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The Impacts of Mobile Platform Openness on Application Developers' Intention to Continuously Use a Platform: From an Ecosystem Perspective

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The Impacts of Mobile Platform Openness on Application Developers' Intention to Continuously Use a Platform: From an Ecosystem Perspective

Goya Choi^{a*}, Changi Nam^{**}, Seongcheol Kim^{***}

Abstract

With the development of information and communication technologies and the emergence of the Internet of things, the open-platform strategy has come into the spotlight. Opening a platform allows external firms or individuals to enter the platform ecosystem without any restriction. Even though a platform connects diverse products and services, previous studies have focused on the bilateral relationship between a platform and a single group of product or service. This research investigates platform openness to multiple groups of products and services in an ecosystem simultaneously; research has especially focused on how the openness of the Android platform to both applications and devices influences application developers' intention to continuously participate. First, openness to applications influences not only the participation intention of application developers directly but also the user base of the platform and competition among developers. An increased user base leads to an enhanced participation intention of developers through indirect network effects, while intense competition does not have a significant effect on intention. Second, openness to devices also influences the participation intention of application developers indirectly. Openness to devices contributes to enlargement of the user base which positively influences the intention of application developers. Openness to device also incurs coordination costs between applications and devices, which have a partially negative effect on the participation of application developers. In this paper, we propose a comprehensive model that explains the impact of platform openness on application developers in order to offer a deeper understanding of the mechanisms of platform openness.

Keyword

Platform openness, Platform ecosystem, Android, Expectation-confirmation model

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1. Introduction

To become dominant and successful, many platforms, such as Android, open their technologies to external firms or individuals (Boudreau, 2010). From the perspective of technology management, platforms serve as a foundation on which external firms can build related products or services, and the platforms gather and organize related products and services into an ecosystem (McIntyre and Srinivasan, 2017). Opening a platform allows outside firms to access, use, and modifies the core technologies of the platform without restrictions. By lowering entry barriers, platform openness leads to the availability and diversity of related products and services which establish indirect network effects. Indirect network effects refer are increased users' benefits due to the increased number of available products and services in the platform. Platform owners disclose their aim of building up indirect network effects. In other words, the primary purpose of platform openness is to encourage other firms to continuously participate in the platform and attract more users.

The importance of the open-platform strategy has been increasing with the development of information communications technologies and the emergence of the Internet of things. As the number of products and services connected to platform is drastically increasing, the role of platform, which is to gather and organize diverse products and services, is receiving more attention from researchers in industrial organization economics, technology management, and strategic management fields (McIntyre and Srinivasan, 2017). Moreover, the Internet of things requires the connection of a wide range of products and services, so platform owners are pressed to open their platforms to secure more products and services than rival platforms. Thus, open strategy becomes a prerequisite for success of platforms.

However, most previous studies have focused on the bilateral relationship between a platform and a single kind of product or service, and there has been little investigation of the impact of openness to multiple products and services. Because the products and services in the ecosystem are interdependent and closely interact with each other, platform openness to one product or service influences other product and service providers. For example, opening the Android platform to device manufacturers allows the generation of devices with diverse features and customized system. This induces Android applications to work differently with these devices, and developers have to adjust their applications for each device, thereby reducing

the participation of application developers. Thus, decision to adopt platform openness influences the whole ecosystem, and platform openness should be understood from a more comprehensive perspective.

The purpose of this paper is to investigate the impacts of platform openness from an ecosystem perspective by considering the interdependency among heterogeneous products and services in a platform. First, we examine how platform openness to both applications and devices influences the participation of application developers simultaneously. From an application developer's viewpoint, openness to the group to which he/she belongs (openness to applications) has a different influence than that which occurs when the platform is open to other groups (openness to devices). Hence, the mechanisms of each type of platform openness are necessary to be analyzed in tandem. Second, the research model considers the advantages and disadvantages of openness. Platform owners open their platforms expecting indirect network effects to occur through encouragement of participation and innovation of related products and services. On the other hand, platform openness could lead to unexpected negative influences, including intensified competition and increased coordination costs among products and services. When platform owners decide to adopt an openness strategy, they have to consider not only expected benefits but also the risks derived from openness. However, only a few studies have dealt with the negative effects of openness, so this research considered both its positive and negative effects. Based on our investigation, we propose a more comprehensive model for the impacts of platform openness.

The remainder of this paper is organized as follows. Section 2 reviews the literature related to the definition of the platform, platform openness, and platform ecosystems. In section 3, the research model is introduced with hypotheses about both openness to applications and openness to devices. Section 4 focuses on the data and methodology we employed, and the research model is analyzed in Section 5. Section 6 presents the discussion and conclusion.

2. LITERATURE REVIEW

2.1. Platform

The concept of the platform has been investigated from the theoretical perspectives of both economics researchers and technology management researchers (McIntyre and Srinivasan,

2017).

