Effect of App Market Conditions on Permissions Usage by App developers

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Abstract

The common mechanism for controlling security and privacy data on mobile platforms is through the app permissions model. Platform owners evolve the model through changes to the APIs provided to app developers. This however places increased responsibility on app developers to determine the privileges they need to deliver the app's functionality. In this paper, we investigate the factors influencing an app developer to seek permissions for privileged access in the context of the Android mobile platform. We find that the apps facing higher competition in their category or targeted at more mature audiences seek more permissions from users. However, apps charging higher prices for downloads ask for a lower number of permissions. The findings suggest that market conditions incentivize app developers to seek more privileges whereas a revenue stream such as download price does not. Therefore, more control exercised by the platform owner on the conditions of their app market would be more beneficial to the platform from the security and privacy perspective.

Keywords: Mobile Platforms, Apps, Security & Privacy, App permissions, Android.

1. Introduction

The popularity and ubiquity of smartphones are driven by the many useful apps available on all the major mobile platforms. As the apps become embedded more and more into the everyday lives of the users, security and privacy concerns have been at the forefront. One way that these concerns are managed by platform owners is by increasing transparency of the privileges that each app has through the permission system framework (Mayrhofer, Stoep, Brubaker, & Kralevich, 2021). Major mobile platforms such as both iOS and Android use this model, where individual apps need to specify what privileged access to the device they request, and the user is provided an opportunity to allow or deny the access request. Some common examples of such requests are access to network, location, and hardware (camera, microphone, storage, etc.) on the mobile device. The permissions framework enables or disables access to parts of the platform API that apps use to access the privileged functions on the devices (Ahmed & Sallow, 2017).

As the platforms have evolved over the years, newer versions of the platform APIs have included more examples of permissions that control a larger proportion of access to parts of the API that require higher privileges (Almomani & Khayer, 2020; Wei, Gomez, Neamtiu, & Faloutsos, 2012). The evolution of the permissions system is a major component for increasing transparency of privileged access provided to the end users of the platform. However, the permissions system also places responsibility on the app developers to choose what privileged access they will ask for from the users thus making app developers an important party to the security and privacy strategy of the platform. Therefore, it is important to take the app developer's perspective to understand the usage of permissions for security and privacy on a mobile platform.

Especially, as platform owners have increased the scope of APIs covered under the permissions system, the effectiveness of the strategy depends on how app developers respond to this evolution. App developers operate under conditions of intense market competition (Soh & Grover, 2020). Therefore, in this paper, we ask, *what app market factors influence the usage of permissions by app developers on a mobile platform.* By investigating this question, we expect to discover the contextual aspects that influence the usage of the permissions system and therefore security and privacy on mobile platforms. The rest of the paper is structured as follows. In section 2, we discuss the literature we draw from, to inform our investigation. In section 3, we build the theoretical discussion, research model, and hypotheses. In section 4, we discuss the empirical approach to test the research model. Section 5 presents the results and implications of our findings. We conclude in section 6 with a note

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on limitations of this study and the future directions that could be taken.

2. Theoretical Background

2.1. Platform Architecture & Evolution

Platform and complementors are two components of platform ecosystem (Tiwana, Konsynski, & Bush, 2010). Platform owners make various decisions such as how to manage the platform ecosystem and how to design the platform architecture, interface APIs, and the security and privacy framework. To better understand how platform owners facilitate innovation, extant studies have examined the role of platform owners in complementary markets. For example, it was found that Google's entry into photography apps market increased complementary innovation by increasing consumers' attention to photography apps (Foerderer, Kude, Mithas, & Heinzl, 2018). Similarly, Facebook's integration with Instagram is positively correlated with the demand for Instagram and has positive spillover effects on large third-party apps (Li & Agarwal, 2017).

Platform owners also make decisions on evolving the platform's architecture. Tight coupling and loose coupling can affect platform performance (Brunswicker, Almirall, & Majchrzak, 2019). Platform's openness can also introduce opportunistic sellers with low-quality products (Geva, Barzilay, & Oestreicher-Singer, 2019). It is also suggested that platform can increase the quantity of the platform user's service innovation by providing toolkits and design autonomy (Ye & Kankanhalli, 2018).

