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RESEARCH ARTICLE

USER SERVICE INNOVATION ON MOBILE PHONE PLATFORMS: INVESTIGATING IMPACTS OF LEAD USERNESS, TOOLKIT SUPPORT, AND DESIGN AUTONOMY

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Appendix A

Additional Tables

Table A1. Definitions of Platforms Related to IT in Previous Literature

Study	Term	Definition
Boudreau and Hagiu (2009)	Multisided platform, e.g. App store	**Platforms** are products, services, or technologies that serve as foundations upon which other parties can build complementary products, services, or technologies A multisided platform is both a platform and a market intermediary. Distinct groups of consumers and "complementors" interact through multisided platforms.
Boudreau (2012)	Handheld computer platforms	**Computer platforms** are a particular type of multisided platforms, which support interactions across multiple sets of actors and can facilitate technical development. Network effects result from a large number of independent software producers creating applications.
Ceccagnoli et al. (2012)	Platform	A **platform** refers to the components used in common across a product family whose functionality can be extended by applications
Fichman (2004)	IT platform	An **IT platform** is broadly defined as a general-purpose technology that enables a family of applications and related business opportunities. This includes computing platforms (e.g., Palm OS), infrastructure platforms (e.g., wireless networking), software development platforms (e.g., Java), and enterprise application platforms (e.g., ERP).
Tiwana et al. (2010)	Software based platform	**Software based platform** is the extensible codebase of a software-based system that provides core functionality shared by the modules that interoperate with it and the interfaces through which they interoperate. Module is an add-on software subsystem that connects to the platform to add functionality to it (e.g., iOS apps, modular innovation). the collection of the platform and the modules specific to that platform as that platform's ecosystem .

Table A2. Previous Research Related to IT Platform Level Innovation

Focus	Study	Constructs	Method	Key Findings
Producer/ Innovator and Task Features	Boudreau et al. (2011)	Independent variables • Number of competitors • Problem uncertainty Dependent variable: • Innovation performance	Field data from 645 software innovation contests in Topcoder from 2001 to 2007 **Unit of Analysis:** • Software contest	• More competitors will improve the average innovation performance of the contest • More competitors enhance contest innovation performance for highly uncertain problems
Producer/ Innovator Features	Boudreau (2012)	Independent variables • Number of producers • Producer diversity and heterogeneity Dependent variables • Application variety on the platform • Individual producers' scope • Time to new version	Field data from application producers on leading handheld computer platforms from 1999 to 2004 **Unit of Analysis:** • Producer level (5994 producers) • Platform level (393 platform-months)	• Number of producers will increase variety of application titles on the platform • Heterogeneity and diversity of producers and the number of producers on the platform enhance the scope of individual producers • The number of producers who produce the same type of applications increases the time for producers to develop a new version
Platform Features	Boudreau and Hagiu (2009)	• Platform regulation on multisided platforms	Case studies of digital (Facebook, Topcoder) and non-digital (Roppongi Hills, Harvard Business School) platforms	• Platform regulation involved using strategic instruments, i.e., legal, technological, informational and others (along with price setting) to implement desired outcomes. The outcomes were to minimize costs associated with a range of externalities, complexity, uncertainty, asymmetric information and coordination problems • The regulatory role played in these cases by multisided platforms was pervasive and at the core of their business models
	Boudreau (2010)	Independent variables • Granting access vs. devolving control Dependent variable • Number of new devices developed	Using data on 21 handheld computing systems from 1990 to 2004 **Unit of Analysis:** • Platform level	• Granting greater levels of access to independent hardware developer firms accelerated the development of new handheld devices by up to five times • Where operating system platform owners went further to give up control (beyond just granting access to their platforms) the incremental effect on new device development was still positive but an order of magnitude smaller
	Tiwana et al. (2010)	• Platform architecture • Platform governance • Environmental dynamics	**Conceptual**	• Platform architecture, governance, and environmental dynamics affect innovation on platforms and platform evolution

Table A3. Previous Empirical Service Innovation Research at User Level (Studies arranged by date within each category)