From the economic perspective, a platform facilitates transactions between two or more sides; otherwise, they are hardly connected to each other (McIntyre and Srinivasan, 2017, Gawer, 2014, Eisenmann et al., 2008a) . A platform mediates exchanges between users, as buyers and suppliers, while delivering related products and services to users (Eisenmann et al., 2008a). Since a user of a platform gains more benefits from a platform that has a larger network with other users and related products and services, the value of a platform depends on ‘network effects’ (Cennamo and Santalo, 2013, McIntyre and Srinivasan, 2017). There are two types of network effects, direct network effects and indirect network effects. Direct network effects are a user’s benefits related to the number of users (McIntyre and Srinivasan, 2017). For example, users choose a social network site, such as Facebook, where they can connect and interact with a larger number of users, and the expected benefits of the site increase as more users join the site. Indirect network effects are a user’s benefit that results from the number of related products and services in a platform (Cennamo and Santalo, 2013). As the availability and variety of products and services provided through a platform increases, users meet their needs more effectively and efficiently in the platform (Eisenmann et al., 2010). For instance, the more social activities, games, and media contents are available in a social network site, the more value users place on the platform. Therefore, platform owners have been attempting to enhance the value of their platforms by leveraging both direct and indirect network effects.

From the technology management perspective, researchers have focused on the relationship between a platform and related products and services as well as the innovation of related products and services, which lead to indirect network effects (Gawer, 2014). A platform, as a technological architecture, provides a foundation on which external firms can build their products or services (McIntyre and Srinivasan, 2017, Gawer, 2014, Baldwin and Woodard, 2008). A technology architecture is a group of common or reused technologies that are adopted to generate related products and services by other firms (Boudreau, 2010). Moreover, the technological architecture includes not only rules that govern the interactions between the platform and related products and services, but also technical standards to assure interoperability among related products and services (Boudreau, 2010, Baldwin and Woodard, 2008). Since other firms are allowed to innovate products and services separately while the

products and services are interchangeable with each other, the platform can achieve economies of scope in innovations (Gawer, 2014). Thus, the value of a platform increases as the platform can satisfy users' needs with a wide range of related products and services. In other words, the platform becomes more dominant by increased indirect network effects with the innovations of other firms.

In this paper, we consider the concept of a platform from the technology management viewpoint, which defines a platform as a technological architecture enabling other firms to develop related products and services as well as indirect effects.

2.2. Platform openness

Becoming a dominant platform depends on whether the platform secures a diverse and large network of external firms to establish indirect network effects (Cennamo and Santalo, 2013). One way to increase indirect network effects is to open the platform by encouraging participation and innovation of other firms (Boudreau, 2010, Eisenmann et al., 2010, Eisenmann et al., 2008a). In previous literature, platform openness is understood as the easing of restrictions on the use of a platform. Eisenmann et al. (2008) stated that platform openness permits outside firms to participate in the use, commercialization, or development of a platform without restrictions. They also stated that, even if some restrictions are in place, a platform is considered to be opened if the restrictions are reasonable and fair to every external firm. Likewise, Boudreau (2010) defined platform openness as the removal of restrictions on the use, development, and commercialization of a platform or related products and services. They proposed two approaches on platform openness, namely, granting access, which allow other firms to generate their own products and services based on the technological architecture, and relinquishing control over the platform, which authorizes the decision rights to other firms to modify and transform the technological architecture itself.

Of these two approaches, several studies have adopted the former approach by emphasizing accessibility to platform architecture. Gawer (2014) stated that a platform owner can open their interface, which is accessible to external firms and supports compatibility between the platform and related products and services, so that external firms can build innovations based on the platform. In the same vein, Ghazawneh and Henfridsson (2013) suggested that platform owners

can provide ‘boundary resources’ to encourage the development of related products and services through the interface. Benlian et al. (2015) also investigated platform openness with technological accessibility and transparency concepts. Granting access is a relatively weak form of platform openness in which platform owners simply allow outside firms to adopt the platform architecture, while adjustment of the platform technology is restricted (Boudreau, 2010). For instance, standard-form licensing contracts lower the entry barriers for external firms and ensure interoperability between the platform and other products and services (Boudreau, 2012).

To stimulate more innovation by external firms, many platform owners devolve their own control over the platform (Boudreau, 2010). Relinquishing control is a strong form of the openness which allows external firms to use and modify the platform (Boudreau, 2010). Control refers to a platform owner’s attempts to regulate other firms to align with the objectives of the platform owner (Goldbach and Benlian, 2015). A platform owner who controls the platform influences other firms through formal control modes, which predetermine the output or process of other firms, and informal control modes, which induce other firms to establish and follow the common rules by themselves (Kirsch, 1997, Goldbach and Benlian, 2015). When a platform owner gives up control, external firms can develop new and various products and services through innovation without restrictions (Boudreau, 2010) On the other hand, devolving control complicates coordination among products and services (Benlian et al., 2015).

We define platform openness as the degree to which external firms use, modify, and develop platform technologies without restrictions, in accord with Boudreau (2010).

2.3. An ecosystem perspective

As relationships and interdependencies between platforms and other firms become strong and complex, the ecosystem perspective has received increasing attention in platform related research. Previous studies have stated that a platform ecosystem consists of a platform and related products and services that enhance the value of the platform (Eisenmann et al., 2008b, Adner and Kapoor, 2010, McIntyre and Srinivasan, 2017).

