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Relevant markets and market power of mobile apps[☆]

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ABSTRACT

Antitrust investigations in the mobile app economy often require a definition of the relevant market of mobile apps and the evaluation of their market power. However, existing antitrust tools face significant challenges due to the non-price nature of mobile apps with multiple revenue sources, two competition margins at the mobile OS and mobile app levels, and the switching costs involved in the choice of mobile OSs. In this paper, we provide a description of the mobile app economy, including its essential components, players, and characteristics, and identify the challenges currently observed in antitrust investigations. We propose a model for mobile app users and advertisers that can address these issues and suggest a method for defining the relevant market of mobile apps and evaluating their market power, which is adaptable to markets with zero-priced products or multiple revenue sources beyond mobile apps.

1. Introduction

The mobile app economy – the collection of markets related to the use of mobile devices and mobile apps that run on them – plays an important role in modern economic activities. Mobile devices have become the main devices for Internet access; the penetration rate of smartphones for Internet access in Japan is 68.3%, which exceeds the 50.4% of Personal Computers (Ministry of Internal Affairs and Communications, 2021). Also, a large number of mobile app developers operate in the mobile app economy; the global mobile app economy in 2020 had more than 100,000 developer accounts registered with app stores (AppAnnie, 2021).

Courts and antitrust authorities have scrutinized the practices of key players such as large-scale mobile app developers and mobile OS platforms. Large-scale mobile app developers, such as Meta, play key roles in the app economy, and antitrust authorities often regard mergers between or acquisitions by such developers as problematic because they might harm the competition between mobile apps. Mobile OS platforms, such as Apple and Google, also play a core role in the mobile app economy by designing rules in various areas of the mobile app economy, some of which have been subject to antitrust scrutiny.

In antitrust litigations or merger reviews, courts and antitrust authorities often need to define the relevant market and evaluate the market power of mobile apps and mobile OSs before assessing the competitive effects of the practices of large-scale app developers and mobile OS platforms. However, the existing antitrust toolkits are often criticized for being unable to address the specificities of the mobile app economy. First, the multi-sidedness and the multiple revenue sources of mobile apps make it unclear what “price” should be considered for the application of a typical hypothetical monopolist test that relies on the concept of “small but significant and non-transitory increase in prices” (SSNIP). Second, two margins of competition at the mobile OS and mobile app levels make the analysis of users’ choices complicated. Third, the switching costs between mobile OSs, which can be reinforced by the complementarity among mobile apps and other products and services, further complicates the analysis.

This study develops a model of mobile app users and advertisers and proposes a method for empirically defining the relevant markets and evaluating the market powers of mobile apps while addressing the aforementioned issues. Specifically, to address the multi-sidedness and multiple revenue sources of mobile apps, we formalize the notion of “cost” for using a product, a concept introduced by Newman (2015), in the context of mobile apps. This notion of cost allows us to conduct a “small but significant and non-transitory increase in cost” (SSNIC) test, which generalizes the SSNIP test to environments with zero prices and multiple revenue sources.

We also informally discuss a way to conduct market definition and market power evaluation of mobile OS, an equally or more important

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Table 1
Components of the mobile app economy and demand-side and supply-side agents.

Components	Demand-side agents	Supply-side agents	Adjacent markets
Mobile app	user	developer	web app & game
App distribution	developer	app store	game store
App monetization	developer & advertiser	payment/ad network	–
Mobile OS	developer & user	OS provider	PC/game OS
Mobile device	app user	device manufacturer	PC & console

agent in the mobile app economy. We conclude that the market definition and market power evaluation of mobile OSs require much more information than that of mobile apps.

Our contributions are twofold. First, we provide an overview of the mobile app economy that is accessible to economists and practitioners.[1] Second, our proposed method of market definition of mobile apps contributes to a small literature on market definition in digital markets.[2] Filistrucchi et al. (2012) discuss several ways to conduct market definition in two-sided markets, including a modification of SSNIP tests to "small but significant and non-transitory decrease in quality" (SSNDQ) tests. Newman (2015) proposed the SSNIC test that generalizes the price to any cost that app users pay for enjoying goods. Franck and Peitz (2021) discuss potential ways to conduct SSNIC tests and the practical issues in implementing SSNIC tests. We propose a well-defined empirical method to conduct SSNIC tests in the context of the mobile app economy, which may help operationalize the SSNIC tests.

The rest of the article is organized as follows. Section 2, discusses the overview of the mobile app economy, including its main components, players, characteristics, and issues related to market definition and market power evaluation. Then, Section 3 discusses a method of market definition and market power evaluation that address the specificities of the mobile app economy. Section 4 concludes with a discussion of the limitations.

2. Overview of the mobile app economy

In this section, we provide the background on which a new method for market definition and evaluation of market power is called for. We start with the description of the mobile app economy. Then, we discuss the key characteristics of the mobile app economy and the challenges faced by the current antitrust toolkits.

2.1. Main components of mobile app economy

First, we describe the main components of the mobile app economy. According to Competition and Markets Authority (2021), the mobile app economy comprises three major product groups. The first product group is mobile devices such as smartphones and tablets. The second product group is mobile OSs, the software necessary for using mobile apps on a mobile device. The third product group is mobile apps, the software that performs certain functions on a device.

In addition to these three major product groups defined by Competition and Markets Authority (2021), additional services exist in the mobile app economy. One is mobile app distribution services such as app stores, which allow app users to install apps on their devices. Another is mobile app monetization services, such as in-app purchases and ad networks, which provide mobile app developers with means of monetization.

Markets adjacent to the mobile app economy may compete with product groups in the mobile app economy. Adjacent markets of mobile devices include devices such as PCs and game consoles; adjacent markets of mobile OSs include OSs of other types of computers such as Windows and macOS and OSs for game consoles; and adjacent markets of mobile apps include other types of apps such as web apps and game software. Mobile app distribution services and mobile app monetization services also have adjacent markets, such as game distribution platforms and online billing services.

Table 1 summarizes the structure of the components of the mobile app economy. In the following, we describe the detail of each component and its suppliers.

Mobile devices Smartphones and tablets are the main mobile devices. We regard portable laptop PCs and game consoles, as well as desktop PCs and game consoles, as products in adjacent markets that may potentially compete with mobile devices.

At the global level, Gartner's survey on the number of smartphones sold in the world in 2020 documents that Samsung had an 18.8% share, followed by Apple, the producer of the iPhone, with 14.8%, followed by Huawei with 13.5%, Xiaomi with 10.8%, OPPO with 8.3%, and other producers had a 33.7% share.[3]

In the Japanese market, Apple and Japanese manufacturers have a large share.[4] For example, according to an IDC survey on the number of smartphones sold in Japan in 2020, Apple had a 47.3% share, followed by Sharp, Fujitsu, Samsung, and Kyocera with a combined share of 36.6%. Although not ranked high in terms of the share, Google also produces pixel-branded smartphones.[5]

Mobile OSs The major producers of mobile OSs in the mobile app economy are Apple and Google, the producers of iOS and Android, respectively. Apple exclusively provides iOS, whereas Google allows third-party OS providers to develop Android OSs.

Apple does not license iOS to other companies and uses iOS exclusively for the iPhone. In addition, Apple does not allow other mobile OSs to be installed on the iPhone.[6]

Android is made of an open-source component and a proprietary component. The open-source component of Android is called Android Open Source Project (AOSP), and the proprietary component is called Google Mobile Services (GMS).[7] AOSP is licensed with the Apache 2.0 license, and third-party developers can develop a mobile OS that contains AOSP as a part of it. By contrast, GMS is exclusively owned by Google. Hence, to use Android, which is a combination of AOSP and GMS, users of the Android OS such as device manufacturers need to obtain a license from Google.

Third-party developers can create Android-based mobile OSs (called Android folk) by combining AOSP with their own software. For example, Amazon's Fire OS is an Android fork that combines AOSP with apps developed by Amazon (e.g., Amazon Appstore), which is used as a mobile OS for mobile devices like Kindle.

[1] For another overview of the mobile app economy with the focus on the antitrust cases against Apple, see Geradin and Katsifis (2021).

[2] See also OECD (2018) and chapter 3 of Crémer et al. (2019) for policy discussions.

[3] https://www.gartner.com/en/newsroom/press-releases/2021-02-22-4q20-smartphone-market-share-release, accessed on April 9, 2022.

[4] https://www.idc.com/getdoc.jsp?containerId=prJPJ47477421, accessed on 28 March 2022.

[5] https://store.google.com/jp/category/phones?hl=ja, accessed on April 15, 2022.

[6] Project Sandcastle can run Android on iPhones, but some hardware functions remain unusable. https://projectsandcastle.org/, accessed on April 7, 2022.

