>

Windows operating system, has ranked high in the list of top contributors to the competing open-source operating system Linux (Corbet et al., 2012).

Greater openness offers users protection against potential hold-up problems. It allows them to switch between various service providers without losing their platform-specific investments, thereby keeping prices competitive. This partly accounts for the appeal of Linux in enterprise servers. Companies often make significant investments in server hardware, software, and training, so the flexibility to switch between different Linux vendors helps them avoid lock-in to more closed systems like Windows Server (Eisenmann, 2008).

More complementors on open ecosystems also promote intra-platform competition (Cennamo & Santaló, 2013). For example, the Google Play Store alone offers over one million apps, a number that grows when considering the entire Android ecosystem, which includes multiple global and regional app stores from OEMs and other companies like Samsung, Lenovo, Orange, and TIM (Telecom Italia). In contrast, less open ecosystems like Apple's iOS typically have a single app store with a more restrictive vetting process.

The proliferation of apps and app stores has led to a corresponding increase in device variety. There are over 24,000 types of Android devices produced by nearly 1,300 different brands. This competition, coupled with the cost-saving benefits of using Android free of charge, has led to lower device prices. Specifically, Android has enabled the emergence of a new smartphone segment priced between \$100 and \$500. In 2015, the average cost of an Android device was \$208, in stark contrast to phones on closed platforms, which can average as high as \$651.¹⁸

Greater Platform Choices

The emergence of open ecosystems often injects competition into the market, offering consumers a broader array of choices. For instance, Internet Explorer (IE), once the dominant web browser rooted in the proprietary Mosaic browser, has seen its market share decline. This decline followed the introduction of open-source alternatives like Mozilla Firefox in 2004 and Google Chrome in 2008, which is based on Google's open-source Chromium project. In 2020, Microsoft launched its new Chromium-based Edge browser to replace IE, and Edge has since become the world's second most popular browser.¹⁹

In the realm of large language models (LLMs), open-source platforms like LLaMA and its successor, LLaMA 2, have democratized access. These platforms enable small firms and even individuals to fine-tune their own models, quickly surpassing the performance of Meta's standard models. Notable fine-tuned models include Stanford's Alpaca and LMSYS Org's Vicuna. Vicuna-13B achieves approximately 92% of OpenAI's ChatGPT 4 in quality—just one percentage point lower than Google Bard.²⁰ In essence, open LLMs are eroding the competitive advantage held by leading closed LLMs.

Furthermore, many open ecosystems allow developers not only to build on them, but also further build against them, thus stimulating inter-firm competition. We have already mentioned that many OEMs

¹⁸ [KPCB - Internet Trends - June 2016](#) (Page 12)

¹⁹ https://en.wikipedia.org/wiki/Microsoft_Edge https://en.wikipedia.org/wiki/Internet_Explorer

²⁰ <https://lmsys.org/blog/2023-03-30-vicuna/>

build their customized implementations based on the AOSP, maintained by Google. These systems are then used in their own devices to compete with Google's Pixel phones, which run Google's implementation of the Android OS. Similarly, Chromium has served as the foundation for several new browsers, including Microsoft Edge, Opera, and Brave, all of which compete with Google Chrome.

Along with the increase in consumer choices, competition among ecosystems is likely to reduce prices for consumers.

Reduced Lock-In

Open ecosystems often enhance the interoperability of diverse systems, facilitating seamless collaboration. Built on standardized protocols and formats, these ecosystems simplify cross-system communication and functionality. Open-source software further adds flexibility by allowing easy adaptation and porting across platforms (Almeida, Oliveira, & Cruz, 2011). This ensures that consumers can easily switch between different products or services without losing functionality.

One effective approach to achieving interoperability is the adoption of standards, such as open APIs. Standards "can set a common communication language and procedure for communication between digital services, and work to interconnect multiple services offered by the same firm as well as services offered by different firms" (OECD, 2021). Open-source software also bolsters trust in interoperability through its transparent nature.

