Diffusion of innovation in mobile communications

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Abstract

This study addresses the impact of technological innovations within the mobile telecommunications sector, using a worldwide dataset to identify factors that affect the diffusion of different generations of mobile telecommunications technologies. For third generation technology, urbanization, per capita income, broadband penetration and regulation acted as positive location parameters fostering the adoption process. Inter-firm competition has been found to be the key determinant of diffusion speed across all generations. Concerning second generation networks, urbanization and per capita income had a positive effect as location parameters and inter-firm competition positively affected diffusion speed. Second-generation markets tilted towards a single technology were faster growing than multi-technology ones. First-generation diffusion speed acted as a boost to the adoption process of second-generation networks whereas second-generation markets were unaffected by third generation. However, third generation technologies were negatively affected by diffusion of second generation.

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1. Introduction

Mobile telecommunications based on cellular wireless technology has been a major innovation whose adoption started some thirty years ago and has since then transformed the telecommunications sector causing a very strong effect on the economy (Roeller and Waverman, 2001). As a matter of fact, across the world the number of mobile subscribers has outpaced the number of fixed lines and revenues from mobile telecommunications in many countries exceed the fixed line revenues, accounting for more than 1% of GDP (OECD, 2007). In several cases the number of mobile subscribers already exceeds the actual population. The mobile revolution started out in the US and in Europe, but expanded to the rest of the world seriously affecting the progress of many developing countries (Waverman et al. 2005). In particular, empirical investigations have found large welfare effects from the introduction of mobile telecommunications (Hausmann, 1997). The main drivers for the adoption of mobile telecommunications have been technological progress that has allowed for relentless cost reduction and performance increase of equipment and regulatory reform that has opened up the telecommunications sector for competition among firms (Gruber, 2005a). This has been confirmed by a number of empirical studies that have investigated the determinants of the diffusion of mobile telecommunications (Gruber and Verboven 2001).

The objective of this paper is to drill deeper into the diffusion process, taking into account the fact that mobile technologies are introduced by technology generations. As in other extensively studied industries where technological progress unfolds through the introduction of new generations of products such as semiconductor memory chips (Gruber,1995), the overall success of the industry depends on the relentless striving for better performance and lower prices per unit of performance. With mobile telecommunications this move across generations is complicated by the fact that network technologies often face backwards compatibility issues, especially intensified by the underlying legacy infrastructure. Moreover, scarce spectrum availability constrains the technology options for firms. The novelty of this study is that it unravels the determinants of innovation moves from one generation of technology to the next in order to shed more light on issues of market design. The emphasis is thus on the second and third generation of mobile telecommunications. The entry pattern for the third generation was completely different with respect to previous technology generations. In many countries, market structure design licensing followed a sort of n+1 rule, with n being the number of second generation firms. This had the purpose of creating more competition but ultimately led to a greater number of licensees that did not provide services, a feature that was not observed for second generation. In any case, third generation turned out to be less successful in the market than expected.

The paper is arranged as follows. Section 2 sketches some stylised facts from the evolution of the market for mobile telecommunications services. Section 3 describes the theoretical model and its econometric specification. Sections 4 presents the results and discusses them. Section 5 concludes and draws lines for further research.

2. The evolution of the market for mobile telecommunications services

The mobile telecommunications industry as it is known today, i.e. using radio waves instead of wires to connect users, is a relatively young industry. Although the basic concepts of wireless interaction were developed during the late 19th century and some relatively poorly performing mobile telecommunications systems were built after World War II, it took until the 1970s that the progress in semiconductor technology allowed the construction of the first cellular mobile networks for commercial use at the beginning of the 1980s. Since then, mobile telecommunications have been a continuous growth story. In 2002 the number of mobile telecommunications users exceeded the number of fixed lines which then were at a stagnating level of 1.1 billion lines. In other words, the mobile telecommunications industry has acquired as many users in about 20 years worldwide for which the fixed line telecommunications industry took more than 120 years. As shown in Gruber (2005a), this extraordinary growth story has been due to mainly two factors: technological progress and regulation. Both are briefly discussed in the following.

Technology

From a technological point of view, mobile telecommunications technologies are introduced by generations, with the distinguishing feature of significantly improved service capability from one generation to the next. First generation (analogue) mobile telecommunication technology was introduced in the early 1980s for voice services. There was a relatively large number of different first generation systems (based on seven mutually incompatible national standards) installed globally. This competition of standards hampered the drive to cost reduction in equipment and also the development of services such as international roaming. Second generation (digital) mobile telecommunication technology was introduced during the first half of the 1990s. The capability to provide voice services was improved and new data services could be developed. This time the technology introduction was much better coordinated, especially in Europe with the setting of the GSM standard, and the number of different systems installed worldwide was reduced to four. GSM was the first to be introduced in a large number of countries and since then it has remained the by far most widespread system both in terms of adopting countries and subscribers. In 1997, of the 40 million digital subscribers worldwide, more than 80 per cent were GSM subscribers (ITU, 1999). There is empirical support standardisation accelerating diffusion (Gruber and Verboven, 2001; Koski and Kretschmer, 2005).

