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Diffusion of Digital Mobile Telephony

Are Developing Countries Different?

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Abstract

Factors determining the diffusion of digital mobile telephony across 200 developed and developing countries in the 1990s are studied with the aid of a Gompertz model. The market size and network effects are found to play more important roles in the developing countries; there is also more need for complementing innovations in, for example, financial and payment systems. Even though the developing countries have disadvantages, being late entrants in digital mobile telephony is to their advantage and promotes cross-country convergence. Overall digital technologies are best seen as equalizers, and thus the divide is rather socio-economic or analog than digital.

Keywords: mobile telephony, technology diffusion, Gompertz model, developing countries

JEL classification: L96, O30, O10

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Introduction

In recent decades wireline (fixed) telephony has increasingly been complemented and also replaced by wireless (mobile), which currently dominates in terms of worldwide usage (ITU, 2002b). While the role of the Internet in economic developed has been emphasized, it should be pointed out that – with well over twice as many users worldwide – mobile telephony also holds considerable potential in this respect.

In both fixed and mobile telephony analog technologies have been taken over by digital ones. Indeed, the worldwide breakthrough of mobile telephony is associated with the commercial introduction of digital technologies in the early 1990s. Among the developed countries the average penetration rate (users per population) of analog mobile telephony peaked at less than five per cent in the mid-1990s, whereas the penetration of digital mobile telephony is currently some 50 per cent. The corresponding penetration rates among the developing countries are some ten times lower. Although also the switch from analog to digital mobile telephony has been somewhat slower among the developing countries, the diffusion patterns *per se* seem to be more similar in the case of digital mobile telephony.

Reasons for the success of digital mobile telephony are manifold. First, by economizing on the use of the limited radio spectrum, digitalization made the current levels of mobile telephony usage technically possible. Second, combined with other industry developments, digital mobile telephony offered end users a more attractive bundle in terms of price, quality, and services. In many countries competition was first introduced in digital mobile telephony with direct consequences on user cost. Digital mobile telephony had advanced data transmission (short messaging service etc.) and improved voice quality. In part thanks to lower power consumption of digital mobile telephony, smaller and lighter end-user terminals (handsets) became available. Third, and perhaps most importantly, with the expanding user base, network effects and economies of scale in both production and use accumulated rapidly. In short, with digitalization mobile telephony truly became a worldwide consumer market.

Dekimpe et al. (1998), Ahn and Lee (1999), Burki and Aslam (2000), Gruber (2001), Gruber and Verboten (2001), Liikanen et al. (2001), Koski and Kretschmer (2002), and Madden et al. (2004) are among the studies modeling cross-country mobile telephony diffusion. Some aspects of these studies are summarized in Table 1.

Several things are noteworthy in Table 1. First, with the exception Dekimpe et al. (1998), the number of countries included in the analyses are relatively low, and none of the studies explicitly focus on comparing developed and developing countries. Second, with the possible exceptions Liikanen et al. (2001) as well as Koski and Kretschmer (2002), the sets of (non-telecom) socio-economic explanatory variables remain rather modest, and only GDP per capita and a population measure are shared across studies. Third, again with the exceptions Liikanen et al. (2001) as well as Koski and Kretschmer (2002), the dependent variable combines both analog and digital mobile telephony, although most studies acknowledge their important differences in one form or an other.

Table 1 Some economic studies modeling cross-country mobile telephony diffusion

Study	Dep.	Independent variables	Countries	Period	Findings
Dekimpe et al. (1998)	Mobile penetr.	GNP per cap., pop. growth, # of major pop. centers, # of competing systems, death rate, communism dummy, # of ethnic groups.	184	1979–1992	High wealth, ethnic homogeneity & low death rate promote diffusion.
Ahn & Lee (1999)	Mobile penetr.	GDP per cap., fixed penetr. & digitalization rate, mobile user cost.	64	1997	High GDP per cap. & fixed penetr. promote diffusion.
Burki & Aslam (2000)	Mobile users	GDP, pop., fixed penetr., digital mobile dummy, analog & digital mobile competition dummies.	25 (Asian)	1986–1998	Analog to digital mobile transition changed diffusion patterns. Competition promotes diffusion.
Gruber (2001)	Mobile penetr.	GDP per cap., sh. of urban pop., fixed penetr. & wait time, digital mobile competition dummy, # of mobile operators, market transition index.	10 (EU accession)	Introd.–1997	Late mobile adoption & multiple operators and high fixed penetr. & long wait times promote diffusion.
Gruber & Verboten (2001)	Mobile users	GDP per cap., fixed penetr., digital mobile technology dummy, analog/digital mobile competition dummies.	15 (EU)	1992–1997	Analog to digital mobile transition & competition promote diffusion. Late entrants adopt mobile faster.
Liikanen et al. (2001)	Ch. in analog and/or digital mobile users	GDP per cap., pop., sh. of urban pop. & pop. over 65, fixed users/penetr., analog/digital users/penetr., # of analog/digital standards & years since introd., NMT & GSM dummies, 5 measures of mobile telephony operation, age-dependency ratio, surface area.	80	1992–1998	Digital mobile introduction hinders analog mobile diffusion. Generation-specific (analog vs. digital) results differ from generic (analog+digital) results: technology shifts should be accounted for.
Koski & Kretschmer (2002)	Mobile penetr., user cost & entry	GDP per cap., sh. of urban pop., telecom regulator dummy & competition measure, analog mobile penetr., digital mobile subscriber & prepaid users, digital mobile standard dummy, market sh. of dominant digital mobile standard, more than 2 mobile operators dummy.	32	1991–1999	Incorporating the time of entry to digital mobile telephony study is important. Both between & within standards competition promote diffusion & lower user cost particularly when more than 2 operators are present.
Madden et al. (2004)	Mobile penetr.	GDP per cap., pop., mobile user cost.	56	1995–2000	High wealth, low users cost & large user base promote diffusion.

Note: Dep. refers to the dependent variable(s) in the study in question.

This paper addresses the afore-mentioned deficiencies in the previous literature in studying the socio-economic factors driving the diffusion of digital mobile telephony. The possible differences between developed and developing countries with respect to these factors are of particular interest.

Model

Mobile telephony diffusion is studied with the aid of a Gompertz growth model, which in the past has been used to study, e.g., the spreading of computers (Stoneman, 1983: Ch. 10) and the Internet (Kiiski and Pohjola, 2002). Although a wealth of alternatives exist (see, e.g., Stoneman, 2002), the Gompertz model is parsimonious, linear in parameters, and allows for simple inclusion of socio-economic explanatory variables. Furthermore, interestingly Madden et al. (Madden and Coble-Neal, 2001; Madden et al., 2004) end up with a specification that is identical to the one derived below, although their starting point is a dynamic optimization problem of an economic agent rather than a diffusion model.