Platform architecture can affect the performance of complements. For example, on a console with complex architecture that complements need to interact with many interdependent components of the platform's core technology through specialized interfaces, multihoming games have lower-quality performance (Cennamo, Ozalp, & Kretschmer, 2018). However, when platform architecture is complex, developers can use sequential development strategy to increase complement quality because sequential development provides developers more time (Cennamo et al., 2018). In addition, platform architecture factors such as coupling and constraints can influence producers' iterative design moves at the individual level (Brunswicker et al., 2019). Loose coupling enables developers to better predict the performance of app (Simon, 1962). In contrast, with tight coupling, developers are hard to assess the performance of app due to functional interdependencies (Baldwin & Clark, 2006). Both architecture factors can increase or decrease platform performance (Brunswicker et al., 2019).

From an architecture perspective, platforms can be classified as orchestration, amalgamation, or innovation platforms based on infrastructure, core, ecosystem, and service dimensions (Blaschke, Haki, Aier, & Winter, 2019). Mobile platforms such as Android are classified as orchestration platforms and feature high openness and can easily integrate with third-party derivatives (Blaschke et al., 2019). A comparison of Android, iPhone, and Qt mobile platform architectures perspective on the dimensions of memory management, communication between components, access to mobile-specific APIs, and core phone functionality finds different strengths and weaknesses for each platform (Lettner, Tschernuth, & Mayrhofer, 2012). However, as Android is a very popular mobile platform, we focus our discussion further on its specifics.

2.2. The Android Platform

The Android platform along with iOS is a leading mobile platform. Android holds a market share of 71.45% by units shipped as of May 2022 (Statcounter, 2022). Android's market share implies that many mobile device users interact with Android's security and privacy framework. A common mechanism for managing security and privacy of end user devices is the permissions system (Mayrhofer et al., 2021). In this system, the platform owner controls the APIs that access sensitive data on the device by having the apps running on the platform request access from the end user (Ahmed & Sallow, 2017). The relevant APIs can be accessed by the app only if the end user chooses to do so.

An early investigation into the effectiveness of Android's permissions mechanism found that the set of permissions that could be requested increased in the period from 2008 to 2012. The increase was not in the direction of providing finer-grained permissions but to control access to new hardware features. Further, it was also found that popular third-party apps were overprivileged and tended to use more permissions over time (Wei et al., 2012).

A more recent update of this work finds that the trend of increased permissions and permissions usage by apps continues and there are still many security issues with the Android permissions system (Almomani & Khayer, 2020). Of course, the security model must balance security, privacy, and usability for users as well as address assurance and system performance concerns of app developers (Mayrhofer et al., 2021). The perspective adopted by extant literature looks at security and privacy on the Android

platform based on the platform owner's actions related to the permissions framework and does not account for the complementary role of app developers. Specifically, we don't know the reason why app developers have continued to request more permissions from the users as more of them have been made available by the platform. Therefore, we next look at the conditions of the Android app marketplace suggesting the contextual conditions that may influence permissions usage by app developers.

2.3. App Developers & App Market Conditions

With many apps available on Google Play Store, there is intense competition between the apps available for the Android platform. Additionally, the competition for user attention results in a winner takes all kind of scenario where successful apps build on network effect benefits and corner a large portion of potential revenue from an app category (Soh & Grover, 2020). The availability of many substitute apps implies that an app developer would need to differentiate their offering through increased innovation and unique features that the app can provide (James, Leiblein, & Lu, 2013). The success of an app in this hyper competitive environment depends on its popularity and adoption by end users.

Translating the usage and popularity of an app into revenue for the app developer needs a monetization mechanism. An app developer may choose to charge a price to download the app from the market, thus directly translating app downloads into revenue (Finkelstein et al., 2017). However, an initial download price could also be a potential barrier to adoption if substitutes with similar functionality are available on the marketplace for no charge. Alternatively, app developers may choose to use other revenue models, such as in-app purchases or advertising to generate revenue from their apps.

Finally, app developers may choose to target different markets for their apps based on demographics (Lin, Liu, Sadeh, & Hong, 2014). The expectations for innovation and features for specific target markets would be a consideration for app developers and reliance on privileged access to the devices of the users. In the next section, we develop the hypotheses for the influence of the competition intensity, revenue model, and target market demographics on the usage of permissions by app developers.

3. Research Model & Hypotheses

For investigating the influence of app market conditions on permissions usage, we propose the research model depicted in Figure 1.

