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Bottleneck Analysis of the Mobile Internet Diffusion in Emerging Markets

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Abstract. *According to the ITU, in 2013, only 6% of the population in developing countries had access to broadband Internet. Nevertheless, mobile Internet penetration rates have already exceeded those of fixed telecommunication services and may help in bridging the digital divide. To understand this phenomenon, we model the mobile Internet diffusion process via a system dynamics model that includes user competence, data price, and mobile network capacity as the main contributors to consumer utility and consequently, the main mobile Internet diffusion bottlenecks. The links that connect the system dynamics model variables are evaluated through a linear regression analysis that includes, for the first time, actual mobile capacity measurements from 17 metropolitan areas in emerging markets. The results suggest that market competition and mobile capacity are the main mobile Internet diffusion bottlenecks in emerging markets.*

Keywords: *Mobile Internet, Emerging Markets, System Dynamics, Mobile Capacity*

1. Introduction

Generally, fixed Internet diffusion can be explained by GDP per capita, and either market competition level [Hargittai 1999], or access price [Kiiski and Pohjola 2002] in the OCDE countries. Surprisingly, literacy levels and English language competence have little statistical significance in studies including developing countries. However, empirical research in India [Pal 2007] and Sri Lanka [Ali 2011] suggests that additional bottlenecks exist as causes of low fixed Internet usage (e.g. the lack of local content, the lack of on-line resource awareness and, language difficulties).

Nevertheless, the mobile Internet penetration rate has already exceeded the fixed Internet in developing countries. According to a survey carried out in 2011, more than 80% of Internet users in Namibia, Uganda, and Ethiopia accessed the Internet via a mobile phone. For South Africa, Kenya, Nigeria, Tanzania, and Rwanda, the corresponding number was 70% [Gillwald et al. 2013]. This penetration disparity was observed in advanced markets as well (e.g. Japan reached 77% mobile, 38.8% fixed in 2003) associated with the substitution of mobile telephony [Ishii 2004].

Certainly, mobile telephony has rapidly diffused in developing countries (e.g. 121,5% in Indonesia, 70.8% in India, 55.7% in Tanzania during 2013). According to [Rouvinen 2006], this was favoured by a late adoption that solved standard and regulatory uncertainties, and a large customer base that enabled operator profitability with a low average revenue per user. But, could mobile Internet diffuse as fast? Are the mentioned fixed Internet bottlenecks relevant?

Although much research has focused on the mobile Internet diffusion in developed countries (e.g. the assessment of handset bundling in Finland [Kivi 2010]), mobile Internet social function in Japan [Ishii 2004]), little research exists about emerging markets. This article proposes a new system dynamics model to describe the mobile Internet diffusion in emerging markets as part of a complex process that includes not only macroeconomic indicators but also variables at the individual and market level. The methodology has been successfully used to assess the impact of changes in the regulatory environment (e.g. mobile number portability [Casey and Töyli 2012]), and changes in the consumer utility function (e.g. utility increases with network size [Madden et al. 2004]).

The research novelty resides in combining mobile capacity measurements from 17 emerging markets with content availability indicators to estimate the degree of demand satisfaction as the aggregated consumer utility. The links that connect the variables in the system dynamics model are evaluated in a linear regression analysis with the focus in three bottleneck hypotheses: user competence with regard to available content, data price, and mobile network capacity. Results confirm that the lack of market competition (high market concentration) and the mobile capacity are the main bottlenecks to the mobile Internet penetration in emerging markets. In addition, the authors propose the Herfindahl-Hirschman Index (HHI) as the mobile Internet penetration predictor in emerging markets beyond the GDP.

The paper is structured as follows. Section 2 presents the diffusion model and justifies the feedback loops driving its dynamic behaviour. Section 3 maps the model variables against the data sources used in the linear regression analysis. Section 4 provides the linear regression analysis results. Section 5 evaluates the model via the three bottleneck hypotheses and, as a result, presents a new diffusion model. Section 6 summarises the research conclusions and Section 7 outlines future lines of work. Finally, Annex 1 presents the data values used in the statistical analysis.