[7] https://source.android.com/license, accessed on April 7, 2022.

Mobile apps A mobile app is an app that can be installed on a mobile device. Other types of apps include web apps that are used on a web browser, which we regard as apps in an adjacent market that potentially compete with mobile apps.

Mobile app developers develop and sell mobile apps. Most mobile app developers are firms independent of mobile OS providers, and their scales vary significantly; while there are prominent large-scale app developers, more than 100,000 small-scale developers, with annual sales of less than $100,000, account for 97% of mobile app developers (AppAnnie, 2021). Among large-scale mobile app developers, those that provide popular mobile apps include Meta (the producer of multiple social apps such as Facebook, WhatsApp, and Instagram) and Match Group (the producer of multiple matching apps such as Tinder and OkCupid). In Japan, LINE Corporation (the producer of the LINE app) is ranked high in terms of the number of downloads and usage time in the Japanese market.

Apple and Google also develop mobile apps. To name a few, Apple provides the Apple Music app for iOS and Android.[8] Similarly, Google provides a Gmail app for both iOS and Android as a mobile app. Google also provides web apps that can be accessed through a browser.[9]

Mobile app distribution services Mobile app distribution services enable app developers to distribute mobile apps.[10] Apple's App Store and Google Play Store are the major mobile app distribution services for iOS and Android.[11] The Competition and Markets Authority (2021) stated that the App Store is the only mobile app distribution service authorized for the iPhone. Google's Play Store app is pre-installed on Android devices. In some cases, Android device manufacturers pre-install their own mobile app stores. For example, the Competition and Markets Authority (2021) stated that Samsung was shipping mobile devices that pre-installed the Galaxy Store. In addition to these app stores, app users with Android devices can download mobile apps from websites.

Mobile app monetization services Mobile app monetization services allow mobile app developers to earn revenues through their mobile apps. These services include billing and ad distribution services. Specifically, mobile app producers can charge app users through billing services or sell advertisement spaces placed on their mobile apps to advertisers through ad distribution services.

A mobile app developer may charge an app user at the time of download (pay-per-download) or charge for specific usage of the app by means of in-app purchases. Apple and Google provide services for pay-per-download and in-app purchases as functions of the App Store and Google Play, respectively.[12]

Ad distribution services allow app developers to monetize advertising spaces in mobile apps. Mobile app developers can choose between using ad networks and setting list prices for ad distribution services.

Ad networks allow mobile app developers to sell advertising spaces in mobile apps to advertisers using algorithms such as auctions.[13] OS providers often provide ad networks. For example, Google provides Google AdMob, a major ad network.[14] Apple ran an ad network called iAD but stopped the service in 2016.[15] Ad networks provided by non-mobile OS producers include AdColony, AppLovin, and InMobi.[16] These four ad networks can distribute ads to mobile apps that run on Android or iOS, but there are also ad networks specialized in Android.[17]

Mobile app developers can often set advertising prices by themselves using the list-price method. The list-price method is a monetization method in which a mobile app developer sets a list of prices for each advertisement in a mobile app to sell advertising spaces to advertisers. Mobile apps that adopt the list-price method are usually those with certain sizes. For example, LINE introduces a wide range of advertising media and combines list-price methods and auction methods.[18]

2.2. Main players

Having described the main components of the mobile app economy, we next describe the three main players therein: app users, app developers, and mobile OS platforms.

App users App users are the primary users of the mobile app economy who purchase mobile devices, download apps at mobile app stores, and use them.

Because most mobile devices are bundled with a certain mobile OS, an app user's choice of mobile OS coincides with the choice of a mobile device. Most smartphones used in Japan are shipped with pre-installed OS, either Apple's iOS or Google's Android. According to a survey result conducted in Japan on February 2021, among the 40,000 men and women aged 18–69 years in Japan, 41.0% were iPhone users, and 45.8% were Android users.[19]

An app user who owns a mobile device can use mobile apps by installing them through mobile app distribution services. When an app user visits an app store, they can search for the mobile app using keyword search, category search, and recommendation by the store. In an app store, app users can read a description of the app written by the developer, see the images posted by the developer, and obtain information on in-app purchases and advertisements. Through user reviews, app users can also learn about other app users' experiences of mobile app usage.

[8] https://www.apple.com/apple-music/ , accessed on April 9, 2022.

[9] https://support.google.com/youtube/answer/3227660, accessed on April 9, 2022.

[10] The means to distribute mobile apps other than mobile app distribution services, including the distribution through a website or repository and attaching them to emails. Google suggests app markets ("mobile app stores" in this study), attaching to emails and websites as means to distribute mobile apps for Android. https://developer.android.com/distribute/marketing-tools/alternative-distribution, accessed on April 15, 2022.

[11] The Competition and Markets Authority (2021) stated that the share of mobile app distribution services for mobile devices with iOS, Android, HMS, or Fire OS in the UK in 2020 was 40%–50% for Apple App Store, 50%–60% for the Google Play Store and 0%–5% for installation from other mobile app stores.

[12] Apple's App Store Connect Help states that the price of app downloads is specified on the App Store Connect. https://developer.apple.com/help/app-store-connect/manage-app-pricing/set-a-price, accessed on April 14, 2022. The Payments section of Google's Play Console Help states, "Developers charging for app downloads from Google Play must use Google Play's billing system as the method of payment for those transactions". https://support.google.com/googleplay/android-developer/answer/9858738, accessed on April 14, 2022.

[13] For example, AdMob adopts an algorithm in which a mobile app developer sets the lowest price to accept ads to an advertisement frame, and ads bid to the advertisement frame at prices higher than the set price displayed. https://support.google.com/admob/answer/3418058, accessed on 9 April 2022.

[14] https://developers.google.com/admob?hl=ja, accessed on 5 April 2022.

[15] https://developer.apple.com/news/?id=01152016a, accessed on April 9, 2022.

[16] The Business of Apps listed 14 ad networks as the top ad networks in 2021 on its website. https://www.businessofapps.com/ads/mobile-ad-network/, accessed on April 9, 2022.

[17] AppBrain lists more than 40 ad networks for Android and their market share on its website. https://www.appbrain.com/stats/libraries/ad-networks, accessed on April 9, 2022.

[18] An example of the list-price method there is LINE Flyer, which sets a monthly base price of 1,000 yen per number of registered stores, metered prices of 30 yen per favorite user who viewed the advertisement, and 10 yen per favorite user who did not view the advertisement. (https://www.linebiz.com/jp/download/, accessed on April 6, 2022).

[19] MMD Labo, https://mmdlabo.jp/investigation/detail_1941.html, accessed on April 9, 2022.

Most app users use mobile app distribution services provided by Apple or Google. In Japan, a questionnaire survey of 3,000 app users conducted by the Ministry of Economy, Trade and Industry reports that 49.5% users of mobile app stores chose Apple's App Store as the primary mobile app store in 2021, and 46.5% of them chose Google Play Store as the primary app store.[20]

App users pay for mobile apps in the form of download prices and in-app purchases. When an app user uses a paid mobile app listed on a mobile app distribution service, the app user pays the download price to the mobile app developer through a pay-per-download service at the first time of download.[21] For apps that offer in-app purchases, app users can purchase it to enjoy additional features or remove restrictions on the mobile app's functions. Examples of the former are the gaming app Fortnite and the matching app Tinder, and an example of the latter is the premium plans offered by the music app Spotify.

Other than mobile apps, app users can enjoy internet services through web apps on a web browser, though its share is small. For example, a Nielsen survey on smartphone use in Japan shows that mobile apps represented 92% and browsers 8% of the time spent using smartphones in December 2019.[22]

App developers Mobile app developers develop mobile apps, sell them through app distribution services, and monetize them using mobile app monetization services.

When submitting an app to a mobile app store, an app developer specifies the app's category, describes the app's functions using text and images, and sets the download price, if any.[23]

App developers monetize their mobile apps by charging app users or selling ad spaces through mobile app monetization services. When charging app users, an app developer can set the price of in-app purchases and the download prices. When an app developer uses an ad network, the developer can create ad spaces on the app using a software development kit (SDK) provided by the ad network.[24] App developers widely use these monetization methods. For example, in the sample analyzed by Ghose and Han (2014), 47% of mobile apps had in-app purchases, and 66% of mobile apps displayed in-app ads.

Mobile OS platforms Mobile OS platforms are the most influential agents in the mobile app economy. Apple and Google provide mobile OSs and vertically integrate various components of the mobile app economy, making them special players. Table 2 shows the vertical integration of Apple and Google.