Consumers can benefit from developer interoperability. Android fosters this interoperability, allowing developers to cater to devices made by a variety of manufacturers using just one OS. This flexibility frees consumers from device lock-in, enabling them to utilize the same apps and transfer data across different Android devices. Conversely, firms in more restrictive ecosystems, like Apple, often adopt strategic lock-in strategies. They design their ecosystems to serve their suite of products (e.g., the iPhone, iPad, and Apple Watch), leading to higher switching costs for consumers. While users enjoy smooth interoperability within such an ecosystem, those contemplating a switch face financial burden. For instance, when moving from an iPhone to an Android device, consumers often need to repurchase apps and subscriptions. It is worth noting that iOS has a smaller selection of free or ad-sponsored apps compared to Android.²¹ Highlighting this strategy, Apple executive Eddy Cue once remarked, "[g]etting customers using our stores (iTunes, App and iBook store) is one of the best things we can do to get people hooked to the ecosystem." He further noted, "[t]he more people use our stores, the more likely they are to buy additional Apple products and upgrade to the latest versions. Who's going to buy a Samsung phone if they have apps, movies, etc. already purchased? They now need to spend hundreds more to get to where they are today."²²

With interoperability, consumers can also experience a seamless user experience. Chrome, available on a wide range of platforms including Windows, macOS, Linux, Android, and iOS, offers users a consistent browsing experience and unified browsing history across all devices. This is a marked

²¹ https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3852744

²² Trial Ex. PDX-0142.15, Epic Games, Inc. v. Apple Inc., No. 4:20-cv-05640-YGR (N.D. Cal. May 11, 2021) (Email from E. Cue to P. Schiller on Feb. 14, 2013), <https://cdn2.unrealengine.com/epic-proposed-findings-of-fact-and-conclusions-of-law-redacted-bafb520e1d4b.pdf>

improvement over Internet Explorer (IE), which was primarily limited to Windows. The situation has further improved with Microsoft's new Edge browser, based on the same Chromium platform as Chrome, ensuring a consistent consumer experience.

3) Value Creation to the Economy

Fueling Economic Growth

Open ecosystems play a significant but often underestimated role in economic productivity. For instance, key components of the Internet's infrastructure, such as Linux (server), BIND (Domain Name Server or DNS), Apache (web server), and MySQL (database management system), are open-source and have been crucial in maintaining the Internet since its inception (Payne, 2002; Hoepman & Jacobs, 2007). Greenstein and Nagle (2014) analyzed a novel dataset of U.S. web servers and estimated that Apache alone could contribute between \$2 billion and \$12 billion to the economy. This underestimation largely stems from the non-pecuniary, zero-revenue nature of open-source software. A more recent study by Murciano-Goroff, Zhuo, & Greenstein (2021) updated this estimate, suggesting that the economic value created by open-source web server software is substantially underestimated by over \$4.5 billion. One study in 2015 on Android indicated that the platform supported approximately 13 million jobs and contributed \$3 trillion to the global GDP.²³

Furthermore, open ecosystems foster entrepreneurship. Previous research has highlighted the positive impact of participation in open-source communities on entrepreneurial activities (Lerner and Schankerman, 2010; Nagle, 2018). Adopting a global perspective, Wright et al. (2023) find a correlation between GitHub participation (used as a proxy for involvement in open-source projects) and entrepreneurial rates, providing evidence that low- and middle-income countries can catch up with, or even surpass, established players by encouraging entrepreneurial activities in software-intensive sectors (Lee & Malerba, 2017).

Improving Equality and Inclusivity

Open ecosystems contribute to economic growth by enhancing inclusivity. We have shown that Android significantly lowers the cost barrier to smartphone ownership, with an average device price of \$208—just a third of the cost of smartphones running on more closed operating systems. Reports indicate that Android-based smartphones are available for under \$100 in India and Africa, below \$60 in Nigeria,²⁴ and even less than \$50 in markets like the Philippines.²⁵ Feature phones operating on open-source operating systems have the potential to be even more affordable. In Zambia, the cost of an entry-level mobile device has decreased from over 50% of monthly GDP per capita in 2016 to less than 20% in 2021, thanks to the availability of cheaper smartphones and smart feature phones. One such example is

²³ <https://www.android.com/everyone/enabling-opportunity/>

²⁴ Smartphonetobuy.com - Cheap Android Phones Under 15000 Naira In Nigeria

²⁵ [Tech in Asia - Smartphone Adoption in the Philippines - April 2014](#)

the MTN Ka Toffee smart feature phone, which is priced at under \$20 and runs on KaiOS, a web-based mobile operating system developed from the open-source project Firefox OS.²⁶