2. Mobile Internet Diffusion Model

In technology diffusion research, two main models are used to explain the adoption process of new technologies over time as an S-curve. The epidemic model assumes that the adoption depends on the availability of information, on the other hand, the probit model considers the agent goals and abilities as the decisive factors of adoption. Given the bottleneck hypotheses under study, the diffusion model proposed in this article falls into the second category.

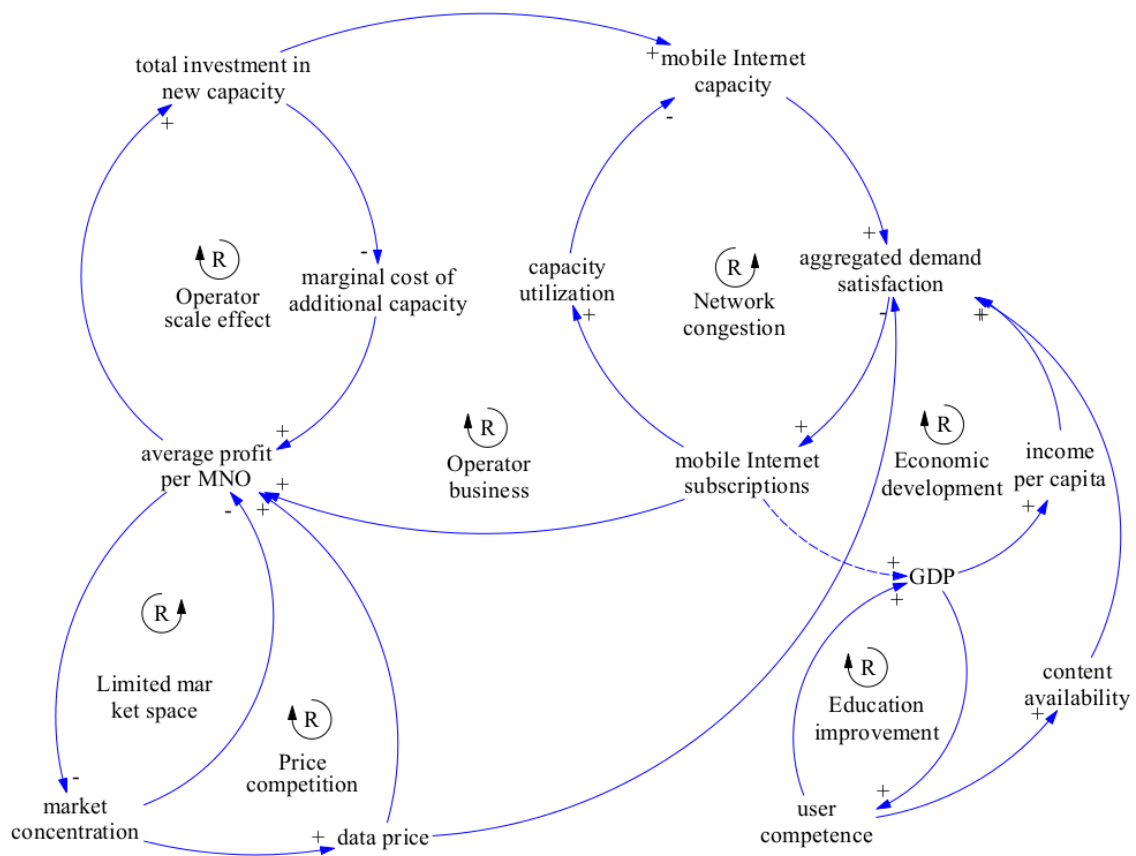
In our model, the initial purchase decision to acquire a mobile Internet subscription is made by a single, rational individual that maximises consumer surplus (S). According to microeconomics theory [Courcoubetis and Weber 2003], the choice of consumer i with respect to a product x is determined by the utility (U_i) and the price (P) as follows:

$$\max(S_i) = \max(U_i(x) - P(x))$$

To guarantee that the three bottleneck hypotheses are taken into account, the consumer assesses x as the bundle comprising mobile network capacity and available content. We note that content availability was a major bottleneck to the fixed Internet diffusion. Moreover, the consumer access cost over a period of time depends on the consumed content type.