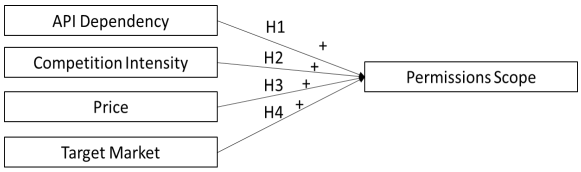

Figure 1. Research Model.

3.1. Construct Definitions

Permission Scope – The permissions scope of an app is the full set of permissions that it seeks from end users. It represents the privileged access an app requests from the users. (Wei et al., 2012).

API Dependency – API dependency is defined as the version of the mobile platform API that an app needs for compatibility purposes. The dependency on a minimum version of the API allows an app to use the defined permissions available in that version and above. (Almomani & Khayer, 2020).

Competition Intensity – The competition intensity faced by an app is the level of competition the app faces on the app marketplace from other apps which could be potential substitutes for it. (Boudreau, 2012).

Price – The price of an app is the amount of money required to download an app from the marketplace. We consider the price to download only and no in-app purchases (freemium models) as this presents an important indicator of the value assessment performed by the app developers that the users need to evaluate before deciding to use the app (Soh & Grover, 2020).

Target Market – The target market of an app is defined as the desired user base the app developer is targeting based on demographics. As mobile platform apps are targeted to individuals, different market segments based on demographics provide app developers with choices on what features they develop and how they compete with other apps in the marketplace. (Lin et al., 2014).

Table 1 below summarizes the definitions of the constructs used in the research model.

Table 1. Construct Definitions.

Construct	Definition
Permission Scope	The level of privileged access an app requests from the user
API Dependency	The minimum API level the app requires to run on a device
Competition intensity	The extent of competition in the focal app's category.
Price	The purchase price paid to download the app from the market.
Target Market	The target market of the app based on demographics

3.2. Hypotheses

Mobile platform owners evolve their API with new releases including the permissions system that is used by the apps on the platform to request privileged access from the users. In the interest of increased transparency, there is generally a trend of an increasing number of permissions that an app can request (Almomani & Khayer, 2020; Wei et al., 2012). Therefore, apps depending on the newer version of the platform API have access to more privileges that they can request from the end users. Additionally, as apps also evolve to include more functionality to compete in the marketplace, there is a higher likelihood that if they target newer versions of the platform API, they must seek additional permissions to deliver their functionality. Therefore, we suggest the following relationship between an app's permission scope and API dependency:

H1: An app's dependency on a higher level of platform API is associated with a higher permission scope required for the app

With respect to the competition that an app faces from its potential substitutes in the app marketplace, the app would need to differentiate itself by providing more utility to its users(Boudreau, 2012). The app developer can potentially do this by providing more functionality to the user which may also require more privileged access to the mobile device of the user. Therefore, we suggest the following for the relationship between competition intensity and app's permission scope:

H2: Higher intensity of competition from an app's potential substitutes is associated with a higher permission scope required for the app

In the mobile apps marketplaces, there are many apps available and there are different revenue models that the apps may use such as being advertising supported or using in-app purchases (freemium), etc. With such a wide variety of choices for the end user, the initial adoption of an app is an important consideration for the app developer without which an app cannot be successful in the marketplace (Boudreau, 2012). In such a scenario, if an app developer chooses to charge for install of an app instead of other strategies of monetization that do not require a user to pay upfront for the app, the payment becomes a significant barrier to the adoption of the app by users. This increases the pressure on the app developer to increase the utility they provide to the end user by developing a larger and more innovative feature set to indicate the value that the user would get in return for their payment. This increases the chances that the app would need more privileged access and therefore we suggest the following:

H3: A price to download an app from the marketplace is associated with a higher permission scope required for the app

Finally, the demographics of the target market for an app, may determine an app developers' approach to what features they deliver and what level of privileged access their target audience may be comfortable with to adopt their app (Lin et al., 2014). For apps targeted at more mature audiences, the app developers may assume that users may be more comfortable with assessing the increased privileges if the developer requests them against the utility the app provides to the users and therefore the developer may be more comfortable requesting more permission from mature audiences. Conversely requesting more permissions for apps that are targeted for general usage might be questioned about their security and privacy posture and less likely to be successful in the marketplace. Hence, we propose,

H4: Apps targeted at more mature audiences are associated with a higher permission scope required for the app compared to apps targeted to general audiences.