Apple and Google differ in their openness, with Apple being closed and Google being relatively open. Apple exclusively provides mobile devices, mobile OS (iOS), mobile app distribution services (App Store), and services to charge app users in its mobile app. Apple also provides its own mobile apps, such as parental control software and a web browser. Google provides mobile devices (Pixel), mobile OS (Android), mobile app distribution services (Google Play), major mobile apps, services to charge app users in its mobile app monetization services, and ad distribution services. Some of Android elements are open-source, and any company can create a compatible mobile OS.

Table 2
Vertical integration of Apple and Google.

Components	Apple	Google
Mobile app	first-party app	first-party app
App distribution	app store (exclusive)	app store
App monetization	IAP (exclusive)	IAP and ad network
Mobile OS	iOS (exclusive)	Android
Mobile device	iPhone & iPad (exclusive)	Pixel

The parenthesis (exclusive) means the mobile OS exclusively provides the component. IAP is the abbreviation for in-app purchases.

Mobile OS platforms determine the choices that mobile app developers can make by designing the terms of service of their mobile app distribution services. Specifically, Apple controls how mobile app developers distribute apps through its App Store Review Guidelines.[25] Similarly, Google defines "Mobile Unwanted Software" and lists the principles that mobile app developers should follow in distributing their apps.[26]

As Mobile OS platforms run both mobile app distribution and mobile app businesses, they can bundle their mobile apps to their mobile OS using their mobile app distribution services, place their products in prominent positions compared to the products of other companies, and observe the sales of other mobile app developers to utilize that information for their mobile app development. Such conduct is often called "self-preferencing".[27]

Mobile OS platforms provide mobile app monetization services for in-app purchases. Apple states in its App Store Review Guidelines that apps cannot use other billing systems.[28] Google states in its Developer Program Policy that apps must use Google Play's billing system to charge for app downloads and in-app purchases, with a few exceptions.[29] Since 2022, Google Play has been piloting to allow external billing systems for in-app purchases in apps downloaded from Google Play in several countries.[30]

Mobile OS platforms charge percentage commissions to pay-per-download and in-app purchases in mobile app distribution services. As of March 2022, both Apple and Google set a commission of 30%,

[20] The Ministry of Economy, Trade and Industry's "2nd Monitoring Meeting on the Transparency and Fairness of Digital Platforms" Material 1 "Results of Questionnaire Survey for Digital Platform Utilization Business Firms" (https://www.meti.go.jp/shingikai/mono_info_service/digital_platform_monitoring/002.html, accessed on April 13, 2022).

[21] In the App Store and Play Store, mobile app downloading rights are tied to the user account of the mobile app store. Once an app user purchases a mobile app using an account, the app user can download the mobile app as many times as the app user desires on multiple devices using that account. See Google Play's explanation of downloading purchased mobile apps (https://support.google.com/googleplay/answer/113410, accessed on April 13, 2022) and App Store's explanation of downloading purchased mobile apps (https://support.apple.com/ja-jp/HT211841, accessed on April 13, 2022).

[22] https://www.netratings.co.jp/news_release/2020/03/Newsrelease20200324.html, accessed on 28 March 2022.

[23] Google Play's explanation of downloading purchased mobile apps (https://support.google.com/googleplay/android-developer/answer/9859152, accessed on April 13, 2022), and App Store's explanation of downloading purchased mobile apps (https://developer.apple.com/jp/app-store/product-page/, accessed on April 13, 2022) state that users can download apps they purchased without paying again.

[24] AdMob's SDK can be obtained from Google Mobile Ads SDK (https://developers.google.com/admob, accessed on April 9, 2022).

[25] In the Guidelines, Apple lists the criteria for prohibiting the distribution of some apps through the App Store, including safety for the kids, respect for users with differing opinions, quality of the app experience, and attempts to cheat the system. (https://developer.apple.com/jp/app-store/review/guidelines, accessed on April 14, 2022).

[26] These principles include "Transparent behavior and clear disclosures", "Protect user data", and "Do not harm the mobile experience" (https://support.google.com/googleplay/android-developer/answer/9970222?hl=ja&ref_topic=9969691, accessed on April 14, 2022).

[27] For the examples of self-preferencing, see Kittaka et al. (2023).

[28] https://developer.apple.com/jp/app-store/review/guidelines, accessed on 9 April 2022.

[29] Google's policy states that Google Play's billing system must be used unless Section 3 or Section 8 applies. Section 3 provides provisions for apps that cannot use in-app purchases, including those for purchasing or renting physical goods. Section 8 stipulates the procedure for using an external billing system when requiring or accepting payments from users in South Korea (see https://support.google.com/googleplay/android-developer/answer/9858738, accessed on November 22, 2022).

[30] https://support.google.com/googleplay/android-developer/answer/12570971?hl=en, accessed on November 22, 2022.

with some exceptions, such as discounts for small-scale businesses and subscription services.[31]

Mobile OS platforms have included anti-steering provisions in their policy to prohibit users of their mobile app distribution services from bypassing their specified billing method. Anti-steering provisions in the mobile app economy prohibit app developers from steering users to a web app through links, texts, or images. Apple states in the App Store Review Guidelines that "Apps and their metadata may not include buttons, external links, or other calls to action that direct customers to purchasing mechanisms other than in-app purchase", except for those that can be recognized as "reader" apps under the terms of Apple.[32] The exceptional measure for "reader" apps was set forth on March 30, 2022, in line with Apple's proposition to revise the guidelines during an investigation by the Japan Fair Trade Commission (JFTC) published on September 2, 2021.[33]

The prominence of Apple and Google has led policy-makers worldwide to pay particular attention to them. In Japan, the Act on Improving Transparency and Fairness of Digital Platforms that came into effect in 2021 designated Apple and Google as "specified digital platform providers" in mobile app stores. In Europe, the European Commission enacted the Digital Markets Act (DMA), which nominates mobile app stores and mobile OSs as "core platform services" to be regulated by the Act.[34]

2.3. Key characteristics and related issues

Now, we discuss the key characteristics of the mobile app economy and the related challenges faced by the current antitrust toolkits. These characteristics include (i) the multi-sidedness of mobile apps and resulting multiple revenue sources and zero-prices; (ii) the multi-sidedness of mobile OSs; and (iii) switching costs and "ecosystem" features of mobile OSs.

Multisidedness of mobile apps and zero prices Mobile apps are two-sided in the sense that they often connect advertisers to app users. Because of the two-sidedness, mobile app developers have multiple revenue sources. They may charge prices to app users, show advertisements, or collect personal or contextual information to monetize it. Specifically, an app developer attempts to earn money out of its app by specifying prices for pay-per-download or in-app purchases or displaying ads in the app.

As a consequence of multiple revenue sources, mobile apps are often free, that is, zero-priced. This poses a challenge to typical traditional antitrust toolkits that rely on price variations.

Multi-sidedness of mobile OSs Mobile OSs and app distribution services are also two-sided: they connect app users and app developers. In the literature on the mobile app economy, or two-sided markets in general, the choices of app users and developers are often divided into membership and usage choices (e.g., Rochet and Tirole, 2006; Gans, 2012; Gaudin and White, 2021).

On the app user's side, "OS choice" and "app usage" can be regarded as the app user's membership and usage choices, respectively. OS choice is the app user's choice to obtain a device necessary for using certain apps. In terms of the classification made in Section 2, it is the choice of mobile devices and mobile OSs or products in the adjacent markets of mobile devices and mobile OSs, such as PCs and game consoles. App usage is the app user's choice to download and use an app via an app distribution service within a platform. It is a choice of mobile apps through mobile app distribution services or other goods and services from adjacent markets, such as web apps.

On the developer's side, we can regard the app developer's "app development" and "app monetization" as membership and usage decisions, respectively. App development is literally the app developer's choice to develop apps that run on specific OSs, including iOS and Android, web apps, and other apps. App monetization is the choice of monetization scheme for a specific app using app monetization services such as billing and ad distribution services.

App users' OS choices, app usage, app developers' app development, and app monetization vary depending on the homing structure of the app users and developers (e.g., Armstrong, 2006; Armstrong and Wright, 2007; Anderson et al., 2018; Bakos and Halaburda, 2020; Teh et al., 2023). In other words, an app user's choice depends on whether developers develop apps that run on only one OS (single-homing) or multiple OSs (multi-homing). A developer's choice also depends on whether app users choose one OS only (single-homing) or multiple OSs (multi-homing). In the context of the mobile app economy, it would be safe to assume that app users are single-homing and developers are, at least partially, multi-homing as depicted in Fig. 1, which is a typical situation in the mobile app economy.[35]

The incentive for an app user to choose a specific OS depends on the number of apps that run on that OS. The incentive for an app developer to develop an app depends on the number of app users who use the OS. Therefore, an OS with more users and apps can offer more value to app users and app developers than other OSs. An OS with a large customer base can easily prevent app users and app developers from using other OSs due to that very fact.