By driving affordability across the globe, it also democratizes access to information around the world, which is particularly crucial in regions where internet access is limited. Many people in these areas gain their first online exposure through mobile devices, opening doors to new opportunities such as starting businesses, sharing content, or gaining an education for themselves or their children. The proliferation of affordable mobile devices has played a significant role in driving the adoption of mobile payment, on-demand services like ridesharing and food delivery (Dash, Sharma, & Yadav, 2023), and government services, including emergency alerts.²⁷ Additionally, it has facilitated mobile innovations that cater to the needs of people in developing countries and rural areas. For instance, Sendy, a delivery service app based in Kenya, was developed on the Android platform. The choice of Android was influenced by its popularity among smartphone users in Kenya and East Africa.²⁸ Another notable app, GiftedMom, addresses maternal and infant mortality in Africa. This app offers vital information on pregnancy, breastfeeding, and child vaccination, providing crucial support to expectant mothers and those with children—a potentially life-saving service. The developers opted for the Android platform since 70% of smartphone users in Africa use Android. This choice also ensured that GiftedMom remained lightweight, facilitating easy downloads in remote areas. The team behind GiftedMom anticipates reaching five million users across Africa in the next three years and plans to expand the concept to other developing nations in the future.²⁹

Open ecosystems also foster broader participation by accommodating diverse skill sets. For instance, IBM's Qiskit team highlighted in a blog post how web developers can contribute to quantum computing. Since its launch in 2017, Qiskit has spurred numerous advances in quantum applications, hardware design, and theory. The open-source community actively reports and fixes bugs, proposes new features, and drafts essential documentation. Notably, some of the most significant contributions don't require any expertise in quantum computing, including the Qiskit.org website and the Qiskit Textbook. Thus, with just a few basic web development skills, everyone can get started with contributing to quantum computing.³⁰

Drawbacks of Open Ecosystems

Open ecosystems come with their own set of challenges, primarily stemming from the relinquishment of control and governance.

²⁶ <https://www.gsma.com/mobileeconomy/wp-content/uploads/2023/03/270223-The-Mobile-Economy-2023.pdf>

²⁷ See, for example,

<https://www.dhs.gov/sites/default/files/publications/Wireless%20Emergency%20Alerts%20Mobile%20Penetration%20Strategy.pdf>

²⁸ <https://www.android.com/everyone/stories/sendy>

²⁹ <https://www.android.com/everyone/stories/giftedmom>

³⁰ Qiskit, "How Web Developers Can Contribute to Quantum Computing" <https://medium.com/qiskit/how-web-developers-can-contribute-to-quantum-computing-b658eae92a3a> [May 4, 2022]

Quality and Fragmentation Concerns

Open ecosystems often struggle to maintain a unified direction due to the diverse visions of multiple contributors. This can result in fragmentation, as seen with Blink, a rendering engine forked from WebKit in 2013. Contributions between WebKit and Blink are not directly transferable, and the two ecosystems differ significantly in work ethics and processes.³¹

Fragmentation problems can undermine the takeoff of the underlying market for complementary products, and lead eventually to the demise of the ecosystem, as in the case of Nokia's Symbian OS. West and Wood (2013) documented how conflicting governance mechanisms between the key actors in the Symbian ecosystem controlling the OS and those controlling access to the market for complementary apps and services (i.e., the different telecom network operators), led to way too fragmented and localized apps markets, and created conflicting incentives that constrained the ecosystem's capacity to evolve. All of this eventually led to multiple failures, including the inability to mobilize app developers and create a thriving marketplace for applications working across multiple devices and telco operators such as those later created by Apple and Google. West and Wood (2013) have highlighted how the lack of unified control over such market interfaces and the ability to set standardized rules were among the primary factors behind the demise of the Symbian OS platform and its ecosystem.

Additionally, the absence of structured management and quality assurance can lead to inconsistent platform quality. Contributions may come from hobbyists or less experienced individuals, posing risks to software or platform reliability. As Wareham, Fox, & Giner (2014) observed, "If a thousand flowers grow, inevitably, some will be undesirable and harmful to the ecosystem. In the extreme, the unconstrained growth of low-quality innovations can kill a platform."

Greater openness can also lead to a wider variance in the quality of complements. Low-quality complements may tarnish the platform's reputation, especially as the ecosystem matures and competition intensifies (Cennamo & Santaló, 2019). Consumers may find themselves navigating through app marketplaces filled with questionable or even hazardous offers, potentially deterring users (Gawer & Cusumano, 2002; Cennamo & Santaló, 2019; Panico & Cennamo, 2022).