4. Data & Empirical Approach

4.1. Research Data Set

The data for the empirical analysis is based on the details of applications from the Google Play Store for android apps, which had approximately 2.1 million apps available as of 2021. Figure 2 depicts the details of a typical app from the Play Store which includes the information using which the measures for all dependent and independent variables and controls are built. First, we obtained a list of applications available on the Google Play Store from appfigures (www.appfigures.com) (Soh & Grover, 2020) including basic app metadata such as the minimum android version, release date, app category classification, price, size, and content rating. Next, for every app on the list, we scraped the associated permissions data from the Google Play Store web interface's home page for the app using an open-source Node.JS scraper. Combining these two data, we generate the measures used in the analysis. In the next section, we describe the measures and how they were constructed from the data.

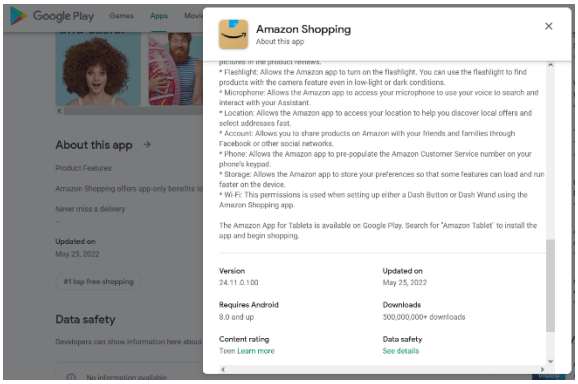

Figure 2. App Store Interface.

4.2. Measures

4.2.1. Dependent Variable

Permission Count - We measured performance scope by counting the total number of permissions an app listed on its Google Play Store page as being requested from the user. We counted the list of permissions scraped for each app and built the variable *Permission Count* as the dependent variable. (Wei et al., 2012).

4.2.2. Independent Variables

Minimum Version - We measured API dependency by using the minimum version of Android that the app needed, indicating the minimum version of the Android API that the app is dependent upon for it to work. Each version of the Android API includes changes to the permissions framework through an overall increase in the number of permissions allowed in newer versions (Wei et al., 2012).

Apps In Category – The competition intensity faced by an app is measured by the number of apps that are classified into the same category (e.g., social, games, etc.) as the focal app and provides an indication of how many potential substitutes the app has (Boudreau, 2012). Popular categories such as games or social media are expected to have more apps that compete for users with the focal app.

Purchase Price – The price of an app is the money the app developer charges to download an app from the marketplace. We consider the price to download only and no in-app purchases (freemium models) as this presents an important indicator of the direct value capture the app developers expect to receive (Soh & Grover, 2020).

Content Rating – The demographic target market of an app is measured using the content rating of the app in the marketplace which defines the intended age group of users that is appropriate for the app (Lin et al., 2014). Apps categorized as for everyone do not have any age restrictions for their usage, and further ratings define the age restriction going up to the mature rating that is intended for apps targeted to adults only. Increasing restriction on the content rating of apps reduces the potential market for an app based on the demographics of the end users.

4.2.2. Controls

We additionally include several controls in our model to account for the effect of other variables on permissions usage that we do not theorize in our research model. We control for *Features Size* (Soh & Grover, 2020) which is the install size of the application on the mobile device and provides an indicator for the number of features the app implements. Apps with more features are expected to be larger in install sizes due to the additional code they would have for feature implementation. More features implemented by the app mean a potentially higher requirement to ask for privileged access. We also control for *App Visibility* indicated by whether the app is included in curated lists like being an editor's choice (Liang, Shi, & Raghu, 2019; Wang, Chen, Xiao, & Fu, 2021). The curated list such as the Editor's choice

determined by the marketplace owner Google provides more visibility to an app and provides an advantage when there is high competition intensity. We also control for *Ad Supported* (Frick & Kaimann, 2017) apps, as such apps may request privileges to track user behavior and target their advertising better. Finally, we include a control for whether the app provides a *Privacy Policy* (Finkelstein et al., 2017). It is likely that an app provides a privacy policy to preempt questions from end users regarding the privileged access the apps seek from them. Table 2 provides a summary of the variables and their measurements.

Table 2. Variables and Measurement.