In line with probit diffusion models, the probability of consumer adoption is different per each consumer provided their different, dynamic utility functions. In contrast, the data price can be considered fixed at the market level given the small price difference between operators. As a result, the aggregated demand function describes the total demand of the mentioned bundle as a function of the price. This logic is described in the context of relevant emerging market indicators in Figure 1 through a system dynamic model [Sterman 2000]. More precisely, the mobile Internet diffusion is estimated by the number of subscriptions which increase along with the satisfaction of the aggregated demand.

Figure 1. Mobile Internet Diffusion Model



The variables that directly contribute to the aggregated demand satisfaction are: mobile Internet capacity, data price, content availability and income per capita. Each contributing variable depends on other system variables and vice versa according to system loops (represented with the letter R) which are considered either reinforcing (clock-wise arrow around the R) or counterbalancing (counter clock-wise arrow) with regard to the number of subscriptions, as shown in Figure 1.

For instance, the *Operator business loop* and the *Operator scale effect loop* are reinforcing loops because these increase the mobile Internet capacity and, by extension, the number of subscriptions. The latter accounts for the cross-side network effect between the network operator and the network equipment manufacturer as described by [Casey and Töyli 2012]. In contrast, the *Network congestion loop* acts as a counterbal-

ancing loop because as the value increases, subscriptions tend to decrease. Also in Figure 1, the *Price competition loop* introduces the price reduction effect derived from competition statistically observed in liberalised emerging markets in the 2008-2013 period [ITU 2014]. In system dynamics modelling, the role of counterbalancing loops is vital. Another example is the *Limited market space loop* which implies that if competition levels are too high, average profits per MNO might decrease and reduce mobile Internet capacity via congestion.

All system loops are selected as the result of a prioritisation process. Other loops such as word of mouth, same-side network effect, and fixed-broadband substitution is not considered relevant in the emerging market case or considered included in existing loops.

3. Model Variables and Data Sources

Given the bottleneck hypotheses under study, only those diffusion model variables directly related to the consumer choice are included in the regression analysis. This section describes in detail these variables and justifies the selected data sources. Data is mainly from 2013 and is fully detailed in Table 5 of Annex 1.

3.1. Content Availability

The content availability variable estimates the amount of content accessible by the consumer. The total supply of content is estimated, on the one hand, by the number of Wikipedia articles in the most popular official language (proxy for user-generated content¹) and, on the other hand, the number of country code top level domain (ccTLD) in 2013 (proxy for organization-generated content²). The consumer reading competence is estimated by the national adult literacy level [ITU 2014].

3.2. Data Price

The data price is approximated by the price of the 500 MB data block devoted to handset devices in 2013. The minimum price is selected between pre-paid and post-paid options because the model assumes that the emerging market consumer is price sensitive. Mobile broadband data prices are extracted from the ITU Report Measuring the Information Society 2014 [ITU 2014]. All prices in the model are normalized to GNI p.c. thus providing insight into the affordability of services from a demand-side perspective for each country.

Complementarily, the model includes the Herfindahl-Hirschman Index³ as the estimated market concentration level. In 2013, all countries included in the analysis had liberalized mobile markets allowing competition among mobile network operators (MNO) as well as Mobile Virtual Network Operators (MVNO).

3.3. Mobile Internet Capacity

The mobile Internet capacity is approximated by the mean value of TCP download goodput performed by the Netradar mobile application [Sonntag et al. 2013]. These measurements are performed by anonymous users in a crowd-sourced approach. This approach

¹Last accessed : 2015-11-11. https://meta.wikimedia.org/wiki/List_of_Wikipedias

²Last accessed : 2016-18-05. <http://ftp.isc.org/www/survey/reports/2013/07/>

³HHI is calculated as the sum of the squared market shares (information is extracted from annual reports of operators and regulators) in terms of the number of subscriptions of each MNO, MVNOs are not taken into account. Bound values are 0 which indicates perfect competition and 1 which indicates monopoly.

ensures that the data reflects the actual capacities received by users and thus is in line with the overall user-centric approach. We note that Netradar TCP upload goodput and latency measures are not taken into account in the regression analysis due to the high multicollinearity between these measures and TCP download goodput.