Whereas the first and second generation of mobile telecommunications systems were mainly designed for voice transmission, the next technological step was the development of systems for data transmission. Third generation (3G) systems were thus designed to significantly increase data transmission rates to allow for services such as multimedia applications. Here three different systems were installed on a world-wide basis, but again the W-CDMA system, which was the technological evolution from GSM, turned out to be the most successful in terms of worldwide diffusion. At the end of 2008 71% of third generation subscribers used W-CDMA[2]. However, the overall performance of the 3G market was disappointing under most aspects: services started late and there was generally much less demand for them than originally expected. Hence the speed of diffusion of third generation subscribers was much slower (Gruber, 2007).

Regulation

[2] See http://www.gsacom.com.

Mobile telecommunications uses radio frequencies as an essential input for operation. However, the spectrum of suitable radio frequencies is limited and contended by alternative uses, such as broadcasting or military applications. Thus, the frequencies allocated for mobile telecommunications have a scarcity value and provide their owners with rents. By fixing the number of licenses, authorities that assign licenses have ample discretion in designing the market structure for mobile telecommunications services. With first generation networks, the allocation of licenses were in most countries in favour of the incumbent fixed line operator, either as a mobile telecommunications monopoly or one of the duopoly firms. With second generation there was a typical sequential licensing process, where the incumbent (analogue) mobile telecommunications monopoly or duopoly firms were given a license plus there was a beauty contest for additional license(s). Gruber and Verboven (2001) have shown that additional licenses increase the speed of diffusion and sequential licensing has a stronger effect on diffusion than simultaneous licensing. The license allocation methods for the 3G market was different from previous technology generations. For the 3G the design of the market structure typically (i.e. in Europe) entailed simultaneous entry of a relatively large number of firms (four to six). The *n*+1 rule of thumb (with *n* being the number of incumbent 2G firms) was frequently applied for determining the number of 3G licences. This rule of thumb had a twofold purpose: to create more competition at the pre-entry as well as at the post-entry stage. At the pre-entry stage, new entry would be encouraged to join the competition for the market; at the post-entry stage, new entry should increase competition in the market. In this game the incumbents were presumed to have a strategic advantage. Without increasing the number of licences, pre-entry competition for a licence would have been weak. Thus the additional licence would have given the new entrants incentives to bid for a licence. For the post-entry stage it was expected that additional entry would increase competition, leading to lower prices and better service.

Looking at the European experience one could observe a general trend towards delaying the build-out of networks and the supply of 3G services (Gruber, 2007). There were a number of technical difficulties with the new technology and the market suffered from non-availability of equipment, in particular handsets. Thus increasing scepticism arouse about the overall market potential of 3G services. 3G was thought to be a continuation of high market growth trends observed with 2G. But it became clear that the growth of data services, the main reason for adopting 3G technology, was far behind expectations and this is would take much more time to develop in the market place. Therefore several firms that did receive a license decided to postpone the building of the network infrastructure or decided even to hand back the license to the regulator, foregoing the license fee paid. With the justification of reducing costs, several firms shared networks with their competitors. The European Commission (2001) expressed concerns about network sharing, as this laid the ground for potential collusion. In fact there tended to be less firms in 3G services than in 2G services.

When a firm is assigned spectrum for 3G services this fact does not necessarily mean that it will actually provide these services. Gruber (2007) has shown that in Europe the number of firms that have introduced 3G services is much smaller than the number of firms that actually received a license. This effect was much more pronounced in countries that have opted for auctions in assigning the licenses. This has an important implication for the actual market structure in the mobile market, as it may significantly differ from what has been designed at the outset. In Europe one could also observe an escalation of license fees paid in auctions, while most of these licensees did not lead to 3G services afterwards. Gruber (2007) thus argued that high license fees coupled with a higher number of idle licenses would be consistent with the strategic “overbidding” hypothesis, i.e. license fees were higher than ultimately compatible with the originally envisaged market structure, forcing thereby a process of increased concentration (Gruber, 2005b). In countries that used auctions a more concentrated 3G market structure emerged than was the case with 2G. The n+1 rule for the design of market structure particularly in countries with auctions appears to be inappropriate.