Sometimes, quality issues can lead to the downfall of an entire ecosystem. A case in point is Atari, a pivotal name in video game history. In the 1970s and 1980s, Atari gained immense popularity with its arcade games, particularly *Pong*. The company's foray into the home console market began with the Atari 2600 in 1977, a revolutionary device that popularized video gaming at home. It featured interchangeable game cartridges, allowing for a diverse gaming experience. However, Atari failed to maintain quality control, resulting in a market saturated with subpar games. For instance, the number of available Atari games surged from 100 in June 1982 to over 400 by December, leading to a glut of unsold inventory.³² This eroded consumer trust and led to a sharp decline in sales in 1983, culminating in Atari's collapse and a crisis in the home video game industry. As Hiroshi Yamauchi, then-president of

³¹ <https://css-tricks.com/the-ecological-impact-of-browser-diversity/>

³² DeMaria, Rusel; Wilson, Johnny L. (2003). *High Score!: The Illustrated History of Electronic Games* (2 ed.). New York: McGraw-Hill/Osborne. pp. 103–105. [ISBN 0-07-223172-6](https://www.isbn-international.org/view/title/1072231726).

Nintendo, observed in 1986, “Atari collapsed because they gave too much freedom to third-party developers and the market was swamped with rubbish games.”³³

It is not easy for open ecosystems to address such quality issues. Google, for example, faces challenges in implementing security patches and rolling out new features across all Android devices. Several factors contribute to this issue: 1) Google does not offer technical support for OEMs using the basic Android Open Source Project (AOSP). 2) OEM modifications to AOSP reduce Google’s control over the OS. 3) Compatibility checks between OEM modifications and Google’s updates are costly and often not in the OEMs’ interest, as their profitability mainly relies on selling new devices. These challenges are exacerbated by the diverse range of devices running Android, including smartphones, tablets, TVs, car systems, watches, and foldable devices. In contrast, Apple’s centralized control over iOS allows for more streamlined updates across its device ecosystem.

Intellectual Property Concerns

One of the challenges inherent in open ecosystems is the vulnerability of ideas, innovations, and code to unauthorized copying or use. This could potentially result in the loss of competitive advantage for the complementor, especially if their contribution is a key aspect of their business model. Intellectual property (IP) issues can also emerge when complementors integrate open-source code into their proprietary applications. Open-source licenses vary, and some mandate that derivative works should also be open-sourced, leading to legal complexities and potential loss of IP control. Such diffuse property rights can diminish the incentives for all parties to invest in and foster innovation within the ecosystem (Katz & Shapiro, 1986, 1994; Shapiro & Varian, 1998; Eisenmann, 2008).

Baidu Baike, a Chinese-language web encyclopedia operated by Baidu, has been criticized for plagiarizing content from Wikipedia without proper attribution, making it one of the most egregious violators of Wikipedia’s copyrights. A unique challenge for Wikipedia is that the Wikimedia Foundation, which operates the platform, doesn’t hold copyrights on the articles; the editors and authors do, as per the foundation’s licensing agreement. This makes legal recourse challenging due to the fragmented nature of intellectual property rights.³⁴

In the evolving landscape of LLMs, firms often choose not to disclose how their models work. OpenAI, for instance, has withheld technical details of ChatGPT-4’s underlying model for competitive and safety reasons.³⁵ Bloomberg has followed suit with its recently released Bloomberg-GPT model, citing safety and business considerations and noting the model’s vulnerability to data leakage attacks.³⁶ While Bloomberg-GPT is likely trained on Bloomberg’s proprietary data, OpenAI has faced legal challenges for using publicly available data that may be subject to IP disputes. Both Reddit and Stack Overflow have filed lawsuits against OpenAI for unauthorized data usage in training their model, along with other smaller entities and individuals.³⁷

³³ <https://aboutthe80s.com/what-happened-during-video-game-crash-1983/>

³⁴ <https://abcnews.go.com/Technology/PCWorld/story?id=3451658>

³⁵ <https://www.zdnet.com/article/with-gpt-4-openai-opts-for-secrecy-versus-disclosure/>

³⁶ <https://www.zdnet.com/article/chatgpts-success-could-prompt-a-damaging-swing-to-secrecy-in-ai-says-ai-pioneer-benio/>

³⁷ <https://www.wired.com/story/stack-overflow-will-charge-ai-giants-for-training-data/>

Difficulty in Value Capture

Capturing value in an open ecosystem can be a complex endeavor, often due to the ecosystem's focus on free and open access to resources. As West (2003) noted, there is a trade-off between adoption and appropriation when determining the level of openness.

Take the AI-generated art industry as an example. The leading players are Stable Diffusion, which is open-source, and Midjourney, which is closed-source. While Stable Diffusion has seen more technological innovation—thanks to the integration of powerful third-party plugins like ControlNet and LoRA—Midjourney has been more financially successful. With just 11 employees, Midjourney reportedly generates \$750,000 in monthly revenue,³⁸ whereas Stable Diffusion is still burning money from the \$100 million raised in its seeding round.³⁹

For open ecosystems that inherently offer free access, alternative value capture strategies are essential. Some, like Red Hat, offer open-source products such as Red Hat Enterprise Linux (RHEL) but sell subscriptions for support, integration, and consulting services. Others, like Wikipedia, rely on voluntary donations or crowdfunding campaigns to fund development. Additionally, some open-source projects opt to generate revenue through advertising or affiliate links.