A platform ecosystem can be partitioned into upstream and downstream parts, and each part plays a distinct role (Tiwana, 2013, Adner and Kapoor, 2010). The products and services in the

upstream part, which are called ‘components’, provide input for the platform (Adner and Kapoor, 2010). Components are bundled to serve the base to operate the platform (Adner and Kapoor, 2010), and the features of the platform might differ depending on which components are added and used. On the other hand, the products and services in the downstream part, which are called ‘complements’, are developed by using the platform as the inputs. Complements contribute to enhancing the richness of users’ experience (Tiwana, 2013). An ecosystem approaches allows coordination among the platform, components, and complements to be understood (Adner and Kapoor, 2010).

Previous studies on platform openness have focused on the bilateral relationship between a platform and a single part of the ecosystem. For example, Boudreau (2010) focused on platform openness and its impacts on components in the case of handheld computing systems and devices. Benlian et al. (2015) and Boudreau (2010) investigated platform openness to complements by investigating the relationship between software operating systems and applications. A few studies have researched platform openness in multiple parts of an ecosystem simultaneously and considered coordination between different parts. In this paper, we investigate the impacts of platform openness on both components and complements.

3. MODEL DEVELOPMENT

3.1. Software platform and application developers

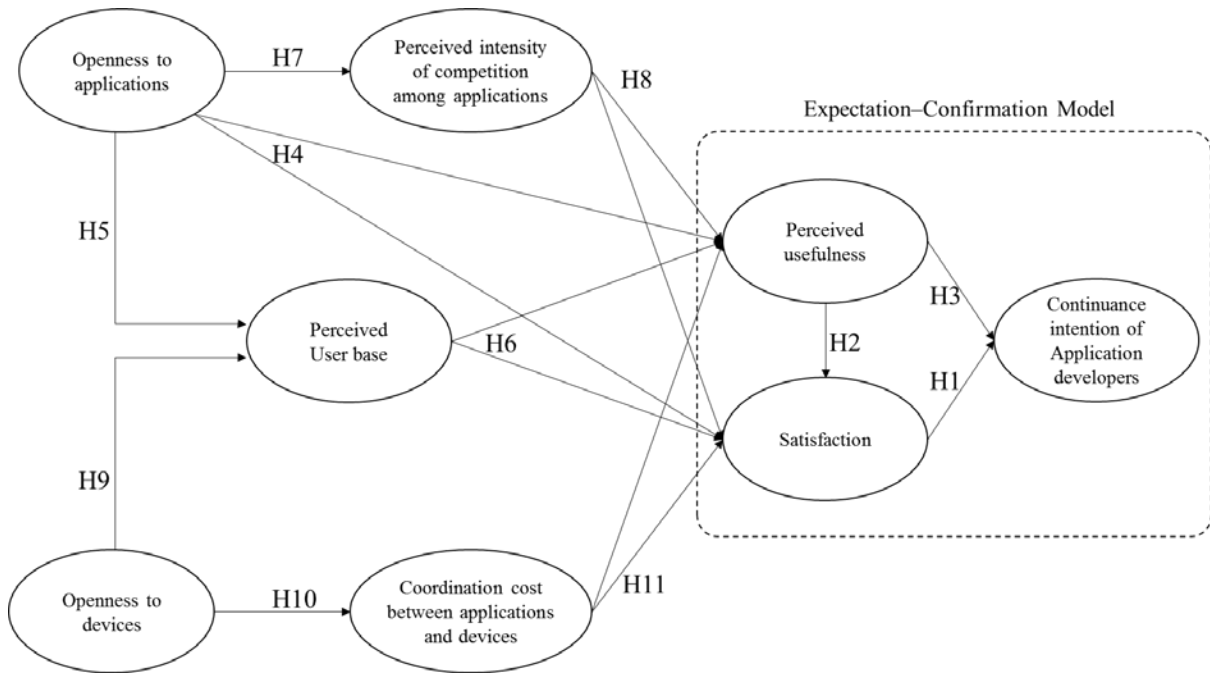
In this study, we researched the openness of software platforms by focusing on the case of Android, a representative open mobile operating system. Software platforms have played a central role in gathering and organizing various products and services, such as devices, networks, and applications. A software platform refers to “the extensible codebase of a software system which offers core functionality shared by complementary products and services” (Tiwana, 2013). The representative forms of software platforms include browsers, (e.g. Firefox, Chrome, and Opera), operating systems (e.g. Window, Android, and iOS), and social networks (e.g. Facebook, .Dropbox, and Twitter) (Tiwana, 2013). In a software platform ecosystem, hardware suppliers, manufacturing partners and network operators are included in the upstream component part, while application developers are located in the downstream complement part

(Tiwana, 2013). These components and complements create value for end-users by bundling with the software platform (Adner and Kapoor, 2010).

Although both components and complements enhance the value of the platform, the importance of complements has been highlighted recently (Tiwana, 2013). Upstream components determine how a platform can be operated effectively, whereas downstream complements determine what end-users can do with a platform (Tiwana, 2013, Adner and Kapoor, 2010). Since the competitiveness of a platform comes from the value creation to users, complements decide the fate of a platform in the competition (Tiwana, 2013). Therefore, this study investigated Android from the perspective of application developers in order to gain insights about complement developers.