With respect to introduction timing, 3G services were generally introduced with a considerable delay relatively to the initial expectations. A factor that accelerates the introduction of services is the number of firms. This is consistent with the hypothesis that increasing the number of firms leads to faster innovation, a hypothesis that has also been confirmed in previous studies with earlier generations of mobile telecommunications technologies (e.g. Gruber and Verboven, 2001). However idle licenses appear to delay the introduction time of first services (Gruber, 2007). Overall, there is no conclusive evidence that with auctions innovation should occur quicker than with other methods, nor do license fees have any significant impact on introduction timing. The implication of this therefore is that neither of the adopted spectrum assignment mechanisms appears to be superior. What however seems to matter crucially is the design of market structure, i.e. finding the maximum number of firms that the market can support, without having unused licenses.

This discussion on introduction timing leads also to the welfare impact of mobile telecommunications technologies. Hausmann (1997) estimated the annual cost in terms of foregone consumer surplus as a result of delayed introduction of first generation mobile services in the US in the range of 25-50 billion US dollars. This reveals that mobile telecommunications has important impacts in the economy. Considering the subsequent market growth and success of second generation services one can assume that the value in terms of consumer surplus was a lower bound to estimates of the value of mobile telecommunications services. Moreover, overall economic welfare has increased as the excess profits from market power have declined. During the first generation and also at least during a large part of the second generation technology firms in the mobile telecommunications market were enjoying profits that were considerably above what would be considered as normal. Gruber (2005b) compared the profitability of selected European mobile telecommunications firms in 1997, a period of high growth in the mobile telecommunications market, and in 2001, the year when most 3G licences were auctioned. It shows that in 1997 many firms enjoyed a profitability in terms of returns on capital employed that is was several multiples of typical industry average. This profitability however declined rapidly in the following years, mainly as a result of enhanced competition in the market. Much of the oligopoly rents therefore have dissipated in the market through increased competition and larger regulatory pressure, such as reduction of termination payments. Indeed interconnection rates may have been used in the industry as a instrument for collusion (Armstrong, 1998) and it has been shown that the regulated decline of termination rates has led to a significant reduction of profit margins as firms had less scope to increase prices on competitive services (Genakos and Valletti, 2008).

3. The econometric model

Like all innovations, mobile telecommunications in general and new services provided on mobile platforms are not immediately adopted by all potential subscribers. The adoption decision takes time. Various alternative diffusion models have been used to describe such an adoption process by users. Out of these, the "epidemic" approach resulted to be particularly popular, as it fits remarkably well the diffusion path of many innovations. The adoption of innovation by the different agents is modelled in a similar way as diseases spread in biology. Griliches (1957) pioneered this approach in agriculture in the study of the diffusion of hybrid corn. The model adopted in this paper is an appropriately modified version of Gruber and Verboven (2001), which used it to estimate the diffusion of mobile telecommunications in general. However, in many countries the number of mobile subscription exceeds the population number, often to a considerable degree[3] indicating a tendency towards saturation in terms of primary diffusion. In such a market context it becomes more appropriate to study the innovations within mobile communications through the study of the diffusion of generations of mobile technologies.

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[3] For instance, at the end of 2007 Italy had a mobile penetration rate of 148.1% and Spain 121.8% (Informa Group)

Let y_{ijt} denote the number of agents that have adopted the new generation of mobile telecommunications i in country j at time t; let y^*_{jt} denote the total number of mobile telecommunications users in country j at time t. The fraction of the total number of adopters of technology generation i in country j that have adopted before time t is specified by the logistic distribution function:

$$\frac{y_{ijt}}{y^*_{jt}} = \frac{1}{1 + \exp(-a_{jt} - b_{jt} t)}. \quad (1)$$

The variable a_{jt} in (1) is a location or “timing” variable. It shifts the diffusion function forwards or backwards, without affecting the shape of the function otherwise. For example, when a_{jt} is very high, we may say that country j at time t is very “advanced” in its adoption rate. The variable b_{jt} is a measure of the diffusion growth as it equals the growth rate in the number of adopters at time t, relative to the fraction of adopters that have not yet adopted at time t. Equivalently, this says that the number of new adopters at time t, relative to the fraction of adopters that have not yet adopted at time t, is a linear function of the total number of consumers that have already adopted at time t. This reflects the epidemic character of the logistic diffusion model.

In our econometric analysis we transform equation (1) as follows:

$$\log\left(\frac{y_{ijt}}{y^*_{jt} - y_{ijt}}\right) \equiv z_{ijt} = a_{jt} + b_{jt} t \,. \quad (2)$$

The dependent variable, z_{ijt}, is the logarithm of total number of adopters relative to the number of potential adopters that have not yet adopted. Equation (2) shows that this measure for the level of adoption evolves linearly through time. Two essential elements determine the diffusion of new generations of mobile telecommunication services: the location variable, a_{jt}; and the growth variable b_{jt}. which can be specified in a general form as follows:

$$a_{jt} = \alpha_j^0 + x_{jt}\alpha \qquad (3)$$

$$b_{jt} = \beta_j^0 + x_{jt}\beta \, . \qquad (4)$$

The parameters α_j^0 and β_j^0 are country-specific location and growth effects. The vector x_{it} includes continuous variables affecting the location or growth variables, e.g. per capita income.