Focus	Study	Constructs	Method	Key Findings
User characteristics	Morrison et al. (2000)	Independent variables • Leading-edge status • In-house technical capabilities Dependent variable • Probability of user innovation behavior	Survey of 122 users of library information systems OPAC	Leading-edge status and in-house technical capabilities positively affect user innovation behavior
	Matthing et al. (2006)	Independent variable • Technology readiness Dependent variables • Propensity to adopt new tech-based services • Seek new tech and solve related problems • Willingness to participate in new tech-based service dev. • Fluency (# of ideas) • Flexibility (# of distinct categories of ideas) • Originality	Survey of 1,004 Swedish users of telecom services, followed by experiment with 52 users	Technology readiness is positively related to propensity to adopt new tech-based services, actively seek new technologies and solve problems related to them, and be willing to participate in new technology-based service development Potential "lead users," are capable of generating a large, diverse and original set of new service ideas
	Kratzer and Lettl (2008)	Independent variable • Betweenness centrality Dependent variables • Lead userness • Creativity	Experiment with 366 children in 16 school-groups to develop ideas on improving an online application, "CineKidStudio," for their personal use	Betweenness centrality positively affects the lead userness and creativity of children
Innovation Toolkit Features	Franke and von Hippel (2003)	Independent variables • Heterogeneity of user needs • Innovation toolkits Dependent variables • User innovation • User satisfaction	Survey of 131 individual users for open source Apache security software (no regression)	Innovation toolkits can better serve heterogeneous needs Heterogeneous needs lead users to customize their software User who customize their software with the help of innovation toolkits are more satisfied than those who do not customize

Table A3. Previous Empirical Service Innovation Research at User Level (Continued) (Studies arranged by date within each category)

Focus	Study	Constructs	Method	Key Findings
User Characteristics and Innovation Toolkit Features	Kankanhalli et al (2015)	Independent variables • Trend leadership • Anticipated enjoyment • Anticipated extrinsic reward • Anticipated recognition • Toolkit support • Potential vs. Actual innovator Dependent variable • Intention to innovate	Survey of 111 potential and 101 actual users for MDS applications	Trend leadership and anticipated extrinsic reward influence both potential and actual user innovators' intentions to innovate Anticipated recognition and toolkit support affect only actual user innovators Anticipated enjoyment affects only potential user innovators Toolkit support strengthens the influence of anticipated enjoyment for actual user innovators but weakens its influence for potential user innovators Potential user innovators value anticipated extrinsic rewards less than actual innovators do

Table A4. Mapping Toolkit Support and Design Autonomy into Innovation Phases

	Innovation Phases	
	Idea Generation	**Idea Implementation**
Toolkit Support	Exploration	Ease of Effort
Design Autonomy	Decision-making autonomy	Work-method autonomy Scheduling Autonomy

Table A5. Comparison between Android and IOS Platforms

	iOS	Android	Mean (Android: iOS)	p-value
Decision-making autonomy	• Need to pay $99 per year for the base developer program that allows access to iOS SDK and the right to publish in Apple's app store • App Store Review Guidelines have many restrictions on type/ content of apps that can be created (e.g., violent or adult content) (https://developer.apple.com/app-store/review/guidelines/)	• There is a one-time fee of $25 for Google Play developers • Apps that contain certain objection-able content are not permitted in Google Play at lower maturity rating but are allowed if the maturity rating is high (https://support.google.com/googleplay/androiddeveloper/answer/188189?hl=en)	5.21: 4.13	0.001
Scheduling autonomy	• Scheduling of app release is con-strained by how long the review process by Apple takes and revisions if the app is rejected	• Quick and mainly automated app review process, but app may be removed and developer account may be terminated for policy viola-tions (https://play.google.com/about/ enforcement.html#enforcement-process)	5.41: 4.88	0.23
Work-method autonomy	• Development environment on Mac • Programming language: C, C++, Objective C, Swift • Apple has design and interface guidelines that apps must use the same basic UI elements • Must publish and download the apps via App Store • More tablets, more commercial infrastructure (e.g., payment processing)	• Can develop apps anywhere since Android SDK available for Windows, Linux, Mac • Programming language: C, C++, Java • No enforced UI guidelines • Can distribute apps openly (http://developer.android.com/distribute/tools/open-distribution.html) • Less tablets, slower in introducing payment processing, etc.	5.27: 5.31	0.75
Ease of effort	• Xcode with iOS SDK is relatively easy to use • App configuration is complex • Simulator is fast and responsive • Relatively mature SDK, stable API • Difficult to publish app	• Eclipse IDE with SDK is unwieldy, Android Studio (in Beta) is better • Easier app permissions • Emulator is slower and can fail • Changes in environment • Different hardware manufacturers use different OS versions • Easy to publish app	5.10: 4.95	0.37
Exploration	• Provides app creators tools to explore existing applications in the market • Provides analytics, i.e., downloads for free and paid apps, in-app purchases, updates, information available per country	• Provides app creators tools to explore existing applications in the market • Provides information of current and total installs	4.97: 5.75	0.01