Regarding the OS substitutability in app monetization, if app users are single-homing, changing the app monetization method for an app that runs on one OS does not affect how app users use the same app that runs on the other OS. Therefore, each app developer decides on app monetization for each OS independently. For that reason, competition does not occur between OSs when it comes to app monetization. Therefore, substitutability does not exist between OSs for app monetization.

Meanwhile, substitutability does exist among app monetization services. For example, developers who provide apps for an OS that charges higher payment fees have stronger incentives to divert transactions to a service outside the apps by using a cheaper payment service in an adjacent market or changing the business model to have an advertisement-based profit structure rather than a payment-based profit structure (Gans, 2012; Kawaguchi et al., 2022b; Zennyo, 2021).

Switching costs and complementarity OSs and devices exhibit switching costs and provide many complementary functions that create user lock-in.

The leading mobile OSs chosen by app users are iOS and Android. Therefore, when evaluating the market power of OSs in the current app economy, the substitution between iOS and Android plays an important role. Regarding this point, Grzybowski and Nicolle (2021) estimated the switching costs in the choice of mobile devices by using user-level panel data on the purchase of mobile devices. To estimate switching costs, Grzybowski and Nicolle (2021) exploited the difference in the

[31] Information on the commission rate at App Store: https://www.apple.com/newsroom/2020/11/apple-announces-app-store-small-business-program/, accessed on April 14, 2022, and the information on commission rate at Google Play: https://support.google.com/googleplay/android-developer/answer/112622, accessed on April 14, 2022 .

[32] https://developer.apple.com/jp/app-store/review/guidelines, accessed on April 14, 2022.

[33] JFTC's release (https://www.jftc.go.jp/houdou/pressrelease/2021/sep/210902.html, accessed on April 14, 2022.), Apple's statements, (https://developer.apple.com/jp/news/?id=grjqafts, accessed on April 14, 2022, and https://developer.apple.com/jp/support/reader-apps/, accessed on April 14, 2022).

[34] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=COM:2020:842:FIN, accessed on April 9, 2022.

[35] Indeed, a survey by Bresnahan et al. (2015) on 1,231 mobile app samples in the U.S. found that 64% of mobile apps were multi-homing.

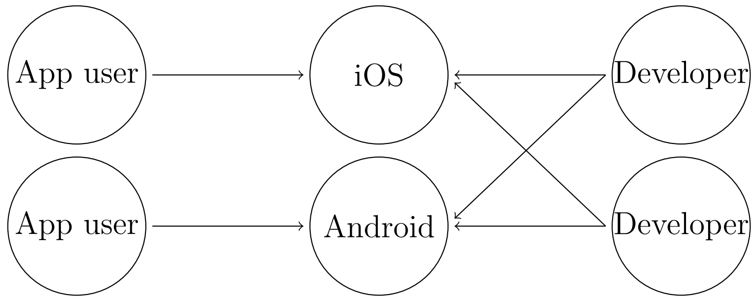

Fig. 1. Typical homing structure. An arrow from app user to OS means selection of the OS. An arrow from developer to OS means development of apps that run on the OS.

mobile device purchasing behavior of app users who held the different devices in the previous month. According to the estimates, the costs of switching from iOS to other OSs were higher than those for switching between other OSs, indicating a low substitutability between iOS and other OSs.

Complementarity services are provided by platform operators across different components. In addition to mobile OSs (iOS and Android) and compatible mobile OS devices, Apple and Google offer products that are highly complementary to them, such as smartwatches (e.g., Apple Watch, Fitbit) and laptop PCs (e.g., Mac Book, Chrome Book). If an app user enjoys the benefits of using multiple products offered by one platform operator, the app user may choose an OS and use apps not only based on the utility of an OS alone but also by considering the complementarity among multiple products. In this case, the substitutability between OSs at the time of OS choice and app development may weaken, and the substitutability between OSs and other competing services in app usage and app monetization may also become weaker.

Implications on market definition and market power assessment The multi-sidedness, multiple revenue sources, and the zero-price feature of mobile apps as well as the multi-sidedness and switching costs of mobile OSs and multiple complementary services provided by OS providers, give rise to the following implications on market definition and market power assessment.

1. Multi-sidedness of mobile apps and the presence of multiple revenue sources give rise to two challenges to the traditional antitrust toolkits. First, zero-prices make the traditional price-based antitrust toolkit difficult to apply (see Crémer et al., 2019; Franck and Peitz, 2021, for example). For example, the traditional SSNIP test is hard to use when the mobile app under consideration charges no price. Second, when an app sets multiple "prices", such as download prices and advertisements, it is unclear how to consider an appropriate way to jointly increase these prices in the traditional antitrust toolkits. Such a difficulty is indeed faced by practitioners. For example, in the review of the merger between Z Holdings Corporation and LINE Corporation (see Appendix A.1 for the detail), JFTC defined separate relevant markets "news distribution service", "advertisement-related business", and "code-based payment service". However, as some of these markets are interdependent, such as news distribution and advertising markets, these market definitions should be made together.
2. Mobile OSs are multi-sided, and there are two margins of competition between mobile OSs, namely, the margin of OS choice and the margin of app usage. The importance of each margin depends on the nature of the conduct that poses a problem in competition policy. For example, conduct that affects competition among apps in a minor category may only affect app usage without affecting the OS choice. Meanwhile, conduct that affects apps that are highly important to all app users (e.g., browsers) or conduct that affects all apps in every category may affect not only app usage but also OS choice. Furthermore, when the conduct affects OS choices, it also affects the app development incentives of app developers, giving rise to positive feedback effects. In the long run, these behavioral responses should be taken into account. In Epic Games, Inc. v. Apple Inc. in US District Court for California (see Appendix A.2 for the detail), Epic Games tried to emphasize that Apple has a monopoly position in app distribution and app monetization services, by defining these markets as "aftermarkets". On the contrary, Apple claimed that the entire video game market was the relevant market for mobile app distribution services. Their claim is common in the sense that they both focus on the margin of app usage, but differ in whether or not to include adjacent markets as relevant markets.
3. Complementarity and switching costs should also be taken into account when we consider the substitutability at the margin of OS choices. When these complementarity and switching costs are significant, the substitutability between mobile OSs at the margin of OS choice would be weak, and market definition would likely be made based on the substitutability at the margin of app usage, as illustrated by Epic Games, Inc. v. Apple Inc. case.

In the following, we address the first issue raised above: multiple revenue sources and the non-price nature of mobile apps. Afterward, we informally discuss the ways to address the second and the third issues within the proposed framework.

3. Market definition and market power assessment

We develop a framework that can potentially address all three issues mentioned in the previous section. Then, we propose a method to define the relevant market and assess the market power of mobile apps that addresses the issue of multiple revenue sources and the non-price nature of mobile apps. We employ the concept of app user disutility in Kawaguchi et al. (2022b) to apply the hypothetical monopolist test (Ivaldi and Lorincz, 2011) and upward pricing pressure (Farrell and Shapiro, 2010) to two-sided markets, including zero-priced goods.

3.1. Baseline model

We start with developing a baseline model that addresses the aforementioned issues. First, we consider a setting where a consumer has disutility for losing money or watching advertisements, and the traditional "price" is generalized to the "cost" of using an app on an OS, thereby addressing the issue of multiple revenue sources and zero prices. Second, we consider a two-step choice of consumers over mobile OSs and mobile apps to capture the two margins of competition when facing single-homing consumers. Third, we allow consumer characteristics to include the consumers' past choices and, by doing so, partially address the issue of app complementarity and switching costs. After laying out the baseline model, we discuss how it can be extended to explicitly consider complementarity among apps and competition with adjacent markets. Then, we discuss how to define relevant markets and assess market power with this framework.

Data requirement To use this approach, we need data on (i) mobile OS choice (iOS, Android, or both) and (ii) installed mobile apps at the app user and year levels, (i) download price, (ii) average in-app purchase, and (iii) an average number of in-app advertisements at the mobile app and year levels. We need data for at least two periods to address the possible lock-in effect on an owned mobile OS. Specifically, we use the data of the first period to capture the degree of the lock-in effect on the mobile OS and the second-period data for estimating the preference of app users.

To obtain these data, one would need to consult ad technology firms and mobile app developers for the mobile app advertisement number and price data. If we focus on a few mobile apps, scraping the data using the developer's tools for mobile apps would be an alternative way to collect relevant data. Also, an app user survey can be conducted or purchased from a private marketing research company.

Decision problem of app users We model the problem of app users as a two-step problem under which an app user chooses which mobile OS to purchase and then chooses whether to download and use mobile apps available on the OS. To capture the lock-in effect, we consider a stylized two-period model, although we assume that app users are myopic and make decisions in a static manner. In each period, an app user chooses the mobile OS and then installs and uses mobile apps available on the OS she purchased.