Let $N_{i,t}$ be the number mobile telephony users in country i at time t. Over time it tends towards its post-diffusion or equilibrium level $N_{i,t}^{*}$ along an S-shaped path. The Gompertz growth model specifies the rate of change as

$$\ln N_{i,t} - \ln N_{i,t-1} = \alpha(\ln N_{i,t}^{*} - \ln N_{i,t-1}) \quad (1)$$

where α is the speed of adjustment. The equilibrium level $N_{i,t}^{*}$ is a function of past supply and demand factors (denoted by a vector $\boldsymbol{X}_{i,t-1}$) including availability, disposable income, and user cost

$$\ln N_{i,t}^{*} = \boldsymbol{\beta}' \ln \boldsymbol{X}_{i,t-1} \quad (2)$$

where $\boldsymbol{\beta}$ is a vector of coefficients. Inserting (2) into (1) yields

$$\ln N_{i,t} - \ln N_{i,t-1} = \alpha\boldsymbol{\beta}' \ln \boldsymbol{X}_{i,t-1} - \alpha \ln N_{i,t-1} \quad (3)$$

which is estimable with an appropriate econometric method as soon as $\boldsymbol{X}_{i,t-1}$ and the stochastic error structure have been specified.

Data

EMC's World Cellular Database, ITU's World Telecommunications Indicators, and the World Bank's World Development Indicators include telephony diffusion information for over 200 countries and regions. Table 2 shows the year of commercial introduction of digital mobile telephony by country. As can be seen, developing countries typically adopt later and one in ten had not adopted at all by the end of 2000.[1]

Table 2 The year of commercial introduction of digital mobile telephony by country

Developed (78 countries/regions)

1992	1993	1994	1995	1996	1997	1998	1999	2000
				Argentina				
				Brazil				
			Bahrain	Brunei				
	Australia	Belgium	Canada	Czech Rep.				
	Austria	Channel Isl.	Costa Rica	Dominica				
Andorra	Greece	Hungary	Croatia	Guam				
Denmark	Ireland	Iceland	Cyprus	South Korea				
Finland	Italy	Israel	Estonia	Libya		Bahamas		
France	Japan	Kuwait	French Polyn.	Mauritius	Barbados	Botswana		
Gabon	Luxemb.	Malaysia	Lebanon	Oman	Bermuda	Cayman Isl.		
Germany	N. Zealand	Netherlands	Macao	Panama	Chile	Dominica		
Hong Kong	Norway	Qatar	New Caled.	Poland	Malta	Faeroe Islands		
Portugal	Singapore	South Africa	Puerto Rico	Saudi Arabia	Slovak Rep.	Greenland		Dominica
Sweden	Switzerland	Turkey	Seychelles	Slovenia	Uruguay	Mexico		Grenada
UK	USA	UAE	Spain	Venezuela	Virgin Isl.	Trinidad & T.		St. Lucia

Developing (102 countries/regions)

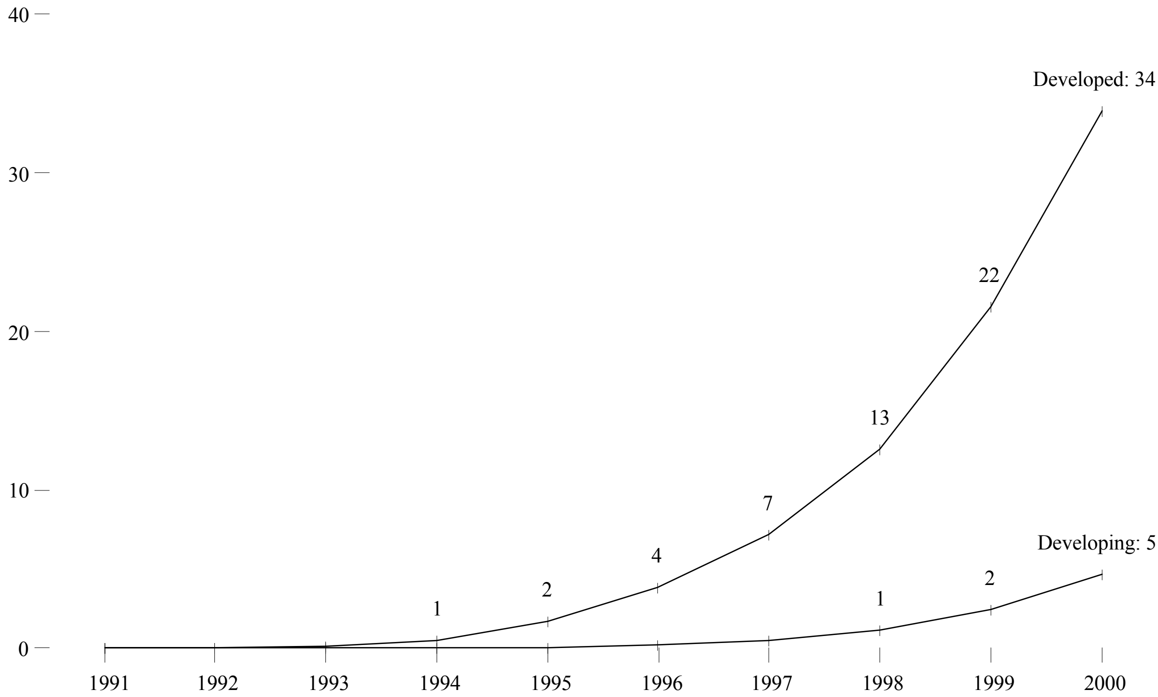
1992	1993	1994	1995	1996	1997	1998	1999	2000
	Nicaragua	Cameroon	Bulgaria	Albania	Bangladesh	Dominican R.	Algeria	Anguilla
		China	Colombia	Armenia	Bolivia	El Salvador	Angola	Benin
		Fiji	Congo, Rep.	Azerbaijan	Cape Verde	French Guiana	Belarus	Burundi
		Indonesia	Georgia	Bosnia-Herz.	Guinea	Guyana	Centr. Afr. R.	Chad
		Iran	Gibraltar	Burkina Faso	Martinique	Moldova	Congo D. R.	Eq. Guinea
		Madagascar	India	Cambodia	Mozambiq.	Paraguay	Cuba	Honduras
		Morocco	Jordan	Cote d'Ivoire	Romania	Peru	Ethiopia	Mali
		Pakistan	Kyrgyz Rep.	Ecuador	Togo	Rwanda	Guatemala	Marshall Isl.
		Philippines	Lao PDR	Egypt	Zambia	Swaziland	Haiti	Mauritania
		Russia	Latvia	Ghana		Tunisia	Jamaica	Sierra Leone
		Taiwan	Lithuania	Guadeloupe			Kazakhstan	Tajikistan
		Thailand	Malawi	Guernsey			Maldives	Turkmenistan
		Vietnam	Myanmar	Kenya			Nepal	
			Namibia	Lesotho			Syrian Arab R.	
			Reunion	Macedonia			W. Bank, Gaza	
			Sri Lanka	Mongolia				
			Suriname	Senegal				
			Tanzania	Sudan				
			Tonga	Ukraine				
			Uganda	Yugoslavia				
			Uzbekistan	Zimbabwe				

Note: Not introduced commercially in the following 21 developing countries/regions by the end of year 2000: Afghanistan, Belize, Bhutan, Comoros, Cook Island, Djibouti, Eritrea, Gambia, Guinea-Bissau, Kiribati, North Korea, Micronesia, Niger, Nigeria, Papua New Guinea, Samoa, Sao Tome and Principe, Solomon Islands, St. Helena, Vanuatu, and Yemen Rep.