The availability of Netradar data from emerging markets is limited to densely populated areas and therefore, large and populated metropolitan areas are selected for the regression analysis and listed in Table 5. All Netradar measurements were performed between 2013-2015. The disparate number of measurements across cities is the result of different adoption levels of Netradar application between cities. However the network measurement procedure is the same regardless of the location, thus ensuring comparability. Measurements span many operators in each city thus providing an advantage over studies with single operator centric data collection.

3.4. Mobile Internet Subscriptions

The number of mobile Internet subscriptions is estimated from annual reports of operators and regulators in the year 2013. For simplicity, the penetration of mobile Internet subscriptions over the total country population is calculated and labeled as mobile Internet penetration (MIP).

4. Regression Analysis

The linear regression analysis evaluates the relationship between the mobile Internet penetration (MIP) and the model variables with a direct relationship to the consumer choice. The analysis is performed twice. Firstly using a global market sample that includes 21 metropolitan areas (4 from advanced markets with MIP greater than 60%, and 17 from emerging mobile markets) and secondly using an emerging market sample that includes only the 17 emerging market metropolitan areas (thus is a subset of the global market sample). As a reminder from the previous section, the regression analysis assumes that changes in the MIP mainly occur in populated metropolitan areas. Linear regression tests are discussed in Annex 1.

4.1. Global Market Sample

Table 1 shows that the GDP and the market concentration (labelled as HHI) have the highest and third highest effect size⁴, respectively. More importantly, the analysis shows that mobile Internet capacity (labelled as capacity) is significant and has a high effect size even though its cross-correlation with GDP is high, as seen in Table 2. Finally, the effect size of ccTLD, Wikipedia articles and adult literacy rate is relatively small.

4.2. Comparison with the Emerging Market Sample

When data from advanced markets is removed from the sample, the effect size of GDP is reduced as shown in Table 3. Furthermore, although the statistical significance and effect size of mobile capacity is reduced, this still remains explanatory power. Interestingly, the effect size of HHI has increased revealing a high explanatory power in emerging markets beyond the well known GDP.

⁴The effect size, also known as standardized regression coefficient, describes the independent variable effect in terms of standard deviations instead of variable units.

Table 1. Linear Regression Global Market Sample Coefficients including Significance Levels^a

Variable	Coefficient	(Std. Err.)	Effect Size (Partial η^2) ^b
GDP	0.001***	(0.000)	0.698
HHI	-61.309*	(26.036)	0.299
Median download	0.007**	(0.002)	0.489
Min price (Norm)	0.251	(1.054)	0.004
Adult literacy rate	0.351	(0.253)	0.129
Wikipedia articles	0.001	(0.001)	0.057
ccTLD	0.000	(0.000)	0.030
Intercept	-10.915	(22.160)	-

^a † : 10%, * : 5%, ** : 1%, *** : 0.1%

^b Model total η^2 is 0.935

Table 2. Cross-Correlation Table for All Markets (Global) including Significance Levels^a

	MIP	Literacy	Wiki	TLD	GDP	HHI	Download	Price
MIP	1.000							
Literacy	0.528*	1.000						
Wiki	-0.001	-0.343	1.000					
TLD	0.218	0.244	-0.155	1.000				
GDP	0.892***	0.467*	-0.004	0.182	1.000			
HHI	-0.275	0.174	0.086	-0.173	-0.101	1.000		
Download	0.833***	0.472*	-0.019	0.044	0.669***	-0.160	1.000	
Price	-0.491*	-0.726***	0.450*	-0.324	-0.476*	0.031	-0.406	1.000

^a * : 5%, ** : 1%, *** : 0.1%

Table 3. Linear Regression Emerging Market Sample Coefficients including Significance Levels^a

