Entry, standards and competition: firm strategies and the diffusion of mobile telephony[*]

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I. Introduction

This paper studies the effect of regulatory settings and competitive environment on the performance of an emerging new technology, digital mobile telecommunication (2G). In contrast to previous studies, however, we take technological performance to consist of several related measures, all of which refer to the degree of market efficiency and the extent of 2G service. Further, we recognize that different dimensions of market performance interact. This interaction potentially creates tradeoffs for public policies aimed at improving overall performance, while econometrically it may yield biased estimates of the effects of regulatory instruments.

The mobile telecommunications industry provides an interesting platform for our study for several reasons: First, countries differ widely in their regulatory and competitive settings as well as their degree of development of the mobile market, which provides us with sufficient variance to test the effect of various independent variables. Second, mobile telecommunications is largely regarded as a "success story", and it is gaining in importance for the economy both due to its direct effects such as positive contribution to employment (OECD, 2000) and its indirect effects, e.g., through facilitation of business practices (Röller and Waverman, 2001). Indeed,

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Röller and Waverman (2001) find that telecommunications investment has a significant and positive effect on economic growth. Finally, the mobile telecommunications industry is one of the few in which rather detailed data has been collected from its beginnings across a large number of economies, thereby providing us with an extensive panel of country-years. Specifically, we use data from 32 industrialized countries over the 1992 – 1999 time period.

Technological diffusion is often used synonymously with performance or market development. For example, an OECD report (OECD, 2000) states that "mobile growth rates […] are important for comparing the performance of the sector across different OECD countries". Stoneman and David (1986) argue that what "determines improvements in productivity and product quality, thereby enhancing economic welfare [is] the speed and extent of [new technologies'] application in commercial operations". Similarly, Wallsten (2001) uses mainline penetration and payphone provision as two measures of sector performance, indicating that higher penetration rates imply better performance. On the other hand, in more mature markets market performance is typically measured by the intensity of competitive conduct – implying that more advanced sectors will be more efficient, yielding lower price-cost margins. This approach has been taken for the telecommunications sector by Parker and Röller (1997) and Nattermann (1999), who estimate conduct parameters for the US and German mobile telecommunications sector, respectively. Gruber and Verboven (2000, 2001) combine both concepts and estimate a diffusion curve that explicitly incorporates the competitive environment of the country and find that increased competition (as measured by entry by additional operators) tends to accelerate mobile diffusion. They further investigate the timing of additional entry and find that immediate competition has a weaker effect on diffusion than sequential entry. Finally, the literature on technology adoption makes the point that the timing of (first) entry has an impact on the performance of the technology. Fudenberg and Tirole (1985) show that the incentive to preempt each other in a duopoly may dissipate the rents to be gained from the introduction of the new technology. What is underlying most results in theoretical papers on the adoption of new technologies is the assumption that technological progress ceases (or at least slows down, see, e.g. Regibeau and Rockett (1996)) with the first adoption of the technology, which can lead to inefficient outcomes.

Our paper attempts to combine these different lines of research by simultaneously estimating equations for pricing and diffusion of mobile telephone services, and further estimating an equation explaining the timing of market entry of the first 2G operators. All these can be interpreted as dimensions of market performance and may be affected differently by different policies or competitive regimes. Our contribution to the existing literature therefore is as follows: We firstly endogenize the decision of firms and countries when to enter the digital mobile market, thereby capturing the supply side effect of the timing of market entry on the diffusion speed of digital mobile telephones. Secondly, by jointly estimating pricing and diffusion equations, we internalize the effect of competition on diffusion. Finally, estimating this system of equations also allows us to identify what influence certain demographic factors have on the development of an emerging technology.

Our estimation results suggest that regulatory factors and competitive environment indeed have varying effects on the different aspects of market performance: Standardization is not found to have a significant effect on the timing of 2G entry, but it accelerates diffusion though it seems to result in less aggressive price competition than between standards competition and be positively related to mobile service prices.

Between firms competition is found to lower prices and accelerate diffusion as expected. Liberalizing markets for older technologies (i.e. fixed line telephony) is also found to accelerate the timing of entry into the next-generation technology. Permitting a substitute technology in the market (prepaid cards) does not significantly affect market performance. Throughout all specifications, however, we find that the wealth of a country has a consistently positive effect on market performance.

The rest of the paper is organized as follows. Section II discusses the evolution of the 2G mobile markets in our sample countries. A discussion on the economics of entry, diffusion and pricing follows in Section III. We introduce the data and define the variables used in Section IV, and report our estimation results in Section V. Section VI concludes the paper with policy implications and suggestions for future research.

II. The market for digital mobile (2G) telephones

The diffusion of 2G began in January 1992, when the first wireless digital telecommunication network was opened in Finland. At that time, eight analogue mobile telephony standards were active in different parts of the world. Analogue mobile telephony used scarce radio frequencies of the radio spectrum inefficiently and, given the limited spectrum available for operators, competition among analogue mobile telephone operators never really took place. The first generation of mobile telephones never reached high levels of penetration (see Figure 1). The launch of digital mobile telephony meant a drastic increase in the efficiency of spectrum use and in service quality. Digitalization facilitated the introduction of new services (e.g. SMS) and led to increased consumer privacy. Simultaneously, regulators allocated more frequency spectrum for mobile communication services.