An app user may choose iOS, Android, or both. Let $\mathcal{W} = \{iOS, Android, Both\}$. Also, let $\mathcal{J}_{iOS,t}$ and $\mathcal{J}_{And,t}$ denote the set of iOS and Android apps, and let $\mathcal{J}_t = \mathcal{J}_{iOS,t} \cup \mathcal{J}_{And,t}$. Let $w_{it} \in \mathcal{W}$ denote app user i's choice of mobile OS, $D_{it} \subset \mathcal{J}_t$ the set of installed apps, and e_j the sum of app j's download price and average in-app purchases, respectively. The mobile OS on which app j is available is $o_j \in \{iOS, Android\}$. The other observable characteristics of app j are denoted by x_{jt}.

We use the second-period data to estimate the preference of app users and the first-period data to capture the lock-in effect by estimating different parameters for each mobile OS used in the first period w_{i1}. For example, using the mobile apps downloaded in the first period, we can construct the overall number of installed apps by category for the first period. Formally, letting z_{i1} denote the observed characteristics of app user i in the first period, such as the mobile OS choice w_{i1}, we can extend the random-coefficient model of the second period as:

$$u_{ij} = \beta_i' x_{j2} - \alpha_e e_{j2} - \alpha_a a_{j2} + \epsilon_{ij2},$$

where ϵ_{ij2} is the preference shock of app user i for mobile app j in the second period, and

$$\beta_i = \beta_0 + \Pi_\beta z_{i1}.$$

This preference specification allows us to address the non-price nature of mobile apps and switching costs in mobile OSs.

First, consumers incur disutilities from monetary payments e_{j2} as well as ad exposure a_{j2}. In terms of utility, these two can be considered as a "price" for using an app. More specifically, we can regard the sum of disutilities $c = \alpha_e e_{j2} + \alpha_a a_{j2}$ as the "cost" for using app j, a concept proposed by Newman (2015), we can generalize the notion of price to the cost, which allows us to use the notion of SSNIC in the market definition. Even if an app charges a zero download price and in-app purchases, it usually shows advertisements to earn revenue. Then, the app user's disutility from using the app is not zero. Thus, we can apply the standard demand estimation method and merger analysis as long as the apps adopt either of these business models.

Second, the parameter Π_β allows us to examine the lock-in effects of mobile OSs by capturing how the app user's demand for mobile apps in the second period could differ according to mobile app choice and usage in the first period. For example, if z_i includes the number of installed iOS apps in the first period, then it can quantify how much the substitution for Android apps could decline when an app user used more iOS apps in the first period. If we are interested in substitution among specific apps, then we can survey the characteristics that are important for the apps. For example, if we are interested in the lock-in effect on photography apps, we can survey the number of apps saved in iCloud and Google Photo.[36]

Given this preference specification, we model the app user's problem. One modeling issue is that apps can be either substitutes or complements. To simplify the analysis, we first impose a somewhat strong assumption that there is neither substitution nor complementarity in the utility from downloading multiple mobile apps.[37] Instead, we capture the substitution and complementarity between the apps installed in the first and second periods through app user characteristics z_i, which includes information on the apps installed in the first period. Practically, this approach would help study issues related to the installation of multiple apps.

To summarize, in the model, an app user first chooses mobile OS $w_i \in \mathcal{W}$ and then decides whether to download each app $j \in \mathcal{J}_{w_i}$.

App usage To consider the problem of app users in each period backwardly, we first consider an app user's problem of installing and using apps given its OS choice w_i.

Let d_{ij} denote a variable that takes the value of 1 if app user i installs app j in the second period and 0 otherwise. Then, the app user's problem in the app usage is:

$$\max_{d_{ij}, j \in \mathcal{J}_{w_i}} \sum_{j \in \mathcal{J}_{w_i}} d_{ij} [\beta_i' x_j - \alpha_e e_j - \alpha_a a_j + \epsilon_{ij}]$$

The decisions made to install mobile apps are mutually independent, and mobile app j is installed if and only if the following condition is satisfied:

$$\beta_i' x_j - \alpha_e e_j - \alpha_a a_j + \epsilon_{ij} \geq 0.$$

Further, assuming that ϵ_{ij} follows an independent standard logistic distribution, the probability of mobile app j being installed is

$$p_{ij}(e_j, a_j) = \frac{\exp(\beta_i' x_j - \alpha_e e_j - \alpha_a a_j)}{1 + \exp(\beta_i' x_j - \alpha_e e_j - \alpha_a a_j)}$$

and the expected indirect utility of mobile apps that can be installed after selecting w is:

$$\begin{aligned} v_{iw}(e, a) &= \mathbb{E}\left[\max_{d_{ij}, j \in \mathcal{J}_w} \sum_{j \in \mathcal{J}_w} d_{ij} u_{ij}\right] \\ &= \sum_{j \in \mathcal{J}_w} \log\left[1 + \exp(\beta_i' x_j - \alpha_e e_j - \alpha_a a_j)\right] + \delta \cdot |\mathcal{J}_w| \end{aligned}$$

where $\delta \approx 5.772$ is the Euler's constant.

OS choice Next, we consider the OS choices of app users in the first step. We write the expected indirect utility for app user i by choosing mobile OS $w \in \mathcal{W}$ as

$$v_{iw}(e, a) + \zeta_w + \epsilon_{iw}$$

and normalize $\zeta_{Both} = 0$, where ζ_w is the utility specific to each mobile OS. This utility is determined by the service provided by the mobile OS and the complementary goods and services for the mobile OS. We can, in principle, estimate the contribution of those services to ζ_w.[38]

[36] Strictly speaking, there are problems in using the data on app users' first-period behavior as a covariate for estimating the lock-in effect in demand for the second period. For instance, even if an app user who used iOS in the first period tended to use iOS more in the second period, we could not distinguish whether this was because the app user specifically preferred iOS or because the lock-in effect played a role. Notwithstanding such flaws, this would still help analyze the overall lock-in effect in practice.

[37] For the model that assumes the substitutability between mobile apps, see Kawaguchi et al. (2022b).

[38] However, doing so accurately requires long panel data, which may be practically difficult to obtain.

Furthermore, assuming that ϵ_{iw} follows an independent Type-I extreme value distribution, the probability of choosing a mobile OS w is:

$$p_{iw}(e,a) = \frac{\exp[v_{iw}(e,a)+\zeta_w]}{\sum_{w\in\mathcal{W}}\exp[v_{iw'}(e,a)+\zeta_{w'}]}.$$

Demand estimation Letting θ denote the parameters $(\beta_0, \Pi_\beta, \alpha_e, \alpha_a, \{\zeta_w\}_{w\in\mathcal{W}})$, the log-likelihood of the mobile OS choice, w_i, and mobile app installation selection, $d_i = (d_{ij})_{j\in\mathcal{J}}$, by app user $i = 1,\ldots,N$ in the second period is

$$l(\theta) = \sum_{i=1}^{N}\sum_{w\in\mathcal{W}}\left[1\{w_i = w\}\log p_{iw}(e,a) + \sum_{j\in\mathcal{J}_w} d_{ij}\log p_{ij}(e,a)\right].$$

Parameter estimates were obtained by maximizing this likelihood.

Based on the estimated parameters, we can predict the number of downloads for each app, $(s_j)_{j\in\mathcal{J}}$, and the number of mobile OSs chosen by app users, $(s_w)_{w\in\mathcal{W}}$, as a function of the download and in-app purchase price, $e=(e_j)_{j\in\mathcal{J}}$, and the ad volume, $a=(a_j)_{j\in\mathcal{J}}$, of each app, as

$$s_j(e,a) = \sum_{i=1}^{N}\sum_{w\in\{o_j,Both\}} p_{iw}(e,a)p_{ij}(e,a)$$

$$s_w(e,a) = \sum_{i=1}^{N} p_{iw}(e,a),$$

This prediction enables us to conduct a market definition and market power assessment. The relevant market definition is described in Section 3.3, and the market power assessment is described in Section 3.4.

Profits of apps An app j charges download price and in-app purchases e_j or shows advertisements by the amount a_j. The profit of such an app is given by The profits (sales) of the hypothetical monopolist under an observed download and in-app purchase price, e, and ad volume, a, are

$$\pi_j(e,a) = (e_j + r_j a_j)s_j(e,a),$$

where r_j is the advertising price for the ad slots on app j.

As a simple benchmark, we assume that the advertising market can be regarded as perfectly competitive. In this case, mobile app developers choose the number of ads shown to app users by taking the market price of the advertisement as given. This assumption is, of course, not always realistic. However, if the focus is on the competition between two large mobile OSs or between mobile app stores and not on the welfare analysis of advertisers, then it would be convenient to simplify the decisions of mobile app developers in the advertising market. The indirect network effect between app users and advertisers is simplified, yet it plays some roles in this model.