Variable	Coefficient	(Std. Err.)	Effect Size (Partial η^2) ^b
GDP	0.003†	(0.001)	0.355
HHI	-82.634*	(27.323)	0.504
Median download	0.004	(0.002)	0.230
Min price (Norm)	0.233	(1.085)	0.005
Adult literacy rate	0.310	(0.274)	0.124
Wikipedia articles	0.003	(0.002)	0.254
ccTLD	0.000	(0.000)	0.011
Intercept	-6.690	(22.184)	-

^a † : 10%, * : 5%, ** : 1%, *** : 0.1%

^b Model total η^2 is 0.855

Table 4. Cross-Correlation Table for Emerging Markets including Significance Levels^a

	MIP	Literacy	Wiki	TLD	GDP	HHI	Download	Price
MIP	1.000							
Literacy	0.530*	1.000						
Wiki	0.025	-0.397	1.000					
TLD	0.395	0.256	-0.208	1.000				
GDP	0.709**	0.720**	-0.285	0.610**	1.000			
HHI	-0.282	0.244	0.133	-0.166	0.134	1.000		
Download	0.701**	0.401	0.106	0.064	0.457	-0.065	1.000	
Price	-0.435	-0.696**	0.538*	-0.339	-0.672**	-0.025	-0.298	1.000

^a * : 5%, ** : 1%, *** : 0.1%

5. Model Evaluation via Bottleneck Analysis

In this section, the validity of the three initial bottleneck hypotheses plus the market competition (as a result of market concentration) is discussed based on the regression analysis results. Finally, a new diffusion model is presented.

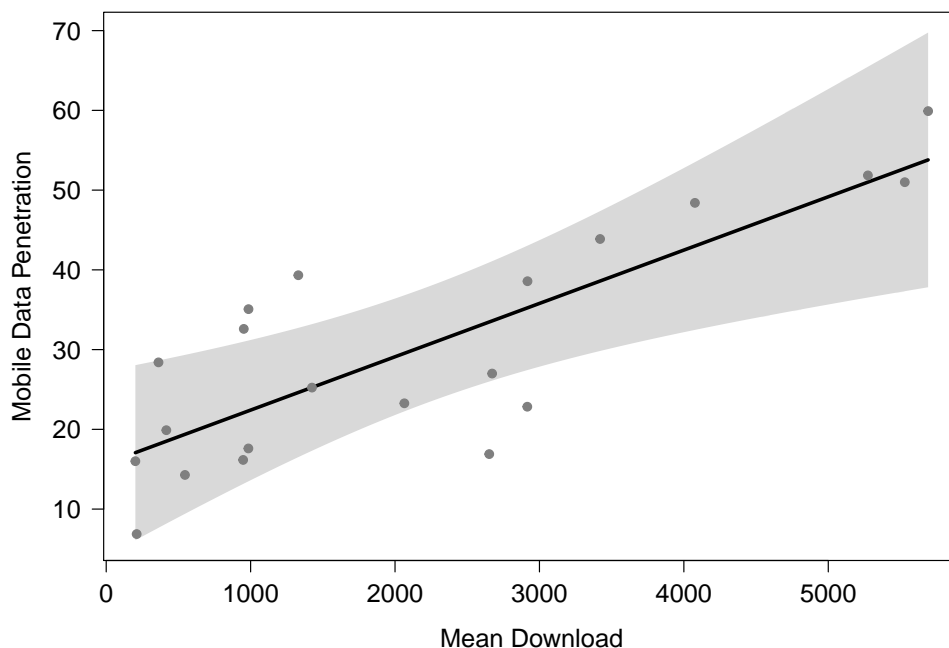
5.1. User Competence Bottleneck

Given the low explanatory power of the adult literacy rate, the ccTDL number, and Wikipedia articles in the most popular official language, the analysis concludes that user competence is not a major bottleneck to the mobile Internet diffusion in emerging markets. The analysis of individual countries supports this observation. For example, urban areas with a large supply of content, such as Lima (in Spanish) and Nairobi (in English), do not necessarily develop faster than those with less available content such as Bangkok (in Thai). It can be speculated that i) the advent of multimedia Internet might lower literacy requirements and ii) that the user generated content is a content supply large enough to satisfy consumer utility. As a result, content availability is removed from the new diffusion model.