1 For the present purposes the developing countries are defined as the low and lower middle income countries in the 2002 edition of World Bank's World Development Indicators CD-ROM. If the country in question is not included in this data source, it is assumed to be a developing country.

Besides the time of adoption, the penetration rates also differ considerably between the developed and developing countries. As shown in Figure 1, the average penetration rate across the developed countries was one third, whereas the corresponding figure for the developing countries was five per cent at the end of 2000.

Figure 1
The average country penetration rates (user per population) of digital mobile telephony (%)



Note: Including 78 developed and 123 developing countries as in Table 2.

Table 3 defines the socio-economic variables used in the analysis. The country's total population as well as population in the largest city are proxies for the overall size of the market.[2] Real GDP per capita controls for the wealth and income effects. Industry value added to GDP and the age-dependency ratio are used to account for the country's overall state of development. Private credit to GDP proxies the country's financial development. The ratio of trade to GDP controls for openness. Two well-known datasets are used to construct an index of political freedom accounting for the degree of democracy in the country's political system. PCs per capita proxies for the country's overall (non-telecom) technological level.

2 Also the inclusion(s) of the share of urban population, population density, and/or the country's surface area were studied jointly and separately, but test statistics did not indicate that they should be included.

Table 3 Definitions of the variables

Category	Variable	Description	Type	Unit	Source	Transf.
Market size	**Population, total**	The total number of the country's residents	Count	1,000	WDI (ITU)	Nat. log
Market size	**Population, city**	The total number of residents in the largest city in the country	Count	1,000	ITU	Nat. log
Wealth	**Income**	GDP per capita in US dollars and 1995 prices	Ratio	US $	WDI (ITU, WB, IMF)	Nat. log
Development	**Industrialization**	Value added in mining, manufacturing, construction, electricity, water and gas per GDP	Share	%	WDI	Nat. log
Development	**Age-dependency**	Dependents (those under age of 15 or over 64) to remainder (ages 15-64) of the pop.	Ratio	%	WDI	Nat. log
Finance	**Credit**	Financial resources provided to the private sector (regardless of the source) per GDP	Ratio	%	WDI	Nat. log
Openness	**Trade**	The sum of exports and imports of goods and services per GDP	Ratio	%	WDI	Nat. log
Democracy	**Freedom**	Index of political freedom from autocracy (0) to democracy (100)	Index	0–100	POLITY IV (FH)	Nat. log*
Technology	**PCs**	Self-contained computers designed to be used by a individual per cap.	Ratio	%	WDI (ITU)	Nat. log
Fixed	**Fixed, penetr.**	Fixed telephone mainlines connecting a customer to the public switched network per cap.	Ratio	%	ITU (WDI)	Nat. log
Fixed	**Fixed, user cost**	Monthly charge for 120 minutes of fixed calling within the same exchange in US dollars and 1995	Price	US $	ITU (WDI)	Nat. log
Analog mob.	**Analog, penetr.**	Analog mobile telephony users per cap.	Ratio	%	EMC, ITU, WDI	Nat. log*
Digital mob.	**Digital, users**	Digital mobile telephony users	Count	1,000	EMC, ITU, WDI	Nat. log
Digital mob.	**Digital, prepaid**	Digital mobile telephony can be access via prepaid calling cards in the country in question	Dummy	0,1	EMC	–
Digital mob.	**Digital, many**	Digital mobile telephony has more than one network standard in the country in question	Dummy	0,1	EMC	–
Digital mob.	**Digital, comp.**	Digital mobile telephony has two or more competing operators in the country in question	Dummy	0,1	ITU-P	–
Digital mob.	**Digital, avail. trend**	Number of years elapsed since digital mobile telephony became commercially available	Trend	1–8	ITU-P	–
Both mob.	**Mobile, user cost**	Monthly charge for 120 minutes of local mobile peak-time calling in US dollars and 1995 prices	Price	US $	ITU (EMC)	Nat. log
Both mob.	**Mobile, handset**	PPP conversion factor to official exchange rate ratio (a proxy for handset prices)	Ratio	%	WDI	Nat. log

Note: * In order to address the problem of zeros, the natural logarithm was taken of the variable value plus one. Sources: EMC = EMC's World Cellular Database, FH = Freedom House (www.freedomhouse.org) world country ratings, IMF = IMF's International Financial Statistics, ITU = ITU's World Telecommunications Indicators, ITU-P: ITU (2002a), POLITY IV: Political Regime Characteristics and Transitions (Marshall & Jaggers, www.cidcm.umd.edu/inscr/polity) dataset, WB = World Bank's Global Development Network Growth Database (Easterly & Sewadeh) macroeconomic time series, WDI = World Bank's World Development Indicators. If data for a given country was unavailable at the primary source(s), it was taken from the next source listed in the parenthesis. If multiple sources are listed but none are in the parenthesis, the data used for the country i at time t is the largest non-missing value among the sources listed.

The remaining variables in Table 3 relate to fixed as well as analog and/or digital mobile telephony. Fixed and analog mobile telephony penetration rates capture their substitutability or complementarity as well as possible network and/or economies of scale effects with respect to digital mobile telephony.[3] It is assumed that fixed telephony user cost captures other relevant aspects of fixed telephony. The dependent variable is constructed by taking a log difference of the number of digital mobile telephony users. Three indicators capture aspects of the digital mobile telephony market: the prepaid dummy takes the value of one (and is zero otherwise), if prepaid mobile telephony calling cards are available in the country in question; the many dummy takes the value of one (and is zero otherwise), if the country has competing standards in digital mobile telephony; and the competition dummy takes the value of one (and is zero otherwise), if the country has competing operators in digital mobile telephony. As mobile user costs cannot be constructed separately for analog and digital mobile telephony with the available data, we are forced to a combined mobile user cost instead. Since mobile handset prices are not available for the countries included to the analysis, the ratio of purchasing power parity to official exchange rate is used as a proxy. The idea behind this is as follows: handset prices are determined in international markets and are thus the same across countries in a given international currency; if, however, the purchasing power of the national currency is less than the official exchange rate suggests, the handsets bought in the international markets and imported to the country are effectively more expensive than in a country without such discrepancy.

Table 4 presents the descriptive statistics of the untransformed variables that are usable in the regression analysis. The developed and developing countries are reported separately in order to aid the comparison of the two groups. The differences in means would seem to suggest that the developing countries are on average larger, their GDPs per capita and (non-telecom) technological levels are eight times lower, they have higher dependency ratios, private sector credit is less readily available, and they are less open and democratic than the developed countries.