The overall model considered in this paper is presented in Figure 1. The main objective of platform openness is to stimulate participation and innovation by complement providers; therefore we investigated how platform openness influences the continuous participation of application developers based on the confirmation-expectation model. Since the Android platform is disclosed to develop both applications and devices, the continuous participation of application developers might be effected by not only the openness to applications itself but also openness to other components and devices. Hence, it could be useful to analyze both types of openness together. Therefore, this study simultaneously examined the relationships between continuance intentions of application developers and openness to applications and devices, complements, and components of the Android ecosystem.

Figure1. Research Model



3.2. Continuance intention of applications developers: expectation-confirmation model

To secure availability and diversity of complements, platform owners have endeavored to increase continuous participation and usage of application developers in their platforms (Benlian et al., 2015, Tiwana, 2013, Boudreau, 2012). In the expectation-confirmation model of Bhattacharjee (2001), continuance intention to use a platform is determined by two factors, satisfaction and perceived usefulness. Satisfaction is an application developers' feeling about the prior use experience of the platform, and it is the primary determinant of platform use (Bhattacharjee, 2001).

H1. Satisfaction has a positive influence on an application developer's continuance intention to use the platform.

Perceived usefulness refers to the instrumentality of the platform for improving effectiveness, productivity, and efficiency (Brown et al., 2014, Bhattacharjee, 2001, Lin and Bhattacharjee, 2008). Since perceived usefulness enhances the expected benefits of platform use, it is associated with satisfaction (Bhattacharjee, 2001).

H2. Perceived usefulness has a positive influence on satisfaction.

Moreover, perceived usefulness means improved performance by using the platform, and it acts as an extrinsic motivation for platform use, such as monetary gain or popularity (Lin and Bhattacharjee, 2008, Bhattacharjee, 2001). Hence, perceived usefulness is considered a direct predictor of continuance intention (Bhattacharjee, 2001).

H3. Perceived usefulness has a positive influence on an application developer's continuance intention to use a platform.

3.3. The impacts of platform openness to applications on application developers

Opening a platform is intended to ease the requirement to access the platform technology and lowers the entry barriers to the platform (Boudreau, 2012). Platform openness to applications encourages a firm or individual, who does not have relevant resources and skills, to jump into the application development (Boudreau, 2012). When a platform owner discloses the platform, the owner provides all facets of the platform technologies as well as development tools, regulatory process, documentation including related information, and a community where application developers share their experiences with each other (Benlian et al., 2015). In the case of Android, application developers can easily access the Android software stack, the technological architecture, by using a software development kit (SDK) and application program interface (API) (Benlian et al., 2015). The platform owner, Google, also provides various tools, such as Android Studio, quality and content checks, help files, tutorials, and forums in the developer community (Benlian et al., 2015). These supports increase the motivation and incentives of application developers to use the platform (Boudreau, 2012). Therefore, openness itself might increase the usefulness and satisfaction of application developers, which induce the participation of developers.

H4-1. Openness to application developers has a positive influence on the perceived usefulness of application developers.

H4-2. Openness to application developers has a positive influence on their satisfaction.

Platform openness allows various application developers to participate in a platform by lowering the entry barriers, and this, in turn, expands the diversity of applications (Boudreau, 2012). A variety of applications attracts more users to a platform, which leads to indirect

network effects (Boudreau, 2010, Boudreau, 2012).

H5. Openness to application developers has a positive influence on the perceived user base.

When application developers recognize that a platform has enough market opportunities from a large user base, more application developers participate in the platform (Boudreau, 2012). The positive feedback loop between the numbers of application developers and users grows exponentially, thereby enhancing indirect network effects (Gawer and Cusumano, 2014). Hence, the perceived user base might increase the intention of application developers to use the platform, and it might be mediated by usefulness and satisfaction.

H6-1. The perceived user base has a positive influence on the perceived usefulness of application developers.

H6-2. The perceived user base has a positive influence on the satisfaction of application developers.

On the other hand, platform openness induces fierce competition among developers (Boudreau, 2010). As lowering entry barriers allows the participation of application developers, hundreds of thousands of application developers introduce new application competitively (Kapoor and Agarwal, 2017). Since applications are distributed through a centralized marketplace such as Google Play, which eases the comparison among applications, application developers feel pressured to reduce application prices (Liu et al., 2014). Moreover, most application developers use the same development tools of the platform, and this leads to more intensive competition among ‘copycat’ or similar applications (Boudreau, 2012).

H7. Openness to applications has a positive influence on the perceived intensity of competition among application developers.

Competition among application developers arouses uncertainty of the market situation and risks reduction of future revenue of application developers, which lead to diminishing incentives of application developers to invest and innovate (Boudreau, 2010, Hagiu, 2014). Hence, intensified competition might have a negative influence on application developers’ perceived usefulness and satisfaction.

H8-1. The perceived intensity of competition among application developers has a positive influence on the perceived usefulness of application developers.

H8-2. The perceived intensity of competition among application developers has a positive influence on the satisfaction of application developers.