Variable	Measurement
Permission Count	The number of permissions for each app.
Minimum Version	The minimum version number of the operating system the app can run on.
Apps In Category	The number of apps in the category into which the app is classified.
Purchase Price	Price of the app in USD.
Content Rating	Categorized as 0 if rated for everyone, 1 if rated for teenagers (younger than 17 years old), 2 if the app is targeted at adults (older than 17 years old)
Features size	The install size of the app on the device.
App Visibility	Categorized 1 if the app is featured in editor's choice list, otherwise, 0.
Privacy Policy	Categorized as 1 if privacy policy URL is present, otherwise, 0.
Ad Supported	Categorized as 1 if app includes advertising, Otherwise, 0.
Release Year	The year an app was first released into the marketplace

5. Results, Discussion & Implications

5.1. Empirical Approach

Before evaluating our hypothesis, we had a potential concern for endogeneity specifically for the relationship between *Minimum Version* and the *Permission Count*. There is potential reverse causation in that relationship because app developers may choose to specify a higher minimum version requirement to seek additional permissions allowed in newer versions of Android API to build the features of their app. Therefore, we chose the instrumental variable technique to handle this issue in our empirical analysis.

5.2. Analysis & Results

We identified the release year of the app as an instrument. It is likely that the app developers would choose to use the latest version of Android available at the time the app was developed and released to ensure that they have the full capabilities of the platform available to them and therefore release year would predict the minimum version required by the app. However, the release year should not be associated with permissions as we expect that the number of permissions requested is dependent on the feature set of the app and not the year it was being developed or released. We report the results of this investigation also in the next section and show that release year is a good instrument to address the endogeneity issue with the variables for hypothesis 1. The first stage results shown in table 3 below indicate that Release year is a good instrument for API dependency.

Table 3. 2-SLS First Stage Results

Variable	Minimum Version
Apps in Category	-0.003***
	(0.001)
Purchase Price	-0.094***
	(0.004)
Content Rating	0.036***
	(0.001)
Features Size	-0.000***
	(0.000)
App Visibility	0.674***
	(0.034)
Privacy Policy	0.283***

	(0.002)
Ad Supported	-0.309***
	(0.001)
Release Year	0.119***
	(0.000)
Constant	-236.254***
	(0.678)
R^2	0.1334
N	2.1M

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4 reports the main results of the 2-stage least squares (2SLS) model with each independent variable introduced stepwise. For hypothesis 1, the results indicate (β=0.058) support that higher Minimum Version requirement is associated with a higher number of permissions requested. Similarly for hypothesis 2, on the relationship between permission count and competing apps in the same category, there is support with (β=0.046). This suggests if there are higher number of apps competing with the focal app, more permissions are requested by the focal app. For hypothesis 4, we again find a positive relationship between content rating and the permission count we find support with (β=0.073), suggesting that apps in more restricted categories ask for more permission from the user.

Table 4. 2-SLS Main Results

Permission Count	(1)	(2)	(3)	(4)
Minimum Version	0.077***	0.076***	0.063***	**0.058*** **
	(0.002)	(0.002)	(0.002)	**(0.002)**
Apps In Category		0.043***	0.042***	**0.046*** **
		(0.001)	(0.001)	**(0.001)**
Purchase Price			-0.161***	**-0.163*** **
			(0.003)	**(0.003)**
Content Rating				**0.073*** **
				(0.001)
Features size	-0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
App Visibility	0.277***	0.311***	0.325***	0.313***
	(0.019)	(0.019)	(0.019)	(0.019)
Privacy Policy	0.658***	0.657***	0.658***	0.655***
	(0.001)	(0.001)	(0.001)	(0.001)
Ad Supported	-0.252***	-0.247***	-0.257***	-0.266***
	(0.001)	(0.001)	(0.001)	(0.001)
Constant	1.178***	0.698***	0.769***	0.746***
	(0.008)	(0.010)	(0.010)	(0.010)
R^2	0.169	0.171	0.171	0.172
N	2.1M	2.1M	2.1M	2.1M

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

However, for hypothesis 3, on the relationship between the purchase price and the number of permissions, the results are opposite to what we hypothesized (β=-0.163). A higher purchase price of the app is associated with a lower number of permissions requested from end users. We discuss the results in detail in the following section.

5.3. Discussion & Implications

Based on the results presented above, we find that the competitive business conditions that app developers must operate in when developing and releasing their apps on a popular mobile platform such as Android have an influence on the scope of

permissions the app developers request from the users. While the mobile platform owner may evolve their API by providing more options for app developers to seek permissions and to improve transparency to the end users, the app developers are competing in a tough marketplace (Mayrhofer et al., 2021). The pressure to provide more value to the users implies that a greater number of permissions allowed by the mobile platform doesn't mean that apps are becoming less privileged. The competition intensity, charging a price for app download, and the target market characteristics still inform app developers in their decisions to seek more privileges from users.