As far as telecommunications related variables are concerned, their fixed telephony penetration rates are four times lower but user costs are twice as high. Analog and digital (not shown) mobile penetration rates are some ten times lower. Although in absolute terms mobile user cost is about one fifth lower in the developing countries, in relative terms (with respect to average income) it is manifold.

Table 5 presents the correlation matrix of the variables. With the exception of the analog mobile telephony penetration, the number of digital mobile telephony users is statistically significantly correlated with all the explanatory variables considered: the correlations are negative with respect to the age-dependency ratio and trade. The latter correlation is driven by the fact that smaller countries tend to be more open.

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3 Also the inclusion(s) of the fixed telephony digitalization rate and/or wait time, ownership and/or competitive status of the incumbent operator, fixed and/or analog mobile competition dummies were studied jointly and separately, but test statistics did not indicate that they should be included.

Table 4 Descriptive statistics

	(a) 75 developed (1993–2000 unbalanced panel)						(b) 90 developing (1994–2000 unb. panel)				
	Obs.	Mean	St. dev.	Min.	Max.		Obs.	Mean	St. dev.	Min.	Max.
Population, total	392	22,138	44,715	35	281,550	Pop.	335	61,677	200,447	27	1,262,460
Population, city	389	2,668	3,542	1	18,131	City	331	2,993	3,678	14	17,419
Income	392	16,181	10,134	2,693	44,603	Inc.	335	2,043	4,097	84	27,681
Industrialization	264	30.98	7.67	12.79	55.34	Ind.	297	27.71	10.07	8.94	76.12
Age-dependency	364	53.00	9.20	36.54	89.03	Age-d.	302	70.49	17.48	40.75	104.00
Credit	320	76.10	45.75	6.54	203.17	Credit	288	26.83	27.33	1.72	165.45
Trade	320	93.22	63.76	15.99	341.35	Trade	289	74.07	35.06	1.13	207.79
Freedom	342	82.48	31.45	0	100	Free	298	57.53	30.68	5	100
PCs	335	17.68	13.06	0.10	58.52	PCs	255	2.52	5.08	0.07	54.74
Fixed, penetr.	392	40.71	18.42	2.92	100.00	Fixed	335	11.22	15.91	0.04	85.92
Fixed, user cost	341	13.65	6.89	3.03	32.13	F.cost	268	6.01	3.89	0.23	18.22
Analog, penetr.	392	3.65	4.56	0	18.33	Analog	335	0.40	1.06	0	10.70
Digital, users	392	3,220	8,707	0	70,530	Digital	335	786	5,305	0	84,533
Digital, prepaid	392	0.49	0.50	0	1	Prepaid	335	0.47	0.50	0	1
Digital, many	392	0.22	0.41	0	1	Many	335	0.29	0.45	0	1
Digital, comp.	392	0.72	0.45	0	1	Comp.	335	0.71	0.45	0	1
Mobile, user cost	367	61.55	33.13	9.70	183.14	M. cost	296	51.03	34.20	0.78	276.61
Mobile, handset	333	86.21	29.63	31.29	174.33	H-set	286	32.82	15.76	9.79	131.69

Note: The above are the descriptive statistics of the untransformed variables, i.e., natural logarithms or lags have not been taken in order to aid interpretation. Since the dependent variable is a log difference, the information on a given country is only usable from the second positive observation onwards. Thus, the observations for the 21 countries that had not introduced digital mobile telephony by and for the 15 countries introducing it in 2000 are not usable. The above table refers to the usable observations.

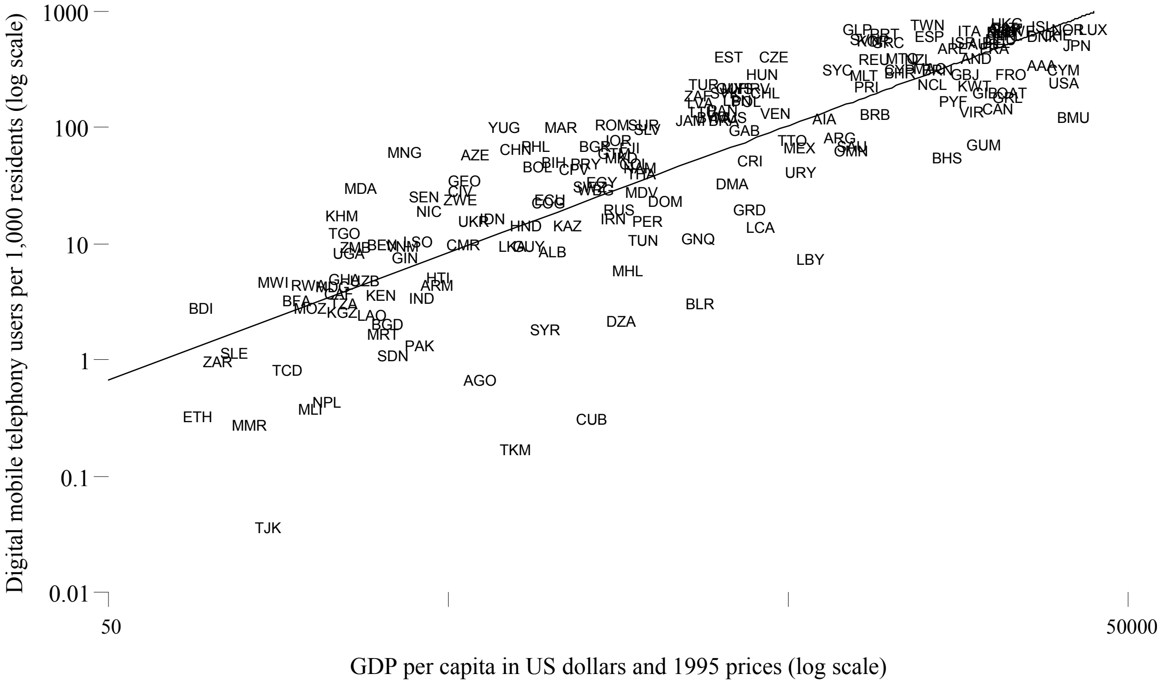
Table 5 Pairwise correlations (correlation coefficients multiplied by one hundred)

	Pop.	City	Inc.	Ind.	Age-d.	Credit	Trade	Free	PCs	Fixed	F.cost	Analog	Digital	Prepaid	Many	Comp.	M. cost	H-set
Population, total	100																	
Population, city	61	100																
Income	-9	-4	100															
Industrialization	20	13	5	100														
Age-dependency	-7	-11	-51	-20	100													
Credit	11	18	64	14	-48	100												
Trade	-21	-30	16	12	-24	23	100											
Freedom	-7	7	41	-8	-42	33	-2	100										
PCs	-10	-9	85	4	-51	57	24	45	100									
Fixed, penetr.	-12	-9	88	7	-68	62	20	57	87	100								
Fixed, user cost	-1	1	67	13	-22	41	-12	39	58	51	100							
Analog, penetr.	-3	0	47	11	-25	33	-9	33	51	48	37	100						
Digital, users	33	39	23	15	-21	38	-14	15	28	22	18	6	100					
Digital, prepaid	2	8	-7	-2	-9	1	1	19	14	4	-5	3	18	100				
Digital, many	22	41	-8	14	-6	17	1	-3	1	-12	-4	26	14	9	100			
Digital, comp.	13	23	-2	13	0	-2	-11	35	9	-5	14	3	15	22	13	100		
Mobile, user cost	-13	-6	29	-6	-15	17	-7	26	13	25	35	6	-2	-20	-10	15	100	
Mobile, handset	-14	-2	91	12	-47	60	12	37	74	81	68	47	20	-10	-5	8	34	100

Note: Underlining indicates that the correlation coefficient is statistically significant at the 1% level.