3.2. Extensions

As we have made a number of simplifying assumptions, we discuss the ways to relax these assumptions. These include imperfectly competitive advertising markets, more general demand specifications, substitutability or complementarity between mobile apps, and the presence of adjacent markets.

Imperfectly competitive advertising market In this case, mobile app developers can decide on the advertisement price, and advertisers decide on the ad volume. When we study the behavior of mobile apps with a large share in the product and advertisement markets, such as Facebook, we need to consider this case. Because the model becomes complicated, it is inevitably more challenging to solve and estimate.

There are several ways to analyze the market power of mobile apps in advertising. In this study, as a relatively simple approach, we propose a discrete choice model that assumes multi-homing advertisers. It is not impossible to consider single-homing advertisers, but it requires a numerical method to solve the equilibrium and disallows us from defining the aforementioned concept of app user disutility.

When a set of mobile apps $\mathcal{J}$ is given, the advertiser's utility for placing ads on mobile app $j\in\mathcal{J}$ is defined as

$$(b_{jl} - r_j)s_j,$$

where

$$b_{jl} = \exp\left(\gamma' x_j + \epsilon_{jl}\right),$$

is the profit advertiser l can make per app user when ads are displayed on mobile app j, ϵ_{jl} is a profit shock, r_j is the advertisement price per ad display, and s_j is the number of users of mobile app j. If mobile app j is an app that runs on a certain mobile OS, the number of users of mobile app j is determined by the number of single-homing app users on the OS using mobile app j and the number of multi-homing app users using the app on the OS.

Assuming that ϵ_{jl} follows the standard normal distribution, the probability that an advertiser places an ad on app j is given by

$$\begin{aligned} a_j(r_j) &= \Pr\left[\exp\left(\gamma' x_j + \epsilon_{jl}\right) > r_j\right]. \\ &= 1 - \Phi\left(\log r_j - \gamma' x_j\right) \end{aligned}$$

where Φ denotes the cumulative distribution function of the standard normal distribution. This shows a one-to-one mapping between advertisement price r_j and ad volume a_j. If ad volume a_j is given, we can derive the app user's choice probability of mobile app p_{ij} and that of mobile OS p_{iw} as well as the perfectly competitive case. Hence, we can write the model as a function of either r_j or a_j: To make this consistent with the notation of the perfectly competitive case, we write it as a function of a_j.

We can estimate the parameter using the maximum likelihood method and a perfectly competitive model. The difference is that we must solve the equilibrium $(s_j^*, a_j^*)_{j\in\mathcal{J}}$ for each parameter, θ. By letting $(s_j(\theta), a_j(\theta))_{j\in\mathcal{J}}$ denote the equilibrium, the probability of mobile app j to be installed is

$$p_{ij}[e_j, a_j(\theta)] = \frac{\exp[\beta_i' x_j - \alpha_e e_j - \alpha_a a_j(\theta)]}{1+\exp[\beta_i' x_j - \alpha_e e_j - \alpha_a a_j(\theta)]},$$

expected indirect utility obtained from apps that can be installed after selecting w:

$$v_{iw}[e, a(\theta)] = \sum_{j\in\mathcal{J}_w}\log\left\{1+\exp[\beta_i' x_j - \alpha_e e_j - \alpha_a a_j(\theta) + \epsilon_{ij}]\right\} + \delta\cdot|\mathcal{J}_{w_i}|,$$

and the choice probability for mobile OS w is

$$p_{iw}[e, a(\theta)] = \frac{\exp\{v_{iw}[e,a(\theta)] + \zeta_w\}}{\sum_{w'\in\mathcal{W}}\exp\{v_{iw'}[e,a(\theta)] + \zeta_{w'}\}}$$

The ad volume on the mobile app j is given by $a_j(\theta)$.

Given this, the log-likelihood of mobile OS choice, w_i, and mobile app choice, $d_i = (d_{ij})_{j\in\mathcal{J}}$, by app user $i = 1,\ldots,N$ in the second period and of the ad volume on each mobile app is

$$\begin{aligned} l(\theta) = &\sum_{i=1}^{N}\sum_{w\in\mathcal{W}}\left[1\{w_i = w\}\log p_{iw}[e,a(\theta)] + \sum_{j\in\mathcal{J}_w} d_{ij}\log p_{ij}[a_j(\theta), e]\right] \\ &+ \sum_{w\in\{iOS,And\}}\sum_{j\in\mathcal{J}_w}\log\phi[a_j - a_j(\theta)]. \end{aligned}$$

where ϕ denotes the density function of the standard normal distribution. This assumes that the ad volume data have observation errors that obey the standard normal distribution. Parameter estimates were obtained by maximizing this likelihood.

By using the estimated parameters, we can predict the number of mobile app installations, $(s_j)_{j\in\mathcal{J}}$, the number of mobile OSs selected, $(s_w)_{w\in\mathcal{W}}$, the advertising price, $(r_j)_{j\in\mathcal{J}}$ as a function of the download and in-app purchase price, $e=(e_j)_{j\in\mathcal{J}}$, and the ad volume, $a=(a_j)_{j\in\mathcal{J}}$, as

$$s_j(e,a) = \sum_{i=1}^{N}\sum_{w\in\{o_j,Both\}} p_{iw}(e,a)p_{ij}(e,a),$$

$$s_w(e,a) = \sum_{i=1}^{N} p_{iw}(e,a),$$

$$r_j(a_j) = \exp[\Psi^{-1}(1-a_j) + \gamma' x_j],$$

This prediction can be used to conduct market definitions and market power assessments.

Substitutability/complementarity between mobile apps Thus far, the discussion has assumed that the mobile app choice after the mobile OS choice is independent. In reality, apps may be substitutes or complements. Here we briefly discuss the ways to take these into account.

Ghose and Han (2014) and Kawaguchi et al. (2022b) use high-frequency data and estimate the model in which mobile apps are substitutes based on the assumption that the number of downloads each day is small. Specifically, they assume that each day or week, app user i downloads one app j from the set $\mathcal{J}_{w_i}$. With their specifications, the choice probability for each app j is then given by

$$p_{ij}(e,a) = \frac{\exp(\beta_i' x_j - \alpha_e e_j - \alpha_a a_j)}{1 + \sum_{k \in \mathcal{J}_{w_i}} \exp(\beta_i' x_k - \alpha_e e_k - \alpha_a a_k)},$$

with the corresponding indirect utility

$$v_{iw}(e,a) = \log\left[1 + \sum_{k \in \mathcal{J}_w} \exp(\beta_i' x_k - \alpha_e e_k - \alpha_a a_k)\right] + \delta.$$

This specification also allows us to conduct market definition and market power assessments.

Another approach would be to directly consider the combinatorial problem of app users in choosing the portfolio of mobile apps to download. To do so, we may have to adopt the framework of multicategory competition (Thomassen et al., 2017). However, this approach is still under development and not yet ready for practical use.

Adjacent markets It is worth noting that this framework applies to competition with adjacent markets such as web apps and console games. In other words, we must only consider a model that extends the device/OS choice $\mathcal{W}$ from $\{iOS, Android, Both\}$ to $\{iOS, Android, PlayStation, iOS\&Android, Android\&PlayStation, All\}$. It is advisable to assume that web apps can be installed under an arbitrary mobile OS choice w. The main issue here is data, not modeling. We need data on (i) devices owned ($\{iOS, Android, PlayStation, iOS\&Android, Android\&PlayStation, All\}$) and (ii) services used at the app user year level, and data on (i) purchase prices, (ii) average in-app purchases, and (ii) average ad volume at the year level.

Other econometric specifications. There could be several ways to generalize demand specifications. For example, the baseline specification does not include a random effect in β_i. Extending the model by including a random effect is easy but increases the computational burden and destabilizes the mobile app's equilibrium price and ad volume computation.

We also did not consider endogeneity between the mobile app's price, ad volume, and unobserved fixed effects. This could be addressed by using the control function approach (Petrin and Train, 2010).

3.3. Market definition

We can conduct a hypothetical monopolist test for mobile apps based on the concept of a "Small but Significant and Non-transitory Increase in Price (SSNIP)" and "Small but Significant and Non-transitory Increase in Cost (SSNIC)" tests. To fix the idea, we consider how to test whether "all iOS apps constitute a single antitrust market". To do so, we consider a hypothetical monopolist who retains the rights to all iOS apps, $\mathcal{J}_{iOS}$. The profits (sales) of the hypothetical monopolist under an observed download and in-app purchase price, e, and ad volume, a, are

$$\pi_{iOS}(e,a) = \sum_{j \in \mathcal{J}_{iOS}} (e_j + r_j a_j) s_j(e,a),$$

where $s_j(e,a)$ is the market share derived from an estimated baseline model of Section 3.1 or an extended model of Section 3.2.