3.4. The impact of platform openness to devices on application developers

Platform owners can open their platforms to multiple locations of the ecosystem, including upstream components and downstream complements (Boudreau, 2010, Eisenmann et al., 2008a), and platform openness to one party has an impact on the other parties in the ecosystem (Xu et al., 2010). For instance, Android is disclosed to not only application developers but also device manufacturers (Eisenmann et al., 2008a). Even though openness to devices might not directly influence application developers, it could have indirect effects on developers because of interdependence between devices and applications. In this section, we investigate the positive and negative effects derived from openness to devices on application developers.

First, openness to devices might have positive effects on application developers because openness increases the number of users of a platform. Since Android is an open-source operating system, mobile device manufacturers, such as Samsung, HTC, and Sony can use and customize Android without constraints (Cecere et al., 2015, Oh and Hong, 2015). Through open strategies, Google has encouraged various device manufacturers to produce Android-based devices in order to increase the adoption of the platform through indirect network effects (Boudreau, 2010). Based on the substantial growth of sales and diversity of these devices, Android has achieved market leadership against rival platforms (Cecere et al., 2015). Therefore, the large user base stemming from Android's openness to devices might attract application developers to use the platform.

H9. Openness to devices has a positive influence on the perceived user base.

Second, opening the platform to devices leads to negative effects with the problem of coordination between devices and applications (Boudreau, 2010). When a platform is open to both applications and devices, application developers and device manufacturers attempt to innovate simultaneously, which leads to loss of coherence across the ecosystem (Boudreau,

2010). In other words, the diversity of devices leads to concerns about whether an application works well with various devices (Xu et al., 2010). Because of these concerns, application developers are required to adjust and modify their applications in relation to devices in order to keep them functioning (Tiwana, 2015). The effort to maintain interoperability between applications and devices is referred to as coordination cost (Tiwana, 2015). In the Android ecosystem, openness to devices causes the problem of device fragmentation, in which the functioning of applications varies according to device (Ham and Park, 2011). The main factor leading to fragmentation is the diversity of features of devices, such as processors, graphic cards, and screen size, and it causes applications to work differently or not to function depending on the devices (Han et al., 2012). Moreover, openness allows device manufacturers to modify and customize the Android operating system, and this customization of the operating system by manufacturers also contributes to the fragmentation problem (Oh and Hong, 2015). The fragmentation problem resulting from openness to devices might increase coordination costs between devices and applications.

H10. Openness to device manufacturers has a positive influence on the coordination cost between devices and applications.

Increased coordination costs require additional tasks and increases the burden of application developers (Tiwana, 2015). Thus, coordination costs might have negative effects on the usefulness and satisfaction of application developers with the platform.

H11-1. Coordination costs between devices and applications have a negative influence on the perceived usefulness of application developers.

H11-2. Coordination costs between devices and applications have a negative influence on the satisfaction of application developers.

3. METHODOLOGIES

3.1. Data

The data was collected in June 2017 through an online survey of Android application

developers. We posted an advertisement on the Android developer community (<http://cafe.naver.com/aphone>) for a week. We invited the developers to participate in the survey in exchange for a mobile gift voucher (\$ 3.5) as a participation reward. The target subjects of this survey were Android developers who had experience in developing at least one Android application. Total responses were 150, and 138 responses were used as the final sample after inconsistent data was excluded. In the final sample, 61% of the respondents were male, and 39% of the respondents were female, and their average age was 30 years old. The average development experience of the sample was 18 months, and the sample included 22% entrepreneurs, 19% employed developers, and 59% hobby developers. The details of the sample characteristics are shown in Table 1.

Table 1. Sample Characteristics

Gender	Male	84
	Female	54
Age (year)	20-29	68
	30-39	63
	40 or more	7
Development experience of Android applications (month)	6 or less	45
	7 ~ 12	30
	13 ~ 24	37
	25 ~ 36	9
	37 or more	17
Professional background	Employed developers	27
	Entrepreneurs	30
	Hobby developers	81
Total		138

3.2. Measurement Items

Table 2 shows the measurement items for each construct. Every item was rated on a 7-point Likert scale that ranged from strongly disagree to strongly agree. Details of items were revised regarding to the context of Android application developers.

Table 2. Measurement Items

Construct	Item	Measurement question	References
openness to application developers		* ‘Technologies of Android’ means Android software stacks and includes SDK, API, Tool, libraries, resources, tutorials, and related documents.	Benlian et al. (2015), Alraimi et al. (2015)
	OAD1	Android is open to application developers.	
	OAD2	Application developers can access the technologies of Android easily.	
	OAD3	Application developers feel free to use the technologies of Android.	
	OAD4	Application developers can adjust and modify freely the technologies of Android to develop applications.	
	OAD5	Android supports the participation and contribution of application developers.	
Openness to device manufacturers	ODM1	Android is open to device manufacturers.	Benlian et al. (2015), Alraimi et al. (2015)
	ODM2	Device manufacturers access the Android device easily.	
	ODM3	Device manufacturers adjust and modify freely the technologies of Android to develop applications.	
Perceived user base	UB1	I think that many people use Android.	Chiu et al. (2013)
	UB2	I think that most people use Android.	
	UB3	Android has an extremely large user base.	
	UB4	Android is considered as a famous operating system.	
Perceived intensity of competition	IC1	Application developers of Android compete intensely.	O'Cass and Ngo (2007), Tsai and Yang (2013), Dedman and Lennox (2009)
	IC2	Price competition among Android applications is highly intense.	
	IC3	Promotion competition among Android applications is highly intense.	
	IC4	The threat of competition from entering new application developers is serious.	
Coordination costs between applications and devices	CC1	When an application is run on Android devices, the application can be broken.	Tiwana (2015)
	CC2	When an application is run on Android devices, the application can show unexpected interactions with the devices.	
	CC3	When an application is run on Android device, the application's internal code is required to change.	