Figure 2 illustrates perhaps the most interesting unconditional pairwise correlation in the data. The scatter diagram shows the correlation between mobile telephony diffusion and average income. As suggested in many previous studies, the correlation is rather strong.

Figure 2 Mobile telephony diffusion and average income in year 2000



Notes: Excluding the 21 countries that had not introduced digital mobile telephony by year 2000.

Abbreviations: AAA = Guernsey; AGO = Angola; AIA = Anguilla; ALB = Albania; AND = Andorra; ARE = UAE; ARG = Argentina; ARM = Armenia; AUS = Australia; AUT = Austria; AZE = Azerbaijan; BDI = Burundi; BEL = Belgium; BEN = Benin; BFA = Burkina Faso; BGD = Bangladesh; BGR = Bulgaria; BHR = Bahrain; BHS = Bahamas; BIH = Bosnia & Herzegovina; BLR = Belarus; BMU = Bermuda; BOL = Bolivia; BRA = Brazil; BRB = Barbados; BRN = Brunei; BWA = Botswana; CAF = Central African Rep.; CAN = Canada; CHE = Switzerland; CHL = Chile; CHN = China; CIV = Cote d'Ivoire; CMR = Cameroon; COG = Congo, Rep.; COL = Colombia; CPV = Cape Verde; CRI = Costa Rica; CUB = Cuba; CYM = Cayman Isl.; CYP = Cyprus; CZE = Czech Rep.; DEU = Germany; DMA = Dominica; DNK = Denmark; DOM = Dominican Rep.; DZA = Algeria; ECU = Ecuador; EGY = Egypt; ESP = Spain; EST = Estonia; ETH = Ethiopia; FIN = Finland; FJI = Fiji; FRA = France; FRO = Faeroe Isl.; GAB = Gabon; GBJ = Channel Isl.; GBR = UK; GEO = Georgia; GHA = Ghana; GIB = Gibraltar; GIN = Guinea; GLP = Guadeloupe; GNQ = Eq. Guinea; GRC = Greece; GRD = Grenada; GRL = Greenland; GTM = Guatemala; GUF = French Guiana; GUM = Guam; GUY = Guyana; HKG = Hong Kong; HND = Honduras; HRV = Croatia; HTI = Haiti; HUN = Hungary; IDN = Indonesia; IND = India; IRL = Ireland; IRN = Iran; ISL = Iceland; ISR = Israel; ITA = Italy; JAM = Jamaica; JOR = Jordan; JPN = Japan; KAZ = Kazakhstan; KEN = Kenya; KGZ = Kyrgyz Rep.; KHM = Cambodia; KOR = South Korea; KWT = Kuwait; LAO = Laos; LBN = Lebanon; LBY = Libya; LCA = St. Lucia; LKA = Sri Lanka; LSO = Lesotho; LTU = Lithuania; LUX = Luxembourg; LVA = Latvia; MAC = Macao; MAR = Morocco; MDA = Moldova; MDG = Madagascar; MDV = Maldives; MEX = Mexico; MHL = Marshall Isl.; MKD = Macedonia; MLI = Mali; MLT = Malta; MMR = Myanmar; MNG = Mongolia; MOZ = Mozambique; MRT = Mauritania; MTQ = Martinique; MUS = Mauritius; MWI = Malawi; MYS = Malaysia; NAM = Namibia; NCL = N. Caledonia; NIC = Nicaragua; NLD = Netherlands; NOR = Norway; NPL = Nepal; NZL = N. Zealand; OMN = Oman; PAK = Pakistan; PAN = Panama; PER = Peru; PHL = Philippines; POL = Poland; PRI = Puerto Rico; PRT = Portugal; PRY = Paraguay; PYF = French Polynesia; QAT = Qatar; REU = Reunion; ROM = Romania; RUS = Russia; RWA = Rwanda; SAU = Saudi Arabia; SDN = Sudan; SEN = Senegal; SGP = Singapore; SLE = Sierra Leone; SLV = El Salvador; SUR = Suriname; SVK = Slovak Rep.; SVN = Slovenia; SWE = Sweden; SWZ = Swaziland; SYC = Seychelles; SYR = Syria; TCD = Chad; TGO = Togo; THA = Thailand; TJK = Tajikistan; TKM = Turkmenistan; TTO = Trinidad & Tobago; TUN = Tunisia; TUR = Turkey; TWN = Taiwan; TZA = Tanzania; UGA = Uganda; UKR = Ukraine; URY = Uruguay; USA = United States; UZB = Uzbekistan; VEN = Venezuela; VIR = Virgin Isl.; VNM = Vietnam; WBG = W. Bank & Gaza; YUG = Yugoslavia; ZAF = South Africa; ZAR = Congo, Dem. Rep.; ZMB = Zambia; ZWE = Zimbabwe.

The time-series cross-section patterns of the data in Table 6 reflect the years of mobile telephony introductions in Table 2, although the first annual observation of each time series is lost due to log differencing, which also leads to the loss of three developed and thirty three developing countries altogether.[4]

Table 6 Data patterns and their frequencies (i.e., countries with the pattern in question)

Developed countries/regions

Freq.	Yrs.	Obs.	Sh.	1993	1994	1995	1996	1997	1998	1999	2000
14	4	56	19%					1	1	1	1
13	5	65	17%				1	1	1	1	1
12	6	72	16%			1	1	1	1	1	1
12	7	84	16%		1	1	1	1	1	1	1
10	8	80	13%	1	1	1	1	1	1	1	1
7	2	14	9%							1	1
7	3	21	9%						1	1	1
75	2–8	392	100%								

Developing countries/regions

Freq.	Yrs.	Obs.	Sh.	1993	1994	1995	1996	1997	1998	1999	2000
21	4	84	23%					1	1	1	1
20	5	100	22%				1	1	1	1	1
15	1	15	17%								1
13	6	78	14%			1	1	1	1	1	1
10	2	20	11%							1	1
9	3	27	10%						1	1	1
1	4	4	1%				1	1	1	1	
1	7	7	1%		1	1	1	1	1	1	1
90	1–7	335	100%								

Note: Patterns after log-differencing the dependent variable, i.e., the observations usable in the analysis.