The hypothetical monopolist test asks whether an increase in price or advertisements, a 5% increase in price, for example, raises the profit of the hypothetical monopolist. The problem is that the hypothetical monopolist can either increase the download and in-app purchase prices by 5% or increase the ad volume by 5%. We propose two approaches to solve this problem.

The first approach is to judge that it constitutes the antitrust market if the hypothetical monopolist can profitably raise either the download or in-app purchase price or the ad volume by 5%. This is because the hypothetical monopolist could increase the profit by more efficiently combining the increase in the download and in-app purchase price and ad volume. Specifically, letting e' denote the price vector when there is a 5% increase in the download and in-app purchase prices, and a' denote the ad vector when the ad volume is increased by 5%, if either of the conditions

$$\pi_{iOS}(e',a) > \pi_{iOS}(e,a),$$

or

$$\pi_{iOS}(e,a') > \pi_{iOS}(e,a)$$

is met, we judge that the iOS apps constitute a single antitrust market.

This is a conservative way of defining a market: if the hypothetical monopolist can increase the profit in this way, then the hypothetical monopolist forms a relevant market; however, even if the hypothetical monopolist cannot increase the profit by this, it is not necessarily true that the market is not defined.

We can follow the same procedure to define the market, even if competition in the advertising market is imperfect. In this case, it should be noted that advertisement price r is a function of ad volume a. The profit of the hypothetical monopolist under the observed download, in-app purchase price e, and ad volume a is

$$\pi_{iOS}(e,a) = \sum_{j \in \mathcal{J}_{iOS}} [e_j + r_j(a_j) a_j] s_j(e,a),$$

and we judge that iOS apps constitute an antitrust market if either of the conditions

$$\pi_{iOS}(e',a) > \pi_{iOS}(e,a),$$

or

$$\pi_{iOS}(e,a') > \pi_{iOS}(e,a)$$

is met.

The second approach uses the concept of SSNIC and rigorously defines the antitrust market by using the concept of app user disutility. The app user's disutility from using app j is defined by the difference in the indirect utility between when the mobile app's download and the in-app purchase price is 0 and ad volume is 0; when they are e_j and a_j, that is, $c_j = \alpha_e e_j + \alpha_a a_j$.

The app user model indicates that $c = (c_j)_{j \in \mathcal{J}}$ is a sufficient statistic of download and in-app purchase price and ad volume in both mobile app choice probability p_{ij} and mobile OS choice probability p_{iw}.

$$p_{ij}(c_j) = \frac{\exp(\beta_i' x_j - c_j)}{1 + \exp(\beta_i' x_j - c_j)}$$

$$v_{iw}(c) = \mathbb{E} \max_{d_{ij}, j \in \mathcal{J}_w} \sum_{j \in \mathcal{J}_w} d_{ij} u_{ij} = \sum_{j \in \mathcal{J}_w} \log\left[1 + \exp(\beta_i' x_j - c_j)\right] + \delta \cdot |\mathcal{J}_w|$$

$$p_{iw}(c) = \frac{\exp[v_{iw}(c) + \zeta_w]}{\sum_{w \in \mathcal{W}} \exp[v_{iw'}(c) + \zeta_{w'}]}$$

This means that the interaction between a mobile app and an app user and between mobile apps matters only through the app user's disutility c. Therefore, conditional on app user disutility c, the optimal download, in-app purchase price, and ad volume are determined independently across mobile apps.

We define the profit of the mobile device under the optimal download, in-app purchase price, and ad volume as:

$$\pi_j^*(c) = \max_{e_j, a_j : \alpha_e e_j + \alpha_a a_j = c_j} (e_j + r_j a_j) s_j(c)$$

or

$$\pi_j^*(c) = \max_{e_j, a_j : \alpha_e e_j + \alpha_a a_j = c_j} [e_j + r_j(a_j) a_j] s_j(c)$$

Then, the profit of the hypothetical monopolist who retains the rights to all iOS apps under app user disutility c is

$$\pi_{iOS}^*(c) = \sum_{j \in \mathcal{J}_{iOS}} \pi_j^*(c)$$

By letting c' denote the vector of app users' disutility when it is raised by 5%, we judge that iOS apps constitute an antitrust market if the condition

$$\pi_{iOS}^*(c') > \pi_{iOS}^*(c)$$

is met.

This method determines a conceptually consistent antitrust market under the current modeling assumption. Also, this method can be applied to an arbitrary set of mobile applications. For example, if we consider all iOS and Android game apps, we can consider a hypothetical monopolist for those apps and apply the aforementioned framework. If we consider all mobile game apps and console games, after estimating demand by incorporating game consoles into the platform choice, we can use the same test.

We put one caveat that while the SSNIC approach proposed here is conceptually consistent within our framework, it relies on several modeling assumptions. For example, the result that the app user's disutility is uniquely determined and works as a sufficient statistic for the interaction across players is no longer true once we consider a random coefficient for the disutility of losing money α_e and the disutility of watching advertisements α_a, because disutility becomes heterogeneous across app users. Hence, if we consider a more complicated setting, using the first approach, which does not rely on well-defined app user disutility, might be an alternative option.

3.4. Assessment of market power

Using this model to express app user demand, advertiser demand, and profits of mobile app developers as a function of app user disutility, we can also define standard indicators for assessing market power, such as elasticity, conversion ratio, and upward pricing pressure of mobile apps.

For example, the app user disutility elasticity of a mobile app can be calculated as follows:

$$\eta_j^s = \frac{\partial \ln s_j(c)}{\partial \ln c_j}$$

If the advertising market is assumed to be in perfect competition, we can use it as an indicator of the mobile app's market power. If the advertising market is in imperfect competition, then in addition to this, the own advertisement price elasticity:

$$\eta_j^a = \frac{\partial \ln a_j(r_j)}{\partial \ln r_j}$$

also need to be considered.

First, we explain why own-price elasticity is an indicator of market power. Let us imagine firm j which sells a product with marginal cost mc_j at price e_j. If the demand for the product is $s_j(e_j)$, the profit is $\pi_j(e_j) = (e_j - mc_j) \times s_j(e_j)$. The first-order condition of profit maximization for e_j is:

$$\frac{\partial \pi_j(e_j)}{\partial e_j} = s_j(e_j) + \frac{\partial s_j(e_j)}{\partial e_j}(e_j - mc_j) = 0$$

Rearranging this gives the Lerner index:

$$\frac{e_j - mc_j}{e_j} = \frac{1}{\eta_j^s}$$

The left-hand side of the equation is the markup rate, and the right-hand side is the reciprocal of the price elasticity of demand. From this equation, the lower the own-price elasticity, the higher the markup rate. Therefore, own-price elasticity is used as a (reverse) indicator of market power.

Similarly, the advertising elasticity of app user demand and the advertising price elasticity of ad demand can be used as indicators of market power for the following reasons. If we consider a situation in which the developer of a paid mobile app j sets the ad volume a_j and charges price e_j, the first-order condition of profit maximization for price e_j is:

$$\alpha_y \frac{\partial s_j}{\partial c_j} \pi_j^*(c_j) + s_j = 0.$$

Rearranging this gives the profit per download $\pi_j^*(c_j)$ as

$$\frac{\pi_j^*(c_j)}{c_j} = \frac{1}{\alpha_y \eta_j^s}$$

where

$$\frac{\pi_j^*(c_j)}{c_j}$$

is the markup rate generalized to situations where the app has multiple ways of earning revenue.

The first-order condition for the ad volume a_j is:

$$\alpha_a \frac{\partial s_j}{\partial c_j} \pi_j^*(c_j) + s_j \left(r_j'(a_j) a_j + r_j(a_j) \right) = 0,$$

and rearranging this yields:

$$\frac{\pi_j^*(c_j)}{c_j} = \frac{r_j \left(1 + \frac{1}{\eta_j^a}\right)}{\alpha_a \eta_j^s}.$$

From the formula above, the higher the advertising rate and the lower the price elasticity of ad demand, the higher the generalized markup rate. Furthermore, as we rewrite the equation for the advertisement price r_j, we obtain

$$r_j = \frac{\pi_j^*(c_j)}{c_j} \frac{\alpha_a \eta_j^s}{1 + \frac{1}{\eta_j^a}},$$

This formula tells us that the higher the advertising price elasticity of ad demand, the lower the advertising rate tends to become, and the larger the ad volume tends to become. The higher the disutility elasticity of app user demand, the higher the advertisement price tends to become, and the lower the ad volume tends to become.