Substituting into the transformed diffusion equation (2), the following obtains, which also becomes the econometric reference model of the diffusion process.:

$$z_{ijt} = \alpha_j^0 + x_{jt}\alpha + \left(\beta_j^0 + x_{ijt}\beta\right)t \, . \qquad (5)$$

Description of data and variables

Concentration index of inter-firm competition:

$HH_{inter} = \sum_{i=1}^{m}\left(\frac{C_i}{TC}\right)^2$, with C_i being the number of mobile subscriber of firm i and TC the total of mobile connections. It is the sum of the squared market shares of each firm, that is a classic of Herfindahl index computed over the market shares. This index has the range of $\frac{1}{m}$ < HH_{inter} < 1, where m is the total number of different firms in the market. The higher the value the more the market is tilted towards monopoly.

Concentration index of inter-generation competition:

$HH_{generation} = \sum_{i=1}^{3} \left(\frac{G_i}{TC} \right)^2$, with G_i being the number of mobile subscribers of generation i and TC the total of mobile connections. It is the sum of the squared market shares of each generation, that is a variant of Herfindahl index computed over the different generation shares. This index has the range of $\frac{1}{3}$ < $HH_{generation}$ < 1. The higher the value the more the market is tilted towards a single generation.

Concentration index of inter-technology competition:

$HH_{technology} = \sum_{i=1}^{7} \left(\frac{T_i}{TC} \right)^2$, with T_i being the number of mobile ubscribers in each network technology (analogue, GSM, CDMA, iDEN, PDC, USTDMA, WCDMA). It is the sum of the squared technology shares of each platform, that is a sort of Herfindahl index computed over the technology shares. This index has the range of $\frac{1}{7}$ < $HH_{generation}$ <1. The higher the value the more the market is tilted toward one network technology.

Regulation Score:

We use a regulation measure to estimate the importance of a sound institutional setting in third generation adoption. Koutroumpis and Waverman (2009) presented this measure of regulatory governance as Telecommunications Regulatory Governance Index (TRGI hereafter). The index used controls for regulatory transparency, independence of the agency from government control, resource availability, enforcement on licensees and market conditions in each country of the sample. Countries without a regulator received a zero score. The index is used as a proxy of telecommunications regulation in the period.

First / Second / Third Generation Network Diffusion speed:

This is a measure of new lines added in each network generation every year compared to total lines in the market. The variable is produced by the formulas:

$$Diff\_Speed_{First} = \frac{FirstGen_t - FirstGen_{t-1}}{TotalLines_t}$$

$$Diff\_Speed_{Second} = \frac{SecondGen_t - SecondGen_{t-1}}{TotalLines_t}$$

$$Diff\_Speed_{Third} = \frac{ThirdGen_t - ThirdGen_{t-1}}{TotalLines_t}$$

and shows the rate of adoption of each generation. It essentially provides a qualitative proxy (it has a range of -1 < *Diff. Speed* < 1) for the dynamics of adoption.

The following table (1) presents the countries of the sample. While we used a global dataset only 62 out of 192 countries were used in the 3G regressions. The criterion for this was the existence of at least one 3G connection in each country for the period 2003 – 2007. Table (2) presents some descriptive statistics of the explanatory variables.

4. Empirical results and discussion

The focus of the econometric analysis was twofold. We first tried to identify the location and speed parameters that critically affected the diffusion process of third generation networks in a global scale. For this we introduced variables to measure competition, individual wealth, urbanisation and regulation. While the determinants for second-generation network adoption have been studied extensively the simultaneous impact of the on-going adoption of substitute generations has never been the focus of a study. In our study we also compare the one-way impact of first generation adoption speed on the first years of 2G adoption.

Turning to the specifications we introduce two different models for third-generation and two models for second-generation networks. The former use inter-generation or inter-technology indexes (due to the high degree of correlation between the two metrics we never used them together in a regression) and differ in the inclusion of second-generation diffusion speed. The latter are essentially the same models but they represent the first (1990-2001) and the second (2001-2007) stages of 2G adoption. The reason for this separation is the co-existence of 1G and 2G in the first part and 2G and 3G in the second part. Therefore the otherwise identical models include a measure of diffusion speeds of the relevant co-existing network generation.