4 Observations for the 3 developed and 12 developing countries introducing mobile digital telephony in, and the 21 developing countries that had not done so at all by 2000 are lost.

Estimation

Although the choice of variables in this study has been dictated by data availability, in several occasions missing values are encountered. For one variable (Industrialization), nearly one fourth and for many nearly one fifth (Credit, Trade, Freedom, PCs, and Fixed user cost) of the observations are missing. Three basic alternatives have been employed to solve the problem of missing values: the explanatory variables with missing observations are excluded, the cross-sectional units and/or points in time with missing observations are excluded (case-wise delete), or some method is used to impute the missing values. The first alternative leads to a limited set of explanatory variables, and the second to a loss of i s and/or t s. Strictly speaking the third alternative is not feasible without additional information is cases of non-random missing observations, which is the case here.

In what follows, a fourth alternative is employed. It economizes on the use of available information without arbitrarily imputing missing values. Every time a missing value is encountered, it is replaced by zero. The novelty is, however, that a set of dummy variables is generated indicating when such replacements have been made. While these dummies do not have economic interpretations, they nevertheless control for the biases that would be introduced by an alternative imputation method.

All the regressions below are 'fully robust', i.e., the standard deviations are White (1980) heteroscedasticity consistent and arbitrary dependence of observations across t (autocorrelation) is allowed. Thus, the standard deviations are robust as long as the i s are independently distributed (for discussion see Stata, 2001: section 23.11). Thus, the estimations are consistent in large samples with a relatively weak set of assumptions (see, e.g., Wooldridge, 2002: sections 7.8.1–3).

In Table 7 a reduced model with the completely non-missing explanatory variables (Col. 1) as well as the full model with case-wise deleting the observations with missing values (Col. 2) and with the missing dummies (Col. 3) are estimated. In some ways results in Column 1 are not entirely unsatisfactory: all of the explanatory variables are statistically significant at conventional levels and findings of the previous literature are largely confirmed. The developing dummy is not statistically significant (wrongly) suggesting that the developing countries might not be too different. If the case-wise delete rule is applied (Col. 2), over one third of the observations is lost. Contrary to Columns 1 and 2, the missing dummies approach (Col. 3) suggests, that the developing countries might indeed be different.

Simply introducing the developing country dummy, as done in Table 7, is a rather crude way of capturing the difference between the developed and developing countries. The two leftmost columns of Table 8 allow for the maximum generality in this respect by performing separate regressions for the developed (Col. 1) and developing (Col. 2) countries. Column 3 formally tests, whether the developed and developing countries effects are indeed different by including (a) the unaltered explanatory variables and (b) their interactions with the developing country dummy. A Chow test on the joint significance of the interacted explanatory variables is highly statistically significant, confirming that the developing countries are indeed different.[5]

Table 7 Fully robust OLS estimations of the reduced model (Col. 1) as well as the full model with the case-wise deleted (Col. 2) and full (Col. 3) samples (dependent variable: log difference of mobile telephony users)

		Column 1			Column 2			Column 3		
Variable		Coeff.	Std dev.	Sg.	Coeff.	Std dev.	Sg.	Coeff.	Std dev.	Sg.
Digital, users	α	0.364	(0.048)	***	0.371	(0.036)	***	0.391	(0.050)	***
Constant	$\alpha\beta_0$	-3.138	(0.864)	***	-0.962	(1.698)		-3.000	(1.299)	**
Developing country	$\alpha\beta_1$	-0.030	(0.106)		-0.233	(0.089)	**	-0.151	(0.076)	**
Population, total	$\alpha\beta_2$	0.295	(0.059)	***	0.284	(0.049)	***	0.314	(0.054)	***
Population, city	$\alpha\beta_3$	0.093	(0.043)	**	0.130	(0.048)	***	0.130	(0.042)	***
Income	$\alpha\beta_4$	0.185	(0.064)	***	-0.104	(0.096)		0.021	(0.080)	
Industrialization	$\alpha\beta_5$				0.100	(0.134)		0.209	(0.098)	**
Age-dependency	$\alpha\beta_6$				-0.451	(0.274)		-0.366	(0.209)	*
Credit	$\alpha\beta_7$				0.062	(0.035)	*	0.057	(0.044)	
Trade	$\alpha\beta_8$				0.059	(0.089)		0.153	(0.059)	***
Freedom	$\alpha\beta_9$				-0.022	(0.034)		0.003	(0.031)	
PCs	$\alpha\beta_{10}$				0.130	(0.057)	**	0.022	(0.033)	
Fixed, penetr.	$\alpha\beta_{11}$	0.190	(0.040)	***	0.111	(0.067)		0.138	(0.047)	***
Fixed, user cost	$\alpha\beta_{12}$				0.062	(0.059)		0.047	(0.038)	
Analog, penetr.	$\alpha\beta_{13}$	0.070	(0.034)	**	0.109	(0.039)	***	0.084	(0.033)	**
Digital, prepaid	$\alpha\beta_{14}$	0.225	(0.067)	***	0.123	(0.069)	*	0.271	(0.071)	***
Digital, many	$\alpha\beta_{15}$	-0.181	(0.083)	**	-0.159	(0.075)	**	-0.239	(0.069)	***
Digital, comp.	$\alpha\beta_{16}$	0.166	(0.076)	**	0.373	(0.090)	***	0.192	(0.070)	***
Digital, avail. trend	$\alpha\beta_{17}$	-0.053	(0.024)	**	-0.043	(0.025)	*	-0.047	(0.022)	**
Mobile, user cost	$\alpha\beta_{18}$				0.030	(0.056)		0.008	(0.037)	
Mobile, handset	$\alpha\beta_{19}$				0.208	(0.151)		0.201	(0.103)	*
Year = 1993	$\alpha\beta_{20}$	-0.041	(0.241)		-0.003	(0.387)		-0.109	(0.224)	
Year = 1994	$\alpha\beta_{21}$	-0.195	(0.191)		-0.028	(0.222)		-0.248	(0.187)	
Year = 1995	$\alpha\beta_{22}$	0.036	(0.106)		-0.081	(0.095)		-0.024	(0.094)	
Year = 1997	$\alpha\beta_{23}$	0.139	(0.060)	**	0.161	(0.074)	**	0.137	(0.061)	**
Year = 1998	$\alpha\beta_{24}$	0.214	(0.089)	**	0.231	(0.111)	**	0.198	(0.083)	**
Year = 1999	$\alpha\beta_{25}$	0.436	(0.102)	***	0.374	(0.128)	***	0.409	(0.098)	***
Year = 2000	$\alpha\beta_{26}$	0.655	(0.122)	***	0.686	(0.176)	***	0.632	(0.116)	***
								Missing dummies for Industr.; Age-depend.; Credit; Trade; Freedom; PCs; Fixed, user cost; Mobile, user cost; Mobile, handset.		
Observations			727			398			727	
R-squared			0.55			0.61			0.59	
No. of countries			165			107			165	

Note: ***, ***, and * respectively indicate significance at the 1, 5, and 10% level. Std dev. in parentheses.