Table A6. Item Weights for LUS

LUS	LUSA (Ahead of Trend)	0.58***
	LUSB (Unmet Needs)	0.52***

***p < 0.001

Table A7. Slope Difference Test Results

Pairs of Slopes	t-value	df
ΔEOE_{high}, SAU_{high}/ EOE_{high}, SAU_{low}	2.14*	122
ΔEOE_{high}, SAU_{high}/ EOE_{low}, SAU_{high}	2.85**	122
ΔEOE_{high}, SAU_{high}/ EOE_{low}, SAU_{low}	3.01***	122
ΔEXP_{high}, DAU_{high}/ EXP_{high}, DAU_{low}	3.45***	122
ΔEXP_{high}, DAU_{high}/ EXP_{low}, DAU_{high}	2.88**	122
ΔEXP_{high}, DAU_{high}/ EXP_{low}, DAU_{low}	8.12***	122

Significance at *p ≤ 0.05, **p ≤ 0.01 ***p ≤ 0.001

Appendix B

Post Hoc Tests for Alternate DVs

Various definitions and indicators of innovation *quality* have been proposed in the literature. Typical indicators include the novelty, feasibility (producibility), and user value of the innovation[1] (e.g., Magnusson et al. 2003; Matthing et al. 2004). In our study context, the feasibility indicator is less relevant since we are considering MDS applications that have already been created by user innovators. Rather, *novelty* and *user value* are considered relevant to MDS innovation *quality* here. Novelty or *radicalness* of the innovation has been noted as an important quality indicator in several studies (Magnusson et al. 2003; Matthing et al. 2004) and will be included in our *post hoc* analysis. Additionally, customer downloads (*popularity*) as an indicator of potential user value and quality of the MDS application, especially for the paid apps (Liu et al. 2012), is evaluated in our *post hoc* analysis. This also aligns with previous work in OSS where downloads are often used as measures of user value (Crowston et al. 2006).

Table B1. Coding Schemes for Popularity and Radicalness

Number of Downloads Shown in Websites	Popularity	Related Apps Available in the Market	Radicalness
<50	1	>10	1
50-100	2	9-10	2
100-500	3	7-8	3
500-1000	4	5-6	4
1000-5000	5	3-4	5
5000-10000	6	1-2	6
10000-50000	7	0	7
50000-250000	8		
>250000	9		

[1]Other indicators of innovation quality are based on expert evaluations or user outcomes such as user satisfaction. However these data were not available in this study.

For MDS applications innovation quality, *popularity* was measured by the number of downloads (Ye et al. 2011). Since a user innovator is the unit of analysis, we computed the popularity of their service innovation by the average score of $\frac{1}{n}\left[\sum_{i=1}^{n}\left(\frac{D_i}{T_i}\right)\right]$, where n is the total number of applications a respondent has developed, D_i is the number of downloads of i application, T_i is the number of months since i application has been published. To obtain the number of downloads D_i for each MDS application developed by a respondent, we mined archival data from the platforms. This was done by searching for the "publishers" name provided by the respondent and averaging the number of downloads from their applications created as per the formula given above. Since the Android and iOS platforms in our study indicate the downloads of each application in an ordinal way (see column 1 of Table B1), we followed established data coding principles (De Vaus 2002) to code the number of downloads using the scheme shown in Table B1. Such nonlinear coding schemes have been found useful for assessing number of downloads in previous studies (Fershtman and Gandal 2011). The platforms also indicate the number of related apps available in the market for each MDS app. We used this information to measure *radicalness* (see Table B1), that was averaged for each user innovator. Both popularity and radicalness variables were collated 3 months after the survey and used for our *post hoc* analysis, as indicators of innovation quality.