5.2. Capacity Bottleneck

Mobile Internet capacity has a high size effect in both samples. Although this loses statistical significance in the emerging market sample (likely due to multicollinearity in the small sample), its effect size remains higher than GDP. Therefore, the analysis suggests that mobile Internet capacity is a major bottleneck to mobile Internet diffusion. For reference the linear relationship predicted by the regression model (included predicted residuals) for the Global market sample is illustrated in Figure 2. Regarding the diffusion model, the regression suggests that mobile capacity has a strong role in the satisfaction of consumer utility.

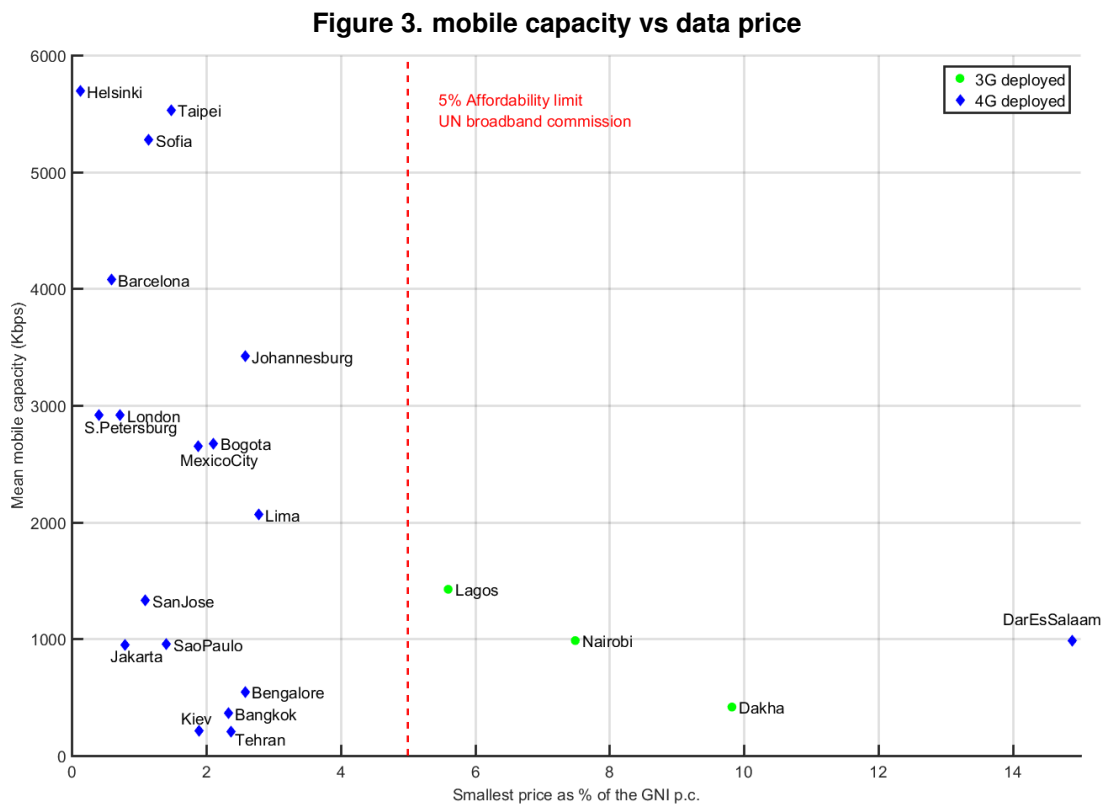
Figure 2. Global Model Prediction of Mean Download vs Mobile Data Penetration



5.3. Price Bottleneck

According to [ITU 2014], mobile prices declined in the period 2008-2013, with a Compound Annual Growth Rate (CAGR) of -5.7% globally. The decrease in prices has affected developed and developing countries alike, with -4.3 and -6.4% CAGR, respectively. In both samples, the majority of countries present a market price value below the 5% of GNI p.c. which is the affordability limit defined by the UN broadband commission, as shown in Figure 3.