Perceived usefulness	PU1	Android enhances my effectiveness in application development.	Brown et al. (2014), Bhattacharjee (2001)
	PU2	Android improves my productivity of application development.	
	PU3	Android improves the performance of the application I developed.	
Satisfaction	SAT1	I feel satisfied with using Android for my app development.	Zhou (2013), Chiu et al. (2013), Bhattacharjee (2001)
	SAT2	I feel contented with using Android for my app development.	
	SAT3	My decision to use Android was an appropriate choice.	
Continuance intention	CI1	I intend to continue using Android rather than discontinue its use.	Goldbach and Benlian (2015), Bhattacharjee (2001)
	CI2	My intentions are to continue using Android rather than use any alternative platforms.	
	CI3	I would intend to continue to using Android in the future.	

4. RESULTS

In this paper, the research model was tested by partial least squares (PLS) based structural equation modeling (SEM) using Smart PLS version 3.0. PLS path modeling is a variance-based SEM method, and it widely used in the fields of information system research, strategic management, and marketing (Henseler et al., 2016). The assumption of distribution is not strictly required (Fornell and Cha, 1994), and the prediction error is minimized in PLS modeling (Chin, 1998). Complex models can be analyzed by using PLS modeling (Ruiz et al., 2010).

4.1. Measurement Model

In the measurement model estimation, the research model satisfied the guidelines for reliability and validity as shown in Table 3 and 4. The reliability of each item was acceptable because the factor loading of all items exceeded 0.7 (Barclay et al., 1995). The general criteria for the reliability measure of constructs are Cronbach's α higher than 0.7 as well as composite reliability higher than 0.8 (Henseler et al., 2016), and the research model satisfied both criteria. In addition, the value of average variance extracted (AVE) for every construct was higher than the threshold value, 0.5 (Henseler et al., 2016); thus the model also had enough convergent

validity.

Table 3. Reliability and Convergent Validity

Construct	Item	Factor Loading	Cronbach's α	Composite Reliability	AVE
Openness to app developers	OAD1	0.771	0.85	0.90	0.96
	OAD2	0.802			
	OAD3	0.821			
	OAD4	0.765			
	OAD5	0.813			
Openness to device manufacturers	ODM1	0.886	0.83	0.90	0.74
	ODM2	0.883			
	ODM3	0.812			
Perceived user base	UB1	0.827	0.84	0.89	0.68
	UB2	0.797			
	UB3	0.846			
	UB4	0.829			
Perceived intensity of competition	IC1	0.839	0.79	0.87	0.62
	IC2	0.634			
	IC3	0.821			
	IC4	0.838			
Coordination costs between applications and devices	CC1	0.848	0.80	0.88	0.71
	CC2	0.844			
	CC3	0.839			
Perceived usefulness	PU1	0.873	0.85	0.91	0.77
	PU2	0.878			
	PU3	0.882			
Satisfaction	SAT1	0.855	0.81	0.89	0.72
	SAT2	0.853			
	SAT3	0.842			
Continuance intention	CI1	0.866	0.87	0.92	0.80
	CI2	0.877			
	CI3	0.932			

Furthermore, each construct that implies distinct theoretical concepts should be different statistically, and the Fornell-Larcker criterion is used to test this discriminant validity (Henseler et al., 2016). In Fornell-Larcker criterion table, the value of AVE of each construct has to be

higher than its squared correlations with other constructs (Henseler et al., 2016). Table 4 shows that the diagonal values are higher than other values in the same row. Therefore, the research model fulfills the recommended guides for reliability and validity.

Table 4. Discriminant Validity

	OAD	ODM	UB	IC	CC	CI	PU	SAT
OAD	0.79							
ODM	0.75	0.86						
UB	0.73	0.70	0.82					
IC	0.65	0.63	0.74	0.79				
CC	0.69	0.67	0.76	0.69	0.84			
CI	0.74	0.69	0.81	0.64	0.69	0.89		
PU	0.74	0.71	0.75	0.64	0.70	0.85	0.88	
SAT	0.72	0.68	0.75	0.62	0.58	0.87	0.84	0.85

Note. OAD: openness to app developers, ODM: openness to device manufacturers, UB: perceived user base, IC: perceived intensity of competition, CC: coordination costs between applications and devices, PU: perceived usefulness, SAT: satisfaction, CI: continuance intention

4.2. Structural Model

The results of structural model assessment are presented in Figure 2 and Table 5. The model accounts for 42.8% of the variance in perceived intensity of competition, 59.2% of variance in perceived user base, 45.1% of variance in coordination costs between applications and devices, 65.7% of variance in perceived usefulness, 75.3% of variance in satisfaction, and 80.7% of continuance intention of application developers.