Starting from the third generation models for each specification we present the Random Effects (RE), Fixed Effects (FE) and Fixed Effects with robust standard errors (FE Robust) estimators as shown in Table (3). Given the heterogeneity of our sample we base our discussion mostly on the results from the last column of the Table (3) (FE Robust) because of the country and time fixed effects and the robust standard errors. From the resulting coefficients we find that urbanisation is positive and significant providing a location parameter that boosted third generation adoption. Moreover broadband penetration and GDPC are found to be positive and significant across all specifications representing two important country level diffusion parameters. In particular the higher the use of Internet and the wealthier the people in a country the more likely it is that they will adopt third generation services. Regulation is also found to be positive and significant providing a healthy institutional framework that fosters third-generation adoption. In terms of the speed parameters the higher level of competition across firms is found to be negative and significant. For the HHI index the smaller value represents higher competition whereas monopoly is given by the maximum value (equal to 1). Therefore competition boosted the adoption of third generation. The inter-generation competition is marginally insignificant.

Some further tests are carried out to check the robustness of the results in Table (4). Full rank conditions and strict exogeneity of the covariates ensure the asymptotic normality of the FE estimator. However the existence of serial dependence of the fixed effects residuals and the non-uniform variance in the idiosyncratic errors (due to the presence of heteroskedasticity) forced us to run a fully robust variance matrix estimator (FE Robust). Provided that the number of periods (T) is small relatively to n (6 compared to 62 in our case) such an estimator is valid in the presence of any heteroskedasticity or serial correlation. In case the assumption of strict exogeneity of the covariates drops –because of the introduction of the Herfindahl indexes - we would have to use a transformation to remove the unobserved individual effects and then search for instruments for the endogenous repressors. While the FE transformation requires strictly exogenous instruments the use of the first difference (FD) transformation allowed us to remove the unobserved individual effects. The instruments employed were the lagged values (two periods back) of the endogenous covariates and are presented in the first column of Table (4). The resulting coefficients show that the previous estimates remain unchanged in terms of signs and statistical significance. In our effort to test a dynamic specification of our model we included a lag of the dependent variable among the regressors. The results are presented in the second column of Table (4). The lagged dependent is found to be positive and significant indicating positive indirect externalities arising from the diffusion process of 3G. The more people adopt the technology the higher the value for each individual that participates to it. The dynamic estimation with the lagged dependent causes endogeneity in the model and prevents us from using the static model methodologies. Thus we follow the Arellano-Bond (1991) estimation procedure introducing lagged values of the dependent and the other endogenous covariates as instruments in the GMM procedure. This allows us to exploit the maximum information in each period in order to improve the efficiency of the estimator. The resulting coefficients remain unchanged compared to the previous estimates. The Sargan test does not reject the over-identification hypothesis confirming the validity of our instruments and the AR(1) and AR(2) tests state that there exists first order serial correlation (because of the use of first-differenced errors) but no serial dependence of higher order. The same process of robustness checks has been used across all models.

Turning to the next model for third-generation adoption we now used the Herfindahl index for inter-technology competition instead of the inter-generation index used before and also introduce a measure of second-generation diffusion speed. The focus of this model compared to the previous one was to check whether the existence of different technologies affected third-generation networks, primarily to assess the impact of second-generation dynamics within the 3G setting. The results for this model are reported in Table (5). Again we focus on the FE robust estimates in the third column of this table. The results for the common variables of the two models are almost identical. GDPC, broadband penetration, urbanisation and regulation all are positive and significant (at the 1% level). However the second-generation diffusion speed is negative and marginally significant relatively to 3G across all specifications. This result implies not only that the co-existence of second and third generation did not boost 3G adoption or even was insignificant but that there was competition for subscribers from the third generation point of view. In particular this result would suggest that the second-generation was 'eating-out' subscribers from the 3G while we do not know if this was the case for the reverse relationship. This question will be addressed in the next models. In terms of the speed coefficients the existence of competition also affects positively the adoption of 3G and was found to be negative and significant across all specifications. The competition among technologies is negative and significant – a result that drops to insignificant when we apply more rigid robustness checks.

We now turn to the second-generation models. The first model is similar to the last 3G model used – we only replaced broadband penetration with Internet penetration because the sample included observations from 1990 to 2001. We also replaced second generation with first generation diffusion speed. The results are presented in Table (7). Again urbanisation, Internet penetration, GDPC and regulation are positive and significant. From these only GDPC and urbanisation remain significant when we apply tougher robustness controls. The first generation diffusion speed is positive and significant across all specifications. Contrary to the previous model this would suggest that there was little or no competition among first and second-generation subscribers. 2G networks appear to be positively affected by the diffusion of first generation implying the migration of subscribers from one generation to the other rather than fight over the same customer base. This result was also obtained when we applied the FD and dynamic panel robustness checks. In terms of the speed coefficients we found that competition has always been a key enabler of second-generation adoption. The same does not stand if the market was tilted towards one or more technologies. All result are presented in Tables (7) and (8).