Operational Challenges

Maintaining an open ecosystem often necessitates careful coordination among diverse stakeholders to ensure compatibility and interoperability, and to prevent forking (Simcoe & Watson, 2019). Such processes can be time-consuming and costly. Due to the collaborative nature of open ecosystems, decision-making by consensus often takes longer than in closed, hierarchically managed systems. The costs associated with failure, monitoring, and communication rise as the number of complementors increases (Casadesus-Masanell & Halaburda, 2014; Choi, Nam, & Kim, 2017; Hagiú & Wright, 2019). Moreover, implementing control mechanisms to mitigate the risks of low-quality contributions can also be expensive (Wareham, Fox, & Giner, 2014).

Potential Malicious Usage

While most developers engage with open ecosystems in good faith, these platforms are not immune to exploitation by malicious actors. This raises concerns about user safety and privacy. Open ecosystems are also susceptible to competitive exploitation, making it easier for rivals to copy, reverse-engineer, or disrupt them (Constantinides, Henfridsson, & Parker, 2018; Karhu & Ritala, 2021). Hostile strategies may include building meta-platforms (Ghazawneh & Henfridsson, 2013), initiating proprietary platforms through open-source licensing (Pon et al., 2014), jailbreaking devices (Eaton et al., 2015), platform forking (Karhu, Gustafsson, & Lyytinen, 2018), and reverse-engineering critical processes using business data (de Prieëlle, de Reuver, & Rezaei, 2020).

³⁸ <https://helplama.com/discord-statistics/>

³⁹ <https://futurism.com/the-byte/stable-diffusion-stability-ai-risk-going-under>

Furthermore, the increased openness that comes with open-source platforms can make it easier for attackers to identify security vulnerabilities. While a large community of contributors can quickly find and fix these vulnerabilities, Hoepman & Jacobs (2007) argue that this openness may give attackers an unfair advantage.

Necessity of Control and Governance Measures

To balance the benefits and drawbacks of open systems, a certain level of control or centralized governance is often essential. The academic literature consistently emphasizes the need for appropriate governance to manage the delicate balance between generativity and control within an ecosystem (Cennamo & Santaló, 2019; Yoo et al., 2012; Tilson et al., 2010; Ghazawneh & Henfridsson, 2013; Wareham et al., 2014; Eaton et al., 2015). Such measures help coordinate activities and ensure the sustainable functioning of the open ecosystem. Without governance, an open ecosystem could devolve into chaos and ultimately fail.

Quality Assurance

The first objective of governance measures is quality assurance. Ecosystem orchestrators may employ various mechanisms to ensure quality (Tiwana et al., 2010; Wareham et al., 2014; Tiwana, 2015).

These gatekeepers can decide which complements are admitted (Ghazawneh & Henfridsson, 2013; Tiwana, 2013; 2015). For example, both the Apple App Store and Google Play Store have a stringent review process in place to ensure the quality and security of the apps available on their platforms. Apps submitted by developers undergo thorough checks to identify any potential security issues, policy violations, or harmful content. While Apple's approach is stricter, leading to fewer security issues, Android's less stringent process results in a broader variety of applications (Tilson et al., 2012; Pon et al., 2014).

After the collapse of Atari, Nintendo implemented tight restrictions on licensees and the number of titles they could produce. This focus on quality, along with a high license fee and a security chip to control content, ensured the sustainable functioning of the ecosystem around Nintendo's new NES console, leading to the recovery of the home video game market.

Ecosystem sponsors can also leverage "soft quality incentives" like selective promotion (Rietveld, Schilling, & Bellavitis, 2019) and rewards for high quality (Claussen, Kretschmer, & Mayrhofer, 2013). For example, Kickstarter's "Projects We Love" badge serves as a quality signal, influencing potential backers' perceptions and increasing a campaign's likelihood of success (Mollick, 2014; Short et al., 2017; McSweeney, 2018; Anglin et al., 2018; Younkin & Kuppuswamy, 2018; Tajvarpour & Pujari, 2022).

These governance measures are crucial for maintaining an ecosystem's reputation and credibility among users and developers. Having such governance measures also reduces the potential malicious behavior of third parties.