Given the low effect size of the price in the linear regression model, the price bottleneck is analysed on an individual country basis in relation to mobile capacity. Figure 3 shows how the individual consumer surplus associated with the mobile Internet capacity is maximized when mobile capacity is also maximized (Y axis) and the price is minimized (X axis).



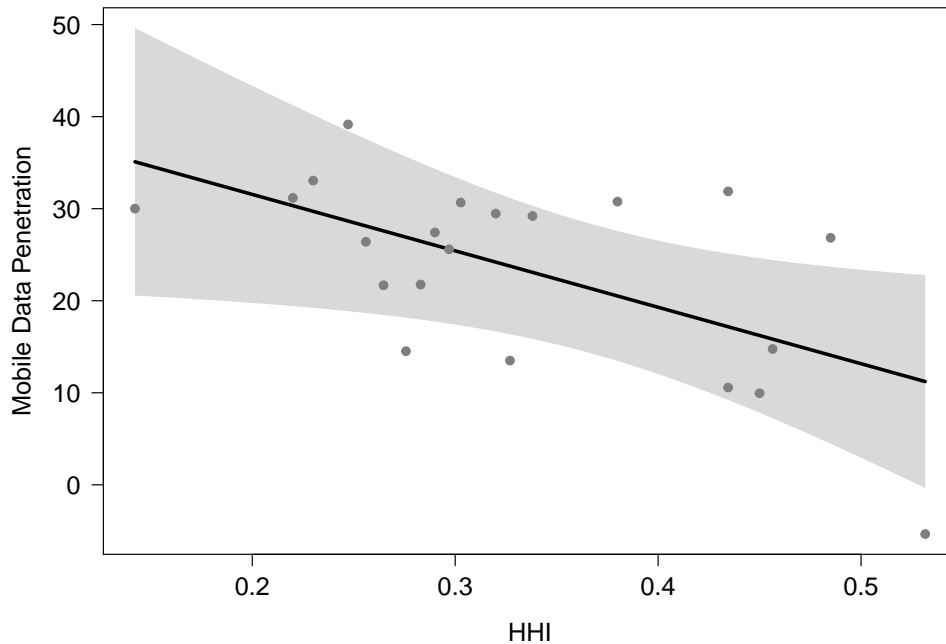
The analysis of Figure 3 suggests that although the price is a mobile Internet diffusion bottleneck in some cities, this phenomenon cannot be as widely generalized as mobile capacity or HHI. These cities case might be explained by the low country GNI p.c. (for example in Tanzania, Bangladesh, Kenya, and Nigeria). Regarding the diffusion model, this result implies that the link connecting data price and consumer surplus might not be as strong as those of mobile capacity and HHI.

5.4. Competition Bottleneck

Regression analysis results show a statistically significant large size effect between HHI and MIP in both the global (as shown in Figure 4) and in the emergent market samples. As a result, the analysis suggests that market competition (as a result of market concentration) is a major mobile Internet diffusion bottleneck.

Although this result does not contradict the proposed diffusion model, the regression result implies that the effect of market concentration on MIP does not only flow via the data price. Therefore, we can speculate that the higher the market competition, the larger the operator effort to reach new customers without this effort necessarily implying a data price reduction. Operators might maintain revenues via more expensive subscriptions while new customers are attracted to the most affordable subscriptions. As a result, the new diffusion market model incorporates new reinforcing loops starting at the market concentration variable.

Figure 4. Global Model Prediction of HHI vs Mobile Data Penetration



5.5. New Diffusion Model

Figure 5 presents the new diffusion model that incorporates three new reinforcing loops (in bold): the capacity competition, the marketing competition and the word of mouth . These loops support the article findings that market competition (resulting from market concentration) is a crucial element in the mobile Internet diffusion. In addition, the effect of competition is not transferred to the consumer via price, most likely because this is already very low, but through other dimensions such capacity and marketing. Consequently, as seen in advanced markets, MNOs no longer compete in price but in capacity, marketing and added value services.