In this example, although the first-order conditions of optimization and the own price elasticity to be evaluated for paid apps are different from those to be evaluated for free apps, the market power of a mobile app can be uniformly assessed from the estimate of the same model.

If we want to calculate the conversion ratio between the mobile app j of mobile app developer d and a mobile app of another mobile app developer d', let $\mathcal{J}_d$ denote apps owned by developer d, $s_d(c_d) = (S_j(c_j))_{j \in \mathcal{J}_d}$, which can be calculated by

$$\left(\frac{\partial s_d(c_d)'}{\partial c_j} \right)^{-1} \left(\frac{\partial s_{d'}(c_{d'})'}{\partial c_j} \right).$$

The upward pricing pressure of app j is defined as the difference between the first-order condition before and after the merger (Jaffe and Weyl, 2013), that is,

$$-\left(\frac{\partial s_d(c_d)'}{\partial c_j} \right)^{-1} \left(\frac{\partial s_{d'}(c_{d'})'}{\partial c_j} \right) \pi_{d'}(c_{d'}),$$

3.5. Analysis of mobile OS

The analysis so far has focused on the market definition and assessment of the market power of mobile apps. To extend the analysis to the mobile OS, we need to complete three additional tasks. First, the decisions of mobile apps, such as pricing, advertising, and app development, must be endogenized, and the parameters governing these decisions must be estimated. Second, the response of consumers and mobile apps to the policies of mobile OS, such as the transaction fee on the download price, needs to be calculated. Third, the profit of mobile OS platforms needs to be estimated, which requires an additional model and data on the profit of mobile OS platforms. Then, we can apply the similar analysis above to the mobile OSs. Kawaguchi et al. (2022b) estimate the cost parameters of mobile apps and study the effects of a transaction fee reduction on pricing and advertising decisions of mobile apps. However, because they do not have information on the profits of mobile OS platforms, they do not conduct a market definition of mobile OSs nor assess their market power.

4. Concluding remark

This paper discussed a method to define the antitrust market and evaluate the market power of mobile apps. To do so, it proposed a consumer's two-step choice between mobile OSs and mobile apps, where the price of an app is generalized to the "cost" of using an app, i.e. the disutility of paying money to download the app and that of watching advertisements to use the app. The proposed method of a market definition based on the concept of consumer disutility and the SSNIC test is applicable to other markets with non-price features and multiple revenue sources. For example, the proposed method would be applicable to other online ad-funded content businesses.

We conclude by mentioning several limitations of our study. We did not discuss the assessment of the market power of mobile OS owners, such as Apple and Google, because it required more analysis on the supply side of the mobile app market. For this, we refer to Kawaguchi et al. (2022b). Second, we treated payment services as exogenous adjacent markets. However, in some cases, such adjacent markets may have to be handled explicitly as markets for payment method service providers. Thus, we need extra data on the payment method usage outside app stores. Third, it addressed the switching cost between mobile OSs in a limited way. A fully-dynamic model is appreciated to address this issue.

Data availability

No data was used for the research described in the article.

Appendix. Antitrust cases

In this appendix, we review two examples of competition law cases shown to help understand the characteristics and issues in the market definition in the mobile app economy.

A.1. Review of managerial integration of Z Holdings Corporation and LINE Corporation by JFTC

In August 2020, the JFTC reviewed the proposed M&A operations between Z Holdings Corporation and LINE Corporation and decided to approve the M&A operations.[39]

The merging parties are mobile app developers. Z Holdings Corporation is a group of combined companies owned by the parent company SoftBank Group Corporation. Its subsidiary, Yahoo Japan Corporation, provides news distribution services through Yahoo! JAPAN app and Yahoo! News app. In addition, its subsidiary, PayPay Corporation, produces a code-based payment app, PayPay. LINE Corporation is a group of combined companies held by the parent company NAVER Corporation. LINE Corporation provides messaging and news distribution services on its LINE app, and its subsidiary, LINE Pay Corporation, produces a code-based payment app, LINE Pay. Both Z Holdings Corporation and LINE Corporation are influential mobile app developers in the Japanese market. In the 2019 ranking of the number of active monthly users released by AppAnnie (2020), LINE, an app provided by LINE Corporation, held the 1st place, and Yahoo! JAPAN, Yahoo! Weather, and Yahoo! Japan Transit, apps provided by Z Holdings Corporation, were ranked 4th, 6th, and 9th, respectively, in the non-game app category.

In the review, the JFTC defined relevant markets in the fields of "news distribution service", "advertisement-related business", and "code-based payment service" as the fields of trade in which the merging parties are competing or trading.

For each field, the JFTC examined the demand substitutability and supply substitutability based on the nature of the business and hearings, "free news distribution services" as the relevant market for news distribution service; "non-search advertising business", "intermediation service of specific digital advertisement where advertising clients/advertising agencies are users", and "intermediation service of specific digital advertisement where media companies are users" for advertisement-related business; and, "code-based payment services where app users are users" and "code-based payment services where member stores are users" for code-based payment services. However, the JFTC did not analyze the influence of the merger of Z Holdings Corporation and LINE Corporation on the mobile app market or the mobile app monetization services.

Based on the results of the market definition above, the JFTC judged that the merger would not substantially lessen competition and decided to approve the merger without remedies other than those for the code-based payment service proposed by the merging parties.

In this review of transactions, the first issue is defining the relevant markets in two-sided markets. Specifically, the merger involves two-sided platforms because "news distribution service" and "advertisement-related business" put the viewers and advertisers together. The code-based payment services match the "app users" and "member stores". The JFTC separately defined markets for news distribution services, advertisement-related businesses, code-based payment services where app users are users, and code-based payment services where member stores are users. However, when defining the relevant market and evaluating the market power of goods and services that face multiple markets for app users and advertisers, such as mobile apps, the market power of multiple businesses needs to be assessed simultaneously. The second issue was the assessment of the competitiveness of code-based payment services, in which profits come from adjacent markets. More discussions are needed to determine how to conduct market definitions and market power assessments in such situations.

A.2. Epic Games, Inc. v. Apple Inc. in U.S. District Court for California

The second example is a lawsuit filed by Epic Games against Apple. In this case, the question was whether Apple's goods and services were in a monopoly position.

In August 2020, Epic Games filed a lawsuit against Apple, alleging Apple's violations of antitrust laws and California's Unfair Competition Law regarding Apple's App Store rules that charge 30% of in-app purchases and prohibit the use of payment systems outside Apple's system.[40] Epic Games claimed that Apple was exerting monopoly power

[39] https://www.jftc.go.jp/houdou/pressrelease/2020/aug/200804.html, accessed on March 28, 2022.

[40] https://cand.uscourts.gov/cases-e-filing/cases-of-interest/epic-games-inc-v-apple-inc/, accessed on 28 March 2022.

in the mobile app distribution and in-app payment markets. The high commission maintained by such monopoly power caused an increase in the price of mobile apps and stagnation of innovation by mobile app developers due to reduced development expenses.

One of the main issues was whether Apple was in a monopoly position. Epic Games defined the entire mobile OS market as the foremarket and the mobile app distribution and monetization service markets as the aftermarkets. Based on this definition, Epic Games argued that while Apple might not have had a monopoly in the foremarket, Apple was exerting monopoly power in the aftermarkets consisting of relevant markets formed by the iOS app distribution and payment processing service markets. In contrast, Apple claimed that the entire video game market including digital mobile games, PC games, console games, and cloud streaming games was the relevant market for the mobile app distribution service. Apple was not the monopolist in mobile app distribution and monetization services. Apple also claimed that a 30% commission level is necessary to ensure transaction safety.

Regarding the definition of relevant markets, both sides used expert testimony accompanying data analysis by economics and business administration experts to prove the presence or absence of the substitutability of smartphone choice by app users and game use by holders of multiple game devices. However, the judge did not adopt either side of the conclusions in defining relevant markets, stating that the expert testimony on both sides lacked validity.

In September 2021, the U.S. District Court for the Northern District of California dismissed the definition of aftermarkets by Epic Games and subdivided the video game market suggested by Apple. Specifically, the Court defined the relevant market of the App Store as a digital mobile gaming transaction market consisting of Apple App Store, Google Play Store, Samsung Galaxy Store, and other similar stores and ruled that Apple was not in a monopoly position in that market. Regarding mobile app monetization services, the Court ruled that the digital mobile gaming transactions market had substitutable stores, and competition existed even for in-app purchases.

Independent of the above decisions on the market definition and the evaluation of market power, the Court ruled that the anti-steering provisions set by Apple violated California's Unfair Competition Law and ordered Apple as a remedy to allow providing links ("outlinking") to direct users to websites with external billing functions in mobile apps.

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