From the results for hypothesis 1, we find that apps that utilize newer versions of the Android API seek more permissions from end users, suggesting that the trend identified in previous academic investigations (Wei et al., 2012) continues to hold. Therefore, more control over app privileges passed on by the platform owner to the app developers would not necessarily mean that app developers will reduce privileging their apps.

Especially, based on the results for hypothesis 2, competition from other apps in the category (Soh & Grover, 2020) implies higher pressure on the app developers to deliver more value through unique features that may require elevated privileges. Therefore, higher competition intensity would force app developers to seek more permissions to avoid being left behind in the race for innovation in a competitive marketplace.

From the results of hypothesis 4, the target market for the app in terms of demographics may make seeking additional permissions in exchange for more innovative features acceptable (Lin et al., 2014). We find that apps targeted at more mature audiences seek more permissions than apps targeted for general use. This provides more transparency to users to make an informed judgment about the tradeoff between the utility that the user would get from the app and the privilege that the app holds in accessing the information on their mobile devices.

However, the results of hypothesis 3 relating to the purchase price of an app and permissions usage are opposite to what we hypothesized. Our argument was based on the utility that a user may expect for paying to download an app from the marketplace, therefore requiring the app developer to justify the price through innovative features potentially requiring more privileges. The results suggest that an alternative argument could be made that low priced or free apps need more access to user data for monetization and therefore are more likely to request more privileges (We would like to thank a reviewer of this manuscript for pointing out this argument.).

Overall, the implications of these findings suggest that the market conditions under which an app is developed influence the permissions usage of the app developers. While a mobile platform evolves to bring more of the platform API under the permissions framework, the increased transparency does not automatically reduce over-privileging by app developers. Therefore, from the mobile platform owners' perspective ensuring security and privacy implies that platform owners' responsibility is not limited to evolving their API for more transparency through the permissions system alone. They also must consider the incentive structure for app developers in their marketplace.

The recent conflict between Apple and Facebook (CNBC, 2022) suggests that the business environment and revenue models for app developers would determine how developers react to the platform owners' actions on the permissions system. Therefore, the evolution of the mobile platform in the direction of increased security and privacy needs both the platform owners and app developers to work together to align market incentives while cooperating from a technical perspective through the permissions system in the platform API.

6. Limitations & Future Work

The important limitations of this study arise from the fact that while there are millions of apps on each mobile platform, there are very few widely used mobile platforms. The choice of Android as the platform where the empirical validation for this paper was performed was since Android remains a popular and widespread platform. However, other platforms like iOS or Windows, and MacOS may not have the distribution of market incentives in the same way as Android and therefore the results may only represent the conditions in the Android marketplace. This study would have to be performed in other popular marketplaces like iOS to assess its validity fully.

The nature of mobile platforms also implies that there are few blockbusters and a long tail of sparsely used or downloaded apps. In this study, we did not have the opportunity to attend to the differential success of apps in the marketplace. There is an opportunity to more granularly differentiate the app marketplace based on various app characteristics and look at their differential influence on app permissions usage.

With respect to app permissions, in this study, we have approached permissions usage at a high level only using the count of permissions requested by an app. As the aim of this paper was to make an initial inquiry into the permissions usage of app developers,

we did not do a more fine-grained analysis of permissions based on permission types, privilege levels, etc. There is an opportunity to look at these aspects to further develop this line of inquiry in more detail.

Finally, from an empirical standpoint, we attempted to control for potential endogeneity with the variables in our research model and controlled for several potential factors that could influence app permissions usage that we controlled for in this study. However, there may be other factors we did not consider that need to be controlled for, so further study will be required for a more in-depth investigation into the usage of app permissions.

7. Conclusion

The app permissions system has been an important way through which mobile platform owners have attempted to ensure higher levels of security and privacy through the increased transparency that the mechanism provides. By taking the app developer's perspective who are the other important stakeholders in this joint platform co-evolution, we investigate the contextual conditions that influence how app developers approach app permissions requests. We find that competition intensity, price to download, and the target market for the app influence the usage of permissions by app developers. Therefore, mobile platform owners would need to pay more attention to the success incentives for the app developers on their marketplace to increase the security and privacy effectiveness of the permission systems of their APIs.

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