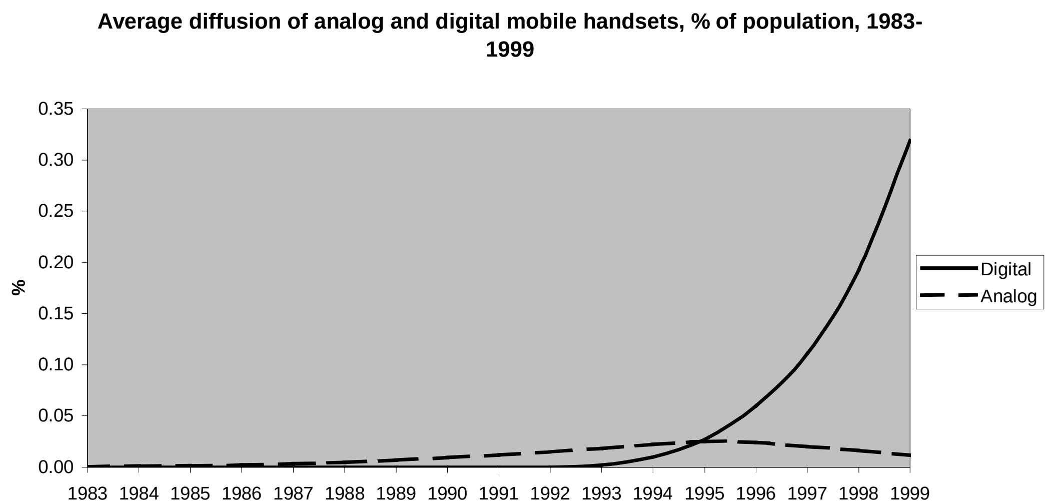

Figure 1: Average diffusion of analog and digital mobile handsets

When examining the latter part of Figure 1, we see that diffusion of 2G mobile telephony is still increasing in 1999 and that the global penetration rate is still relatively low. When we plot the maximum, minimum and average diffusion rates of the countries in our sample however, we find that diffusion rates differ dramatically (Figure 2). Explaining the divergence in diffusion rates across countries is one of the main goals of our paper, and we will discuss potential drivers of the diffusion in following sections of the paper.

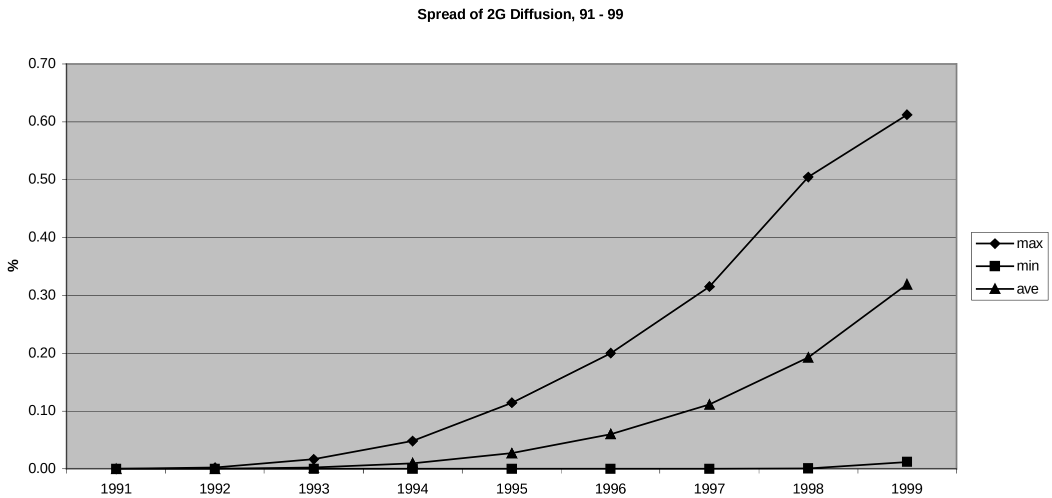

Figure 2: Spread of 2G diffusion rates, 91 – 99

Another important regulatory decision that was in turn informed by technological considerations was the degree of technological standardization. That is, even where multiple licenses were issued, various national regulators required all license holders to operate in the same technological regime (e.g., GSM in European Union countries). However, various countries such as the United States have left the choice of standard open, letting the market decide upon the degree of standardization. Altogether, the global markets have introduced four groups of digital mobile telephony systems: GSM, CDMA, TDMA and PDC.

The question of whether an ex-ante (*de jure*) standard or an ex-post (*de facto*) standard generates superior results remains open. Advocates of *de jure* standard setting will point towards the failure of quadraphonic sound in the 1970s, where two competing technologies increased technological uncertainty, which eventually served to kill off the market altogether.[1] Supporters of market-driven (*de facto*) standardization will emphasize the race character of a standards war and contend that the resulting

[1] See Postrel (1990) for an analysis of the case and Kretschmer (2002) for a more general discussion of the effect of multiple technologies on the likelihood of successful technology adoption.

technological progress will outweigh the losses from non-standardization in the interim. Cabral and Kretschmer (2002) show that the discount factor of the policymaker, i.e. how important it is to find a quick solution relative to the importance of the right solution, is instrumental in a regulator's decision to accelerate setting a standard or favouring a market-driven solution.

Typically, more than one 2G license was issued per country. Operators that have been issued a license, however, did not automatically start servicing straightaway, so that competition developed only gradually in the mobile market. In 1992, only about one fourth of the sampled countries had more than one digital wireless service provider, whereas in 1999, about 97% of the markets were oligopolies. Previous empirical studies suggest that there is a clear positive relationship between competition and diffusion of mobile telephones (see, e.g., Barros and Cadima, 