Community Coordination

Another key objective of control and governance measures is to facilitate community coordination and preserve the ecosystem's identity (Constantinides, Cennamo, and Aaltonen, 2023). Open ecosystems involve a diverse array of stakeholders, necessitating a framework for dispute resolution and decision-making that aligns with the community's broader interests.

For example, Wikipedia allows users to collaboratively contribute and edit articles while adhering to strict editorial policies and community guidelines. Volunteer editors and administrators monitor contributions, enforce citation standards, and resolve disputes to maintain content reliability and accuracy. Some editors are granted additional privileges to assist with site maintenance.

Many open-source communities and open standards organizations adopt formal or informal social structures to manage membership (von Krogh et al., 2003; O'Mahony & Ferraro, 2007; Boudreau, 2010). In large and complex ecosystems like Linux, Apache, and the World Wide Web Consortium (W3C), institutional arrangements ensure transparent and democratic decision-making, with clear guidelines for community collaboration, thereby promoting effective coordination and contribution consolidation.

Sustainable Functioning

For participants in open digital ecosystems, having a strong central authority can be both necessary and beneficial for adapting to changing circumstances. As these ecosystems evolve and face new challenges, a central authority can effectively prevent fragmentation and stalemates, as well as coordinate responses to external threats (Farrell & Saloner, 1988; Eisenmann, 2008; Eisenmann, Parker, & van Alstyne, 2009).

In the Android ecosystem, Constantinides, Cennamo, and Aaltonen (2023) recently analyzed how Google has introduced centralized governance rules to address challenges such as fragmentation, interoperability, and varied user experiences. They show that Google has mitigated fragmentation by enforcing compatibility standards, like Android's Compatibility Test Suite.

Google also plays a central role in preparing Android developers for new innovations, such as foldable devices. It collaborates with developers on new devices and offers incentives for adaptation and innovation. Google provides the basic infrastructure and toolkit, allowing OEMs and developers to focus on their unique advantages and build upon Google's efforts. Importantly, this process maintains the core principle of openness in the Android ecosystem, giving developers and OEMs the flexibility to make their own trade-offs.

In summary, contrary to the common belief that complete openness maximizes an ecosystem's value creation, it is often more beneficial for the overall health of the ecosystem to have a central authority exercising necessary control and governance measures.

Implications for Policymakers

Recent Development of Regulations

The concept of openness in digital ecosystems has garnered significant attention from regulators across various jurisdictions.

In the European Union, the Digital Markets Act (DMA) aims to compel large digital platforms—often referred to as digital “gatekeepers”—to open their services and platforms to other companies. This includes imposing extensive interoperability requirements for messaging services. While the DMA outlines a series of obligations to foster “fairness” and “contestability” in digital markets, its implementation phase has raised questions about its specific objectives and how these obligations will be executed. Other related EU regulations include the Digital Services Act, which mandates transparency reporting for online platforms, and the Data Act, which focuses on interoperability provisions, particularly for cloud services.

In the United States, several legislative proposals aim to address the issue of ecosystem openness. The Open App Markets Act seeks to allow users to install apps from third-party stores and use alternative payment systems. The Augmenting Compatibility and Competition by Enabling Service Switching (ACCESS) Act establishes data portability and interoperability mandates for large companies meeting specific user and revenue criteria. The Platform Accountability and Transparency Act (PATA) requires digital platforms to comply with data requests from university researchers for projects approved by the National Science Foundation.

Specifically, the American Innovation and Choice Online Act (AICOA) targets major tech companies like Apple, Alphabet (Google), Amazon, Meta (Facebook), and potentially Microsoft. The bill aims to prevent these companies from leveraging their size, market power, proprietary data, or platform exposure to create an unfair advantage for their own products, thereby disadvantaging other companies’ products or services.

In China, regulatory scrutiny of large digital platforms has increased since the 2019 release of the “Guiding Opinions on Promoting the Regulated and Healthy Development of the Platform Economy.” In October 2021, the State Administration for Market Regulation released draft guidelines stating that large platform operators should promote interoperability with services provided by other platforms.

Against this backdrop, our discussion above suggests several key perspectives that policymakers should consider when regulating open ecosystems.

Embracing Ecosystem Openness as a Spectrum

Understanding that ecosystem openness exists on a continuum is essential for crafting effective policies. Rather than relying on rigid binary classifications, policymakers should develop flexible regulatory frameworks that adapt to different digital ecosystems and encourage firm experimentation with different levels of openness. This enables the preservation of innovation, differentiation, and competition processes across firms. Regulatory emphasis should shift towards maintaining the overall health of the ecosystem, considering factors like high-quality innovation and potentially malicious behavior, and not

operate under the assumption that an unconditioned open ecosystem will serve all purposes and maximize the benefits for all.