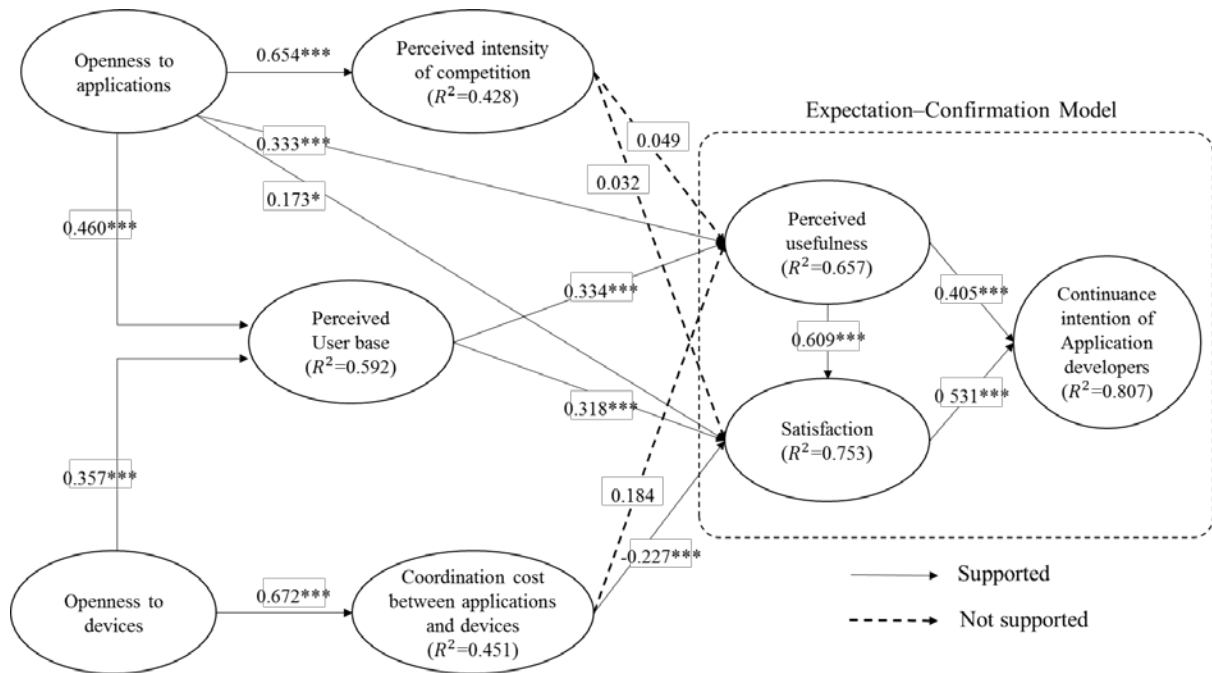
<Table 5. Result of Hypotheses Tests>

	Path	Path coefficient	Supported or not
H1	Satisfaction → Continuance intention	0.531***	Supported
H2	Perceived usefulness → Satisfaction	0.609***	Supported
H3	Perceived usefulness → Continuance intention	0.405***	Supported
H4-1	Openness to app developers → Perceived usefulness	0.333***	Supported
H4-2	Openness to app developers → Satisfaction	0.173*	Supported
H5	Openness to app developers → Perceived user base	0.460***	Supported
H6-1	Perceived user base → Perceived usefulness	0.334***	Supported
H6-2	Perceived user base → Satisfaction	0.318***	Supported
H7	Openness to app developers	0.654***	Supported

	→ Perceived intensity of competition		
H8-1	Perceived intensity of competition n → Perceived usefulness	0.049	Not supported
H8-2	Perceived intensity of competition → Satisfaction	0.032	Not supported
H9	Openness to device manufacturers → Perceived user base	0.357***	Supported
H10	Openness to device manufacturers → Coordination costs between applications and devices	0.672***	Supported
H11-1	Coordination costs between applications and devices → Perceived usefulness	0.184	Not supported
H11-2	Coordination costs between applications and devices → Satisfaction	-0.227***	Supported

Note. *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$

Figure 2. Results of the Research Model



As a results of analysis, most of the hypotheses except for H8 were found to be supported in the research model. The openness of Android to applications directly influences the perceived usefulness and satisfaction of application developers. The coefficients of each path were 0.333($p < 0.001$) and 0.173(, $p < 0.05$), respectively, supporting H4. Openness to applications also has a positive effects on the perceived user base ($\beta=0.460$, $p < 0.001$), and this indicates that application developers recognize the indirect network effects derived from the

variety of applications, and this supports H5. At the same time, the perceived user base has a significant influence on the perceived usefulness and satisfaction of application developers ($\beta=0.334$, $p<0.001$; $\beta=0.318$, $p<0.001$). These results imply that the positive feedback between the numbers of users and application developers is built up in the Android platform ecosystem. Additionally, openness to applications has a positive impact on the perceived intensity of competition among application developers ($\beta=0.654$, $p<0.001$), and this supports H7. However, the perceived intensity of competition is not significantly related to perceived usefulness and satisfaction; therefore, H8 is not supported.