In the last diffusion model we regressed second-generation adoption for the countries that experienced co-existence of 2G and 3G for the period (2001 -2007). The model used the same variables as before but we now replaced the first generation diffusion speed with third generation diffusion speed. The results are presented in Tables (9) and (10). Urbanisation, GDPC and Internet penetration are positive and significant across all specifications. Regulation does not seem to affect the diffusion process of 2G for this subset of countries. The third generation diffusion speed is always insignificant relatively to the second-generation adoption. This means that even though the second generation co-existed in a market with a technologically superior alternative its diffusion was not affected by this phenomenon. There might be more than one explanations about this. Perhaps some second-generation (contracts or pre-paid) subscribers remain uninterested by the existence of a superior technology. Its features might not be useful for a large base of 2G subscribers or the increased price for the additional services might not fulfil the expectations of the traditional voice clients. In any case the contradiction is obvious. While first generation diffusion speed helped the diffusion of second generation the same does not hold for second and third generation respectively. To the contrary third generation is hurt by the co-existence with second generation while the latter remains unaffected. The competition coefficient is again negative and significant across all specifications. Finally the technology coefficient changes from negative and significant to positive and significant when we apply tougher robustness controls. This means that the markets that were tilted towards one technology rather than more, experienced higher diffusion rates for second generation networks.

5. Conclusions

This paper has investigated the determinants of mobile diffusion of different generation of mobile telecommunications technologies in a dataset consisting of 192 countries for the period 1990-2007. Particular emphasis was placed on competition among firms and network technologies. For third-generation networks we found evidence that urbanization, GDPC, broadband penetration and regulation acted as positive location parameters fostering the adoption process. Inter-firm competition has been found to be the key determinant of diffusion speed across all generations. Concerning second-generation networks we found that urbanization and GDPC also acted as positive adoption parameters with inter-firm competition critically affecting the process. Second-generation markets tilted towards a single technology were faster growing than multi-technology ones. In this study we also attempted to measure inter-generation competition and particularly the effect of different generations' diffusion speeds in co-existing markets. For the early 1990's first-generation diffusion speed acted as a boost to the adoption process of second-generation networks. Since the start of third generation services in 2001, third-generation adoption suffered because of the continuing growth of 2G leading suggesting the hypothesis that these network technologies were competing for a common customer base. Nevertheless, during the same period, second-generation markets were found to be unaffected by the co-existence with the 3G counterparts. These results combined suggest that while second-generation technologies retained a high rate of diffusion, third generation technologies had to absorb part of the existing 2G subscribers and at the same time were not able to extend the scope of the market by attracting new subscribes. This may be partly to the fact the mobile penetration was much higher in the around 2000 than in the early 1990's, leading in several countries to saturation points. But it also suggests that second-generation subscribers were composed or two – not necessarily equal parts: voice service and information service subscribers. The former needed just the voice service provided by second generation and thus did not actually need to migrate to third generation services. Only the latter part demanded substitute services provided both by 2G (WAP) and 3G (WCDMA). This led to market segmentation of subscribers where not all subscribers demanded the most advanced technology. This sheds some interesting light into the scope for product differentiation strategies open to mobile firms. The dynamics on the supply side are an interesting area for further research.

Some of the limitations of this study are caused by the macro-economic nature of the statistics. For example GDPC is an income proxy but not the actual income of the mobile subscribers and urbanization is a demographic measure but not necessarily the way the subscribers are geographically dispersed. Therefore this study acts as a starting point for future research – perhaps with a region-specific focus – that control for these issues and could possibly lead to an update of the assessment of the welfare effects of the diffusion of mobile telecommunication services.

Table 1. Countries in the sample

Angola	Greece	Paraguay
Argentina	Hong Kong, China	Philippines
Australia	Hungary	Poland
Austria	Iceland	Portugal
Bahrain	Ireland	Romania
Belgium	Israel	Saudi Arabia
Brunei Darussalam	Italy	Seychelles
Bulgaria	Korea, Republic	Singapore
Canada	Latvia	Slovak Republic
Chile	Lithuania	Slovenia
Croatia	Luxembourg	South Africa
Cyprus	Malaysia	Spain
Czech Republic	Malta	Sri Lanka
Denmark	Mauritius	Sweden
Ecuador	Morocco	Switzerland
Egypt, Arab Rep	Namibia	Tanzania
Estonia	Nepal	United Arab Emirates
Finland	Netherlands	United Kingdom
France	New Zealand	United States
Georgia	Norway	Uruguay
Germany	Oman	

Table 2 Descriptive statistics

	Obs.	Mean	Std. Dev	Min	Max
Urban	320	69.36	18.90	14.84	100
GDPC	307	6164.43	12420.35	230.287	54,482
Broadband Penetration	296	9.01	9.15	0	36.21
Regulation	320	0.52	0.19	0	0.81
Mobile Penetration	320	0.75	0.32	0	1.59
HHI Competition	320	0.46	0.19	0.131	1
HHI Generation	320	0.93	0.10	0.551	1
Second Generation Diffusion Speed	320	0.151	0.140	-0.175	0.763
Third Generation Diffusion Speed	320	0.020	0.038	0	0.263
HHI Technology	320	0.858	0.193	0.28	1