Fostering the Economic Benefits of Open Ecosystems

Policymakers can foster the economic benefits of open ecosystems through several measures. These may include advocating for the adoption of open systems, prioritizing such ecosystems in procurement policies, offering direct financial support to open projects, and integrating the study of open ecosystems into academic curricula.

Policymakers should also work to raise public awareness about both the benefits and challenges of open ecosystems. This effort should involve collaboration with industry stakeholders, such as companies operating the ecosystems and their complementors.

Considering the operational challenges of maintaining open ecosystems, policymakers could offer financial incentives to encourage openness. These incentives might take the form of grants, subsidies, or tax benefits, which can help companies invest in collaborative projects and overcome obstacles to openness.

Policymakers should prioritize situations where the decision to open or close an ecosystem can have a broad societal impact and lead to significant consumer benefits or harms. This is particularly crucial for services that have the potential to serve as essential digital infrastructure.

For instance, as the trend towards contactless payments on mobile devices continues to grow, any restrictions imposed by dominant operating systems like iOS and Android can exert a substantial influence on the development of a truly open ecosystem.⁴⁰ While Android allowed banks direct access to its Near Field Communication (NFC) technology, enabling a tap-to-pay experience within their apps, Apple imposed restrictions on banking apps, preventing them from directly accessing the NFC chip in iPhones. As a result, banks had to pay fees to Apple to provide a tap-to-pay experience to iPhone users through Apple's exclusive payment service, Apple Pay. Apple argued that its method enhanced the security of its mobile payment system compared to Android's, a claim that Google contested.⁴¹ Given the increasing importance of mobile payments in our daily lives, it is crucial for policymakers to closely examine the benefits of maintaining a closed system.

Nevertheless, due to the potential drawbacks of open ecosystems, policymakers should exercise caution. Rather than hastily implementing policies to promote greater openness, they should create regulatory sandboxes for experimentation. These controlled environments allow businesses to explore the pros and cons of openness while complying with existing regulations. The insights garnered from these sandboxes can subsequently guide policymakers in determining whether to advocate for increased openness.

⁴⁰ <https://www.consumerfinance.gov/data-research/research-reports/big-techs-role-in-contactless-payments-analysis-of-mobile-device-operating-systems-and-tap-to-pay-practices/full-report/>

⁴¹ <https://9to5mac.com/2021/07/26/apple-pay-versus-google-pay-battle-over-security-in-australian-antitrust-hearing/>

Balancing Ecosystem Openness and Centralized Governance

Open ecosystems flourish under the guidance of visionary leadership and centralized governance. This entails establishing rules that regulate both access to core technology and the creation and exchange of content. Implementing certain limitations on what developers and users can do within the platform is essential for maintaining product quality, preventing ecosystem fragmentation, ensuring user safety and privacy, and fostering innovation.

Empirical evidence (e.g., Boudreau 2012; Miric & Jeppesen 2020; Panico & Cennamo, 2022) suggests that, under specific conditions, limiting access to core platform services can be pro-competitive and pro-innovative. This creates greater value for consumers by encouraging third-party businesses to develop superior complementary products, such as apps and games. Gatekeeping governance also serves as a key differentiator for the platform ecosystem (e.g., Cennamo & Santaló, 2013).

The challenge lies in striking the right balance between openness and governance. Given the diverse landscape of industries and the rapidly evolving nature of digital ecosystems because of new technologies and new business models, there is no one-size-fits-all solution for determining the optimal level of openness. When it is not obvious that being more open or closed can lead to a substantial increase in social benefits, policymakers may want to allow firms to experiment with varying degrees of openness, thereby letting the market decide whether multiple ecosystems with different levels of openness can coexist and cater to a range of consumer needs. However, they should remain vigilant about potential negative externalities.

In the case of LLMs, the closed-source ChatGPT 3.5 and 4.0 were groundbreaking, reaching one million users faster than any other apps in history. However, the recent announcement of LLaMA 2 has also garnered significant global attention. Developers appreciate LLaMA's openness and customizability. It's evident that the two products target different consumer groups: ChatGPT appeals to less tech-savvy users seeking general-purpose applications, while LLaMA caters to tech enthusiasts interested in specialized tasks. If in the end, the market has chosen to sustain multiple types of ecosystems, this outcome will be preferable to forcing ChatGPT to open up or LLaMA to close down.