5 To be precise, we perform a slightly more general Wald test using the generalized variance-covariance matrix: $F(35, 164) = 2.50$, i.e., Probability > F = 0.0001.

Table 8 Fully robust OLS estimations of the full model with the developed (Col. 1) and developing (Col. 2) country subsamples as well as with the full sample and the developing dummy interactions (Col. 3)

		Column 1			Column 2			Column 3					
		Developed			Developing			(a) Unaltered variables			(b) Developing interact.		
Variable		Coeff.	Std dev.	Sg.	Coeff.	Std dev.	Sg.	Coeff.	Std dev.	Sg.	Coeff.	Std dev.	Sg.
Digital, users	α	0.408	(0.034)	***	0.466	(0.097)	***	0.408	(0.034)	***	0.058	(0.102)	
Constant	$\alpha\beta_0$	-2.704	(1.594)	*	-2.020	(1.802)		-2.704	(1.594)	*			
Developing country	$\alpha\beta_1$										0.683	(2.399)	
Population, total	$\alpha\beta_2$	0.259	(0.053)	***	0.462	(0.098)	***	0.259	(0.053)	***	0.202	(0.110)	*
Population, city	$\alpha\beta_3$	0.182	(0.044)	***	-0.044	(0.055)		0.182	(0.044)	***	-0.226	(0.070)	***
Income	$\alpha\beta_4$	0.116	(0.109)		0.028	(0.105)		0.116	(0.109)		-0.088	(0.151)	
Industrialization	$\alpha\beta_5$	0.282	(0.140)	**	0.192	(0.180)		0.282	(0.140)	**	-0.089	(0.227)	
Age-dependency	$\alpha\beta_6$	-0.491	(0.292)	*	-0.546	(0.316)	*	-0.491	(0.292)	*	-0.054	(0.429)	
Credit	$\alpha\beta_7$	0.113	(0.043)	***	0.046	(0.059)		0.113	(0.043)	***	-0.067	(0.073)	
Trade	$\alpha\beta_8$	0.038	(0.067)		0.164	(0.103)		0.038	(0.067)		0.126	(0.122)	
Freedom	$\alpha\beta_9$	0.056	(0.037)		-0.097	(0.062)		0.056	(0.037)		-0.153	(0.072)	**
PCs	$\alpha\beta_{10}$	-0.113	(0.063)	*	0.102	(0.050)	**	-0.113	(0.064)	*	0.215	(0.081)	***
Fixed, penetr.	$\alpha\beta_{11}$	0.159	(0.104)		0.089	(0.074)		0.159	(0.104)		-0.070	(0.127)	
Fixed, user cost	$\alpha\beta_{12}$	-0.014	(0.073)		0.068	(0.050)		-0.014	(0.073)		0.082	(0.088)	
Analog, penetr.	$\alpha\beta_{13}$	0.082	(0.033)	**	0.590	(0.148)	***	0.082	(0.033)	**	0.507	(0.151)	***
Digital, prepaid	$\alpha\beta_{14}$	0.134	(0.068)	*	0.338	(0.116)	***	0.134	(0.068)	**	0.204	(0.133)	
Digital, many	$\alpha\beta_{15}$	-0.198	(0.093)	**	-0.425	(0.123)	***	-0.198	(0.093)	**	-0.227	(0.154)	
Digital, comp.	$\alpha\beta_{16}$	0.129	(0.087)		0.256	(0.109)	**	0.129	(0.087)		0.127	(0.139)	
Digital, avail. trend	$\alpha\beta_{17}$	-0.014	(0.022)		0.019	(0.039)		-0.014	(0.022)		0.033	(0.045)	
Mobile, user cost	$\alpha\beta_{18}$	0.032	(0.064)		-0.005	(0.061)		0.032	(0.064)		-0.037	(0.088)	
Mobile, handset	$\alpha\beta_{19}$	0.112	(0.164)		0.157	(0.146)		0.112	(0.164)		0.045	(0.219)	
Year = 1993	$\alpha\beta_{20}$	-0.186	(0.237)					-0.186	(0.237)				
Year = 1994	$\alpha\beta_{21}$	-0.353	(0.179)	*	-0.076	(0.202)		-0.353	(0.179)	**	0.277	(0.269)	
Year = 1995	$\alpha\beta_{22}$	-0.089	(0.088)		-0.043	(0.217)		-0.089	(0.088)		0.046	(0.233)	
Year = 1997	$\alpha\beta_{23}$	0.134	(0.070)	*	0.153	(0.099)		0.134	(0.070)	*	0.019	(0.121)	
Year = 1998	$\alpha\beta_{24}$	0.234	(0.097)	**	0.284	(0.164)	*	0.234	(0.097)	**	0.050	(0.189)	
Year = 1999	$\alpha\beta_{25}$	0.482	(0.106)	***	0.444	(0.190)	**	0.482	(0.106)	***	-0.038	(0.217)	
Year = 2000	$\alpha\beta_{26}$	0.634	(0.115)	***	0.701	(0.223)	***	0.634	(0.115)	***	0.067	(0.250)	

Missing dummies for Industr.; Age-depend.; Credit; Trade; Freedom; PCs; Fixed, user cost; Mobile, user cost; Mobile, handset.
(Also the interacted versions of the missing dummies are included in Column 3).

	Column 1	Column 2	Column 3
Observations	392	335	727
R-squared	0.72	0.57	0.65
No. of countries	75	90	165

Note: ***, ***, and * respectively indicate significance at the 1, 5, and 10% level. Std dev. in parentheses.

The leftmost column in Table 8 suggests, that the effects of five socio-economic explanatory variables and three missing dummies (not shown) are statistically significantly different between the developed and developing countries. Table 9 presents the final model, where this information is exploited by estimating separate coefficients for these variables (Sep. / Developed and Sep. / Developing) and joint ones for the others (Joint coeff.).