	Obs.	Mean	Std. Dev	Min	Max
Urban	3186	53.41	23.94	5.4	100
GDPC	2988	258,483	12420.35	100.486	54,482
Internet Penetration	2587	9.53	16.29	0	95.26
Regulation	2412	0.27	0.28	0	0.81
HHI Competition	3186	0.74	0.28	0.064	1
HHI Generation	3186	0.94	0.13	0.500	1
HHI Technology	3186	0.90	0.18	0.247	1
Second Generation Diffusion Speed	2529	0.151	0.140	-0.175	1
First Generation Diffusion Speed	2529	0.020	0.038	0	1

Table 3. Results for 3G

3G	RE	FE	FE Robust
Location Variables			
Urban	-0.111	2.163	2.163
	(-3.12***)	(4.71***)	(5.03***)
Regulation	-0.145	14.005	14.005
	(-0.06)	(1.90*)	(30.41***)
GDPC	1.534	29.563	29.562
	(2.62***)	(7.74***)	(7.52***)
Broadband Penetration	0.388	0.282	0.282
	(7.18***)	(4.55***)	(3.28***)
Diffusion Variables			
HHI Competition	-0.002	-0.006	-0.006
	(-1.32)	(-3.24***)	(-2.60***)
HHI Generation	-0.005	-0.003	-0.003
	(-3.23***)	(-1.86*)	(-1.40)
Constant	-7.610	-428.754	-428.754
	(-1.53)	(-10.66***)	(-9.52***)
R^2	0.46	0.67	0.67
F-test/ Wald	192.15	74.97	36836
Obs (Groups)	286(62)	286(62)	286(62)

*** Statistical significance at the 1% level

** Statistical significance at the 5% level

* Statistical significance at the 10% level

Table 3. Results for 3G

3G	FD Instrumental Variable Estimator	Dynamic Panel
Location Variables		
L1	-	0.616 (5.72***)
Urban	1.995 (2.16**)	0.867 (2.13**)
Regulation	15.266 (1.94**)	9.814 (1.73*)
GDPC	13.637 (1.68*)	9.987 (2.30**)
Broadband Penetration	0.532 (4.35***)	0.237 (3.27***)
Diffusion Variables		
HHI Competition	-0.019 (-1.87*)	-0.006 (-2.60***)
HHI Generation	0.005 (1.56)	0.004 (2.19**)
R^2	0.50	
F-test/ Wald	101.31	627.86
Sargan Test		78.57
Arellano-Bond test AR(1)		-5.473***
Arellano-Bond test AR(2)		-1.225
Obs. (Groups)	220(62)	220(62)

Table 5. Results for 3G with 2G speed

3G with 2G speed	RE	FE	FE Robust
Location Variables			
Urban	-0.106	1.646	1.646
	(-3.39***)	(3.50***)	(2.69***)
Regulation	0.334	14.849	14.849
	(0.16)	(1.90*)	(20.79***)
GDPC	0.398	24.433	24.433
	(0.65)	(6.40***)	(4.16***)
Second Generation	-14.916	-6.437	-6.437
Diffusion speed	(-4.37***)	(-1.94*)	(-1.83*)
Broadband Penetration	0.141	0.202	0.202
	(5.42***)	(5.49***)	(3.90***)
Diffusion Variables			
HHI Competition	-0.001	-0.005	-0.005
	(-1.20)	(-2.65**)	(-2.08**)
HHI Technology	-0.002	-0.002	-0.002
	(-1.59)	(-1.80*)	(-1.88*)
Constant	-4.375	-346.791	-346.791
	(-0.96)	(-9.08***)	(-4.55***)
R^2	0.44	0.64	0.64
F-test/ Wald	175.10	74.97	56296.87
Obs (Groups)	296(62)	296(62)	296(62)

*** Statistical significance at the 1% level

** Statistical significance at the 5% level

* Statistical significance at the 10% level

Table 6. Results for 3G with 2G speed

3G with 2G speed	FD Instrumental Variable Estimator	Dynamic Panel
Location Variables		
L1	-	0.515
		(5.37***)
Urban	1.673	0.843
	(1.78*)	(2.16**)
Regulation	15.519	10.424
	(1.95**)	(1.91*)
GDPC	12.967	11.865
	(1.58)	(2.98***)
Second Generation Diffusion speed	-7.331	-3.866
	(-1.86*)	(-1.29)
Broadband Penetration	0.497	0.251
	(4.25***)	(3.72***)
Diffusion Variables		
HHI Competition	-0.021	-0.008
	(-2.04**)	(-3.66***)
HHI Technology	0.006	0.004
	(1.97)	(2.86**)
R^2	0.50	
F-test/ Wald	102.75	660.01
Sargan Test		88.84
Arellano-Bond test AR(1)		-5.483***
Arellano-Bond test AR(2)		-1.346
Obs. (Groups)	282(62)	282(62)