Finally, unlike publicly funded state scale fixed Internet development programs (e.g. e-Sri Lanka funded by the World Bank [Ali 2011]), mobile technology and operators have been able to overcome the lack of local content, awareness and language difficulties achieving a consistent penetration growth in developing countries. This observation is, first, consistent with the user competence bottleneck finding, and second, from a regulatory point of view, it supports the speculation that market competition is a more useful tool than subsidies to foster connectivity in emerging markets. However, some diffusion bottlenecks cannot be addressed by competition only. For example, in Tehran, the price is similar to other emergent markets, but the mobile capacity is significantly lower most likely due to economic sanctions. In contrast, the mobile capacity in Dar es Salaam is similar to other emergent markets, but the main bottleneck is the price due to low GNI p.c. In the later case, business model innovations might be required to introduce subsidies from governments or content providers (e.g. Free Basics from Facebook, M-cent from Jana).

7. Future Work

The linear regression analysis could introduce mobile capacity measurement from: more metropolitan areas to increase the sample size, other data sets beyond Netradar to increase the number of measurements per area, more wireless technologies such as Wi-Fi. New data sources might be required to understand the type of content preferred in emerging markets and the implications for consumer costs.

Acknowledgment

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Annex

7.1. Linear Regression Tests

In terms linear regression model assumptions, we test for linearity of relationships between independent and dependent variables (augmented partial residual plots) and multicollinearity (check of variance inflation factors). Regarding the ordinary least square, we checked for normality of residuals (Shapiro-Wilk W test), heteroskedasticity of residuals (Breusch-Pagan test), and model specification (link test and regression specification error test for omitted variables). We find no issues in the assumption tests given test significant level of 0.05 and variance inflation factor limit of 5. Though we note that with the relatively small sample multicollinearity is still a concern.

Figure 2 and 4 include partial residuals with co-variates kept at median values.

7.2. Linear Regression Data

Table 5. Regression Analysis Data Sources

City	adult literacy rate	wikipedia	ccTLD	price (norm)	HHI	GDP \$	mean down (kbps)	MIP ^a
Helsinki	99,0	384	4572642	0,13	0,34	49365	5691,40	116,76
Barcelona	97,9	1219	4147699	0,59	0,30	29475	4076,65	80,71
London	95,2	5034	8116718	0,72	0,28	42409	2915,89	79,36
Taipei	95,1	893	6429021	1,48	0,26	22619	5529,93	76,00
SaintPetersburg	99,7	1332	15122103	0,41	0,23	14501	2917,37	57,63
Sofia	98,4	219	882692	1,15	0,22	7670	5274,40	57,56
Johannesburg	93,7	5034	3358989	2,58	0,32	6853	3420,00	47,66
SaoPaulo	91,3	897	33691951	1,41	0,25	11711	952,72	47,22
SanJose	97,4	1219	155768	1,10	0,43	10462	1330,35	36,50
Bangkok	96,4	107	3674102	2,33	0,38	6229	362,18	22,33
Bogota	96,3	1219	4721748	2,11	0,43	8028	2672,45	21,60
Nairobi	72,2	5034	73142	7,49	0,49	1257	985,39	14,06
Lima	93,8	1219	490419	2,78	0,45	6564	2064,58	13,34
Jakarta	92,8	279	1881475	0,80	0,26	3624	948,28	11,79
MexicoCity	94,2	1219	17658991	1,88	0,53	10173	2652,34	10,30
Lagos	51,1	5034	1350	5,60	0,30	2980	1424,87	10,23
DarEsSalaam	67,8	5034	27088	14,88	0,28	908	984,60	8,80
Bengalore	62,8	100	7429638	2,58	0,14	1513	545,32	5,31
Kiev	99,7	646	2589021	1,90	0,33	4218	211,02	2,80
Tehran	84,3	477	203221	2,37	0,46	6631	202,03	1,35
Dakha	58,8	43	124483	9,82	0,29	977	416,40	0,01

^a Mobile Internet penetration

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