With the rise of the “metaverse” concept, major tech firms like Meta (Facebook), Microsoft, Apple, and Alphabet (Google) have made significant investments in XR. Most XR devices adhere to a common set of standards known as OpenXR. However, Apple's recently announced Vision Pro is an exception, as it is exclusive to the Apple ecosystem.⁴² While a common standard generally benefits developers and consumers through increased cross-platform interoperability, Apple's closed solution offers similar benefits within its own device family. One particular concern is data privacy: XR devices can generate a wealth of personal data, potentially revealing users' emotions, abilities, and desires. These data are essential for the core functionality of VR services. Open solutions inherently pose privacy risks due to data sharing, but closed solutions can mitigate these risks by limiting unauthorized data access.⁴³

⁴² <https://www.forbes.com/sites/tiriasresearch/2023/07/05/apples-vision-pro-what-it-is-and-what-it-is-not/?sh=746a8a72f16a>

⁴³ Kate Kaye, “WTF Is Interoperability,” DIGIDAY, July 6, 2021, at <https://digiday.com/marketing/wtf-isinteroperability/>.

Nevertheless, regulators may still need to implement measures to ensure responsible centralized governance and minimize potential malicious usage. One example is the regulation against “deepfakes”—AI tools that generate fake photos or videos featuring real faces. Similar risks of malicious usage exist for LLMs, XRs, and other emerging technologies.

Policymakers should enforce transparency requirements for ecosystem orchestrators. Clear rules of engagement and decision-making processes must be readily available to all participants within the ecosystem. To mitigate potential distortions, policymakers could introduce decentralized monitoring mechanisms, such as third-party auditors or industry experts, to oversee compliance with governance rules. These monitors would serve as checks and balances, ensuring fair governance practices are upheld. In addition, regular engagement with ecosystem participants, including businesses, developers, and users, is essential for understanding their needs and concerns.

Overcoming Possible Biases Against More Open Ecosystems

A lack of understanding of the challenges associated with open ecosystems can sometimes lead to regulatory biases against them. Open ecosystems often generate more value than closed ones. Yet paradoxically, they tend to attract more regulatory scrutiny. For example, both Apple’s iOS and Android face similar regulatory issues, but because the operation of Android often relies on contractual arrangements between the platform and participants, which are more likely to be public and observable, it often draws more critics and regulation attention. Apple’s practice of pre-installing its own apps on iOS rarely raises questions, whereas similar actions by Google have been criticized as an abuse of power.

Moreover, when reducing openness to all complementors can improve the health of the whole ecosystem, a firm sponsoring an open ecosystem may opt to tighten controls, effectively rendering the ecosystem more “closed.” Such actions are frequently viewed as detrimental to complementors and criticized as abuses of power. Interestingly, this issue rarely surfaces in systems that are more closed or have always been closed. Constantinides et al. (2023) provide an analysis of the evolution of Apple’s iOS and Android ecosystems and illustrate these contrasting dynamics.

The asymmetric stance towards more open vs. more closed ecosystem providers may stem, in part, from the belief held by some regulators that any restrictions on the use of open-source software constitute a violation of the open-source license, or *ipso facto* anticompetitive behavior. However, as noted above, openness should be seen more as a spectrum; some degrees of centralization are necessary mechanisms to guarantee an effective governance of the ecosystem.

In the mobile OS market, the emergence of Android has transformed the landscape from fragmented systems—such as those from BlackBerry, Nokia, and Motorola—to a duopoly of iOS and Android. The existence of an open ecosystem, managed by a centralized entity that provides development support and competes with a more closed operating system, has reduced the cost of innovation and market entry for complementors. This includes both device manufacturers and app developers, making their innovations accessible to a broader user base. Consequently, we have witnessed significant enhancements in overall

welfare with just two major mobile OSs—an accomplishment that might not have been feasible in a market fragmented by numerous mobile OSs

Summary

In conclusion, our study explores the impact of open ecosystems in the digital era. We argue that the concept of ecosystem openness should be understood as a spectrum, and we delve into the trade-offs between greater openness and more restrictive governance. Our research suggests that specific controls and governance structures are essential for maintaining a healthy, robust ecosystem. We frame our findings in the context of emerging technologies such as LLM, XR, and quantum computing. As policymakers navigate the complexities of open ecosystems, they should encourage firms to experiment with varying degrees of openness. This approach will allow the market to determine whether multiple ecosystems, each with its own level of openness, can coexist and cater to diverse consumer needs. Policymakers should remain vigilant about the overall health of these ecosystems and be aware of potential negative externalities. Our study also sheds light on potential biases that may affect the regulation of open ecosystems.

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