Table 9 Fully robust OLS estimation of the final model with separate coefficients for the developed and developing countries if applicable (dependent variable: log difference of mobile telephony users)

		Joint coeff.			Sep. / Developed			Sep. / Developing		
Variable		Coeff.	Std dev.	Sg.	Coeff.	Std dev.	Sg.	Coeff.	Std dev.	Sg.
Digital, users	α	0.417	(0.049)	***						
Constant	$\alpha\beta_0$	-2.843	(1.147)	**						
Population, total	$\alpha\beta_2$				0.268	(0.052)	***	0.435	(0.063)	***
Population, city	$\alpha\beta_3$				0.202	(0.041)	***	-0.031	(0.048)	
Income	$\alpha\beta_4$	0.049	(0.075)							
Industrialization	$\alpha\beta_5$	0.191	(0.111)	*						
Age-dependency	$\alpha\beta_6$	-0.377	(0.196)	*						
Credit	$\alpha\beta_7$	0.063	(0.041)							
Trade	$\alpha\beta_8$	0.136	(0.055)	**						
Freedom	$\alpha\beta_9$				0.043	(0.033)		-0.052	(0.049)	
PCs	$\alpha\beta_{10}$				-0.055	(0.054)		0.082	(0.041)	**
Fixed, penetr.	$\alpha\beta_{11}$	0.107	(0.050)	**						
Fixed, user cost	$\alpha\beta_{12}$	0.036	(0.039)							
Analog, penetr.	$\alpha\beta_{13}$				0.079	(0.036)	**	0.464	(0.143)	***
Digital, prepaid	$\alpha\beta_{14}$				0.117	(0.071)	*	0.331	(0.083)	***
Digital, many	$\alpha\beta_{15}$				-0.225	(0.089)	**	-0.406	(0.107)	***
Digital, comp.	$\alpha\beta_{16}$	0.246	(0.068)	***						
Digital, avail. trend	$\alpha\beta_{17}$	-0.016	(0.026)							
Mobile, user cost	$\alpha\beta_{18}$	0.007	(0.041)							
Mobile, handset	$\alpha\beta_{19}$	0.157	(0.100)							
Year = 1993	$\alpha\beta_{20}$	-0.212	(0.212)							
Year = 1994	$\alpha\beta_{21}$	-0.323	(0.180)	*						
Year = 1995	$\alpha\beta_{22}$	-0.063	(0.091)							
Year = 1997	$\alpha\beta_{23}$	0.134	(0.058)	**						
Year = 1998	$\alpha\beta_{24}$	0.244	(0.082)	***						
Year = 1999	$\alpha\beta_{25}$	0.443	(0.095)	***						
Year = 2000	$\alpha\beta_{26}$	0.656	(0.114)	***						

Joint missing dummies: Industr.; Age-depend.; Credit; Trade; Mobile, user cost; Mobile, handset.
Separate missing dummies: Freedom; PCs; Fixed, user cost.

Observations	727
R-squared	0.62
No. of countries	165

Note: ***, ***, and * respectively indicate significance at the 1, 5, and 10% level. Std dev. in parentheses.

The final results suggest that the speed of adjustment (Digital, users) in digital mobile telephony does not differ between the developed and developing countries. The absolute size of the coefficient is slightly lower than the corresponding (cross-sectional) estimates in the Internet study of Kiiski and Pohjola (2002). The market size effect (Population, total) is stronger in the developing countries. The population in the largest city (Population, city), measuring the size of the largest pool of demand that can be captured with relative ease, is only statistically significant in the developed countries.[6]

[6] This may be an indication of the fact that in the developing countries the size of the largest city sometimes rather measures the size of slums that the potential user base.

Interestingly the wealth effect (Income) is not statistically significant after controlling for the other factors, which goes against the findings in the previous literature. Higher degree of industrialization, a lower age-dependency ratio, and openness (Trade) boost diffusion. The sign for the democracy measure (Freedom) is different between the developed and developing countries, but the variable itself is not statistically significant in either case. The overall (non-telecom) technological level seems to boost diffusion only in the developing country case. The positive signs for the fixed and analog mobile penetration rates indicate that network effects are present at the country level. Analog mobile penetration is a much more important factor in the developing country case. The may be an indication of two additional factors, i.e., the general economic potential for as well as the cultural and social acceptability of mobile telephony. The availability of prepaid mobile calling options is understandably more important in the developing countries, as the payment systems needed for per subscription services are likely to be less sophisticated. Having multiple standards in digital mobile telephony is more detrimental to diffusion in the developing countries, i.e., the unavoidable duplication of digital mobile telephony infrastructure and market uncertainty caused by the standards competition is more costly in terms of diffusion in the developing countries. According to our results, competition promotes diffusion in the developed and developing countries alike, which goes against the findings of Mureithi (2003). The raising and (mostly) statistically significant coefficients of the time dummies are interpreted as an indication of worldwide network effects and economies of scale. With globally expanding user base, the quality-adjusted[7] real prices of both digital mobile telephony network equipment and handsets have dropped constantly, and simultaneously uncertainties with respect to standards and dominant designs have reduced. Indeed, late entrants will experience more rapid diffusion once other things have been accounted for.

Conclusions

Yes – developing countries are different when it comes to the diffusion of digital mobile telephony, but not in the most obvious ways. The speed of adjustment is not too different from its developed world counterpart, and the wealth effect does not explain diffusion patterns but rather factors that it drives. The developing countries benefit from being late entrants in digital mobile telephony, as the developed countries have carried the burdens of accumulating global critical mass and resolving uncertainties related to standards and dominant designs. This is not to say that the developing countries would not be in a disadvantageous position: their typical penetration rates are lower and relative user costs (per average income) higher by the order of ten. It is, however, to say that the recent discussion on the digital divide and its widening may be somewhat misleading. In fact, digital technologies and their diffusion patterns rather promote cross-country convergence and, as compared to previous analog technologies, are exceptionally democratic in the sense that they are generally available and applicable worldwide shortly after their discoveries. Thus, these technologies are rather equalizers, and the divide is in fact socio-economic or analog rather than digital – observed differences in the diffusion of digital technologies are thus merely reflections of the analog divide.

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[7] Availability may in this context be considered one aspect of quality.

As far as the other differences are concerned, it seems quite natural that in a developing country case having a large potential user base is more important, as the average revenue per user is likely to be lower. Network effects play a more important role in the developing countries, not least because infrastructure and logistics are, at least in relative terms, more expensive to build and maintain. Technological and market uncertainties have more detrimental effects on diffusion in the developing world. There is also more need for complementing (non-technical) innovations in the developing countries, e.g., in relation to (micro)finance and payment systems.

Up until now market developments in digital technologies have been driven by the needs of the developed world. Two factors are, however, slowly but surely changing this. First, as most developed markets are approaching their full penetration levels, equipment and service providers are increasingly focusing on the developing markets and adjusting their offerings accordingly. In digital mobile telephony some leading manufacturers have already introduced new network infrastructure equipment and accompanying handsets that enable profitable mobile telephony operation with less than one fifth of the previously necessarily average user revenue. With a few complementing financial and/or social innovations, e.g., *á la* GrameenPhone, new business models are altogether viable. Second, as the user bases in the developing countries expand, endogenous supplies of locally adapted and/or developed technical and non-technical innovations will emerge.

Various digital technologies are rapidly converging to a world where all voice and data communications are based on Internet protocols (IP) – technically quite similar content and delivery is merely being tailored for various channels and end-user needs. In the all-IP world digital mobile telephony, with its two- to threefold user base in a given developing country, might be a more potential way in attempting to catch up and even leapfrog the developed countries than the current PC-centric Internet world.

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