Table B2. Descriptive Statistics and Correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Age	1.00														
2. Gender	0.17	1.00													
3. P. Skill	0.44**	0.01	1.00												
4. Educ.	0.24*	-0.03	0.49***	1.00											
5. Tenure	0.44**	-0.13	0.61***	0.54	1.00										
6. LUSA	0.20*	0.12	0.06	-0.02	-0.04	1.00									
7. LUSB	0.12	0.20	0.02	0.01	-0.08	0.40***	1.00								
8. EOE	0.29	-0.03	0.23***	0.08	0.26	0.20	0.12	1.00							
9. EXP	0.26	0.03	0.14**	0.17	0.15	0.22*	0.32*	0.39*	1.00						
10. SAU	0.21	-0.14	0.11	0.05	0.27	0.07*	0.10*	0.05	-0.03	1.00					
11. DAU	0.05*	0.12	-0.11	0.02	0.03	0.15**	0.22*	-0.11	-0.02	0.29**	1.00				
12. WAU	0.25*	-0.06	0.06	0.07	0.19	0.11	0.01	0.11	0.10	0.31*	0.11*	1.00			
13. QNT	0.22*	0.13	-0.02	-0.08	-0.05	0.21**	0.23*	0.47*	0.36*	0.08	0.21*	0.15*	1.00		
14. Popu.	0.24*	0.04	0.18	0.01	0.25*	0.23*	0.18*	0.45*	0.38*	0.10	0.25**	0.35**	0.35***	1.00	
15. Rad.	0.05	-0.03	-0.11	-0.05	-0.16	0.21*	0.30*	0.07	0.30*	0.07	0.16*	0.17*	0.06	0.16*	1.00
Mean	21.95	0.73	4.71	2.45	10.9	4.35	4.52	4.95	5.22	5.33	5.30	5.17	3.20	2.91	3.91
SD	5.35	0.44	1.31	0.68	4.14	0.73	0.68	0.86	0.72	1.06	1.04	1.16	1.95	0.67	1.22

Notes: 1. Indicates that the value is not applicable for single indicator variable
2. Significance at *p < 0.05, **p < 0.01, ***p < 0.001

We *post hoc* test innovation quality outcome variables (popularity and radicalness). Correlations and descriptive statistics are shown in Table B2 and the regression results are shown in Models 1 and 2 of Table B3. The results using popularity as DV are similar to the original results except for one of the three-way interactions, whereas the results for radicalness differ on two of the three-way interactions, requiring further investigation in future research.

Table B3. *Post Hoc* Test Results for Alternate DVs

	Model 1 (DV = Popularity)	Model 2 (DV = Radicalness)
Age	0.05 (0.004)	0.05 (0.008)
Gender	-0.14 (0.005)	-0.08 (0.008)
Prog. Skill	-0.02 (0.02)	0.03 (0.000)
Education	-0.01 (0.001)	-0.13 (0.001)
Tenure	-0.30 (0.11)	0.08 (0.010)
Platform	0.10 (0.009)	0.10 (0.011)
LUS	0.23* (0.003)	0.15* (0.009)
EOE	0.20* (0.011)	0.17** (0.005)
EXP	0.27** (0.008)	0.25** (0.004)
SAU	0.07 (0.007)	-0.09 (0.011)
DAU	0.23** (0.005)	0.25** (0.001)
WAU	0.18* (0.001)	0.16* (0.005)
EOE*SAU	0.01 (0.002)	0.02 (0.004)
LUS*EOE	0.05 (0.004)	0.03 (0.010)
LUS*SAU	-0.04 (0.005)	0.11 (0.003)
EOE*WAU	0.23* (0.002)	0.16* (0.002)
LUS*EXP	-0.02 (0.11)	0.03 (0.005)
LUS*WAU	0.11 (0.12)	0.09 (0.005)
EXP*DAU	0.15 (0.004)	0.07 (0.008)
LUS*DAU	0.01 (0.004)	-0.11 (0.000)
LUS*EOE*WAU	0.04 (0.005)	0.04 (0.001)
LUS*EOE*SAU	0.19** (0.010)	0.06 (0.001)
LUS*EXP*DAU	-0.13 (0.012)	0.22* (0.008)
R^2	0.32	0.23** (0.005)

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