Openness to devices influences application developers indirectly through the effects on the ecosystem. Openness to devices has a significant influence on the perceived user base with a positive value of coefficient, 0.357, which supports H9. Moreover, openness to devices has a positive influence on coordination costs between devices and applications ($\beta=0.672$, $p<0.001$), which supports H10. These coordination costs have a negative effect on the satisfaction of application developers ($\beta=-0.227$, $p<0.001$), while it does not have any significant effect on perceived usefulness. Hence, H11 is partially supported in the model.

Furthermore, the research model reconfirms the expectation-confirmation model. Perceived usefulness has a positive influence on satisfaction ($\beta=0.609$, $p<0.001$), and H2 is supported. Both perceived usefulness and satisfaction are positively related to the continuance intention of application developers by positive coefficients, 0.405 and 0.531, respectively, at a 0.1% significant level.

5. DISCUSSION AND CONCLUSION

This paper investigated the impact of platform openness in multiple locations of the ecosystem. Platform owners open their platform technologies to external firms and individuals in order to encourage participation and innovation in the whole ecosystem. In other words, the main objective of openness is to enhance the availability and diversity of components or complements in the ecosystem, which leads to indirect network effects. The platform owner who successfully establishes indirect network effects dominates the market and beats the competition of rival platforms.

Previous studies have suggested that platform openness contributes to increasing the indirect effects based on the bilateral relationship between a platform and a single component or complement group. However, a platform owner can open their platform to multiple locations of the ecosystem simultaneously. Hence, this study examined the influence of platform openness on complement providers' intention by considering not only openness to the complement group they belonged to but also openness to other component or complement groups.

We focused on platform openness to two different locations, namely, applications and devices in the Android ecosystem, which is a representative open software platform ecosystem. We proposed different mechanism for each type of openness.

First, openness to applications directly influences the intention of application developers. Openness allows application developers to access, use, and modify the technological architecture of the platform and provides general support, such as tools, rules, and information related to application development. It lowers the entry barriers of the platform ecosystem to application developers. We found that openness to applications has a positive influence on the intention of continuous participation of application developers.

Openness to applications also influences application developers indirectly through the user base and competition. As diverse application developers enter an ecosystem, the variety of applications is enhanced, and this leads more users to adopt the platform. The increased user base also positively influences the participation of application developers. The research model showed a positive feedback loop between the numbers of users and application developers, which is called indirect network effects, in Android.

At the same time, openness to applications induces intense competition among application developers. However, the results suggest that intensity of competition does not affect the intention of application developers to continuously use the platform. Rather, they indicate that competition is not a significant determinant of participation in the platform for application developers. Even though application developers are reluctant to jump into fierce competition, the benefits of participating in the platform can cancel out the negative effects of competition (Cennamo and Santalo, 2013).

Second, openness to devices indirectly influences application developers' participation.

Since both devices and applications are included in the same ecosystem, they interact and are interdependent. Most of all, openness to devices induces the participation of thousands of device manufacturers into the platform ecosystem and increases the diversity of the devices they produce. Since the platform meets various needs of users based on the large pool of devices, the attractiveness of the platform to users is reinforced. Our results show that openness to devices positively influences the user base of the platform.

On the other hand, diversity of devices derived from openness incurs coordination costs between applications and devices. Because each device has different features and characteristics, an application can work differently or be functionally disordered in some devices. Application developers are required to adjust and modify their applications to keep them functioning. These additional efforts raise coordination costs with devices. In the research model, the coordination costs have negative effects on the satisfaction of application developers, while they do not influence the perceived usefulness of the platform. Application developers' burdens caused by coordination costs are not high enough to significantly reduce the overall expected benefits of using the platform, but application developers may worry about whether their applications will work well in various devices.

This study has both academic and practical implications. First, we have proposed a comprehensive model of the effects of platform openness from an ecosystem perspective. We distinguished openness to components and complements and considered the advantages and disadvantages of openness. Second, this study established the importance of coordination between components and complements in the platform. Only a few previous studies have concentrated on the relationship between openness and coordination costs, and we empirically investigated this relationship. Third, this paper suggested practical insights for platform owners who may consider opening their platforms. In particular, if a platform owner discloses their platform to multiple groups in the ecosystem, the platform owner should consider both indirect network effects and coordination costs simultaneously.

There were several limitations in this research. First, we investigated the openness strategy of a single dominant platform. Openness strategy and its impacts can differ between platforms; thus, further research on the openness of other platforms is required. In addition, we examined the Android platform, which has already established indirect network effects as a dominant

platform in ICT industries. If we test a new entrant platform, its platform openness might show different impacts. Second, the sample in the analysis was limited. The sample size was relatively small, and a substantial portion of the sample comprised hobby developers. Hobby developers are relatively free of the negative effects of openness such as competition and coordination costs because they are not as seriously concerned about the follow up after application development as employed developers and entrepreneurs. Nevertheless, this research provides a deeper understanding of platform openness in the ecosystem.

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