Table 7. Results for 2G (1990-2001)

2G (1990-2001)	RE	FE	FE Robust
Location Variables			
Urban	-0.014	0.693	0.693
	(-0.90)	(10.49***)	(6.22***)
Regulation	4.339	4.132	4.132
	(7.67***)	(7.21***)	(6.04***)
GDPC	0.479	7.040	7.040
	(2.12**)	(6.44***)	(3.53***)
Internet Penetration	0.195	0.129	0.129
	(11.56***)	(8.24***)	(4.16***)
First Generation Diffusion speed	0.035	0.047	0.047
	(2.44**)	(3.86***)	(1.99**)
Diffusion Variables			
HHI Competition	-0.005	-0.005	-0.005
	(-16.67***)	(-17.50***)	(-9.13***)
HHI Technology	-0.006	-0.006	-0.006
	(-16.94***)	(-18.93***)	(-11.53***)
Constant	4.634	-87.645	-87.645
	(3.32***)	(-10.02***)	(-5.39***)
R^2	0.70	0.75	0.75
F-test/ Wald	1987.90	450.44	180.74
Obs (Groups)	1186(129)	1186(129)	1186(129)

*** Statistical significance at the 1% level

** Statistical significance at the 5% level

* Statistical significance at the 10% level

Table 8. Results for 2G (1990-2001)

2G (1990-2001)	FD Instrumental Variable Estimator	Dynamic Panel
Location Variables		
L1	-	0.473
		(16.06***)
Urban	1.078	0.276
	(1.77*)	(2.82**)
Regulation	0.466	1.374
	(0.63)	(2.12**)
GDPC	7.560	10.387
	(1.94**)	(5.73***)
Internet Penetration	-0.029	0.032
	(-0.44)	(1.93**)
First Generation	0.044	0.081
Diffusion speed	(4.11***)	(8.73***)
Diffusion Variables		
HHI Competition	-0.009	-0.003
	(-1.73*)	(-8.49***)
HHI Technology	-0.001	-0.005
	(0.38)	(15.82**)
R^2	0.61	
F-test/ Wald	195.12	4286.55
Sargan Test		173.875
Arellano-Bond test AR(1)		-8.912***
Arellano-Bond test AR(2)		-1.384
Obs. (Groups)	930(129)	930(129)

Table 9. Results for 2G (2001-2007)

2G (2001-2007)	RE	FE	FE Robust
Location Variables			
Urban	0.007	0.246	0.246
	(0.70)	(4.71***)	(2.94***)
Regulation	-0.353	0.386	0.386
	(-0.81)	(0.92)	(1.10)
GDPC	0.457	6.451	6.451
	(2.92***)	(11.51***)	(7.14***)
Internet Penetration	0.052	0.038	0.038
	(8.96***)	(7.05***)	(4.19***)
Third Generation	7.847	-2.210	-2.210
Diffusion speed	(3.59***)	(-1.11)	(-1.04)
Diffusion Variables			
HHI Competition	-0.002	-0.002	-0.002
	(-5.67***)	(-6.40***)	(-5.42***)
HHI Technology	0.001	0.001	0.001
	(7.19***)	(4.51***)	(3.48***)
Constant	-6.784	-74.390	-74.389
	(-6.40***)	(-10.02***)	(-8.35***)
R^2	0.57	0.74	0.74
F-test/ Wald	438.39	118.60	58.32
Obs (Groups)	369(62)	369(62)	369(62)

*** Statistical significance at the 1% level

** Statistical significance at the 5% level

* Statistical significance at the 10% level

Table 10 Results for 2G (2001-2007)

2G (2001-2007)	FD Instrumental Variable Estimator	Dynamic Panel
Location Variables		
L1	-	0.387
		(9.92***)
Urban	0.269	0.053
	(2.51**)	(1.45)
Regulation	0.433	0.199
	(1.15)	(0.92)
GDPC	5.585	3.557
	(5.86***)	(8.02***)
Internet Penetration	0.035	0.042
	(4.23***)	(10.49***)
Third Generation	-0.236	-1.157
	(-0.10)	(-0.78)
Diffusion speed		
Diffusion Variables		
HHI Competition	-0.003	-0.001
	(2.03**)	(-4.81***)
HHI Technology	0.002	0.001
	(4.65***)	(5.50***)
R^2	0.68	
F-test/ Wald	227.09	3328.55
Sargan Test		276.477
Arellano-Bond test AR(1)		-0.981
Arellano-Bond test AR(2)		-0.814
Obs. (Groups)	307(62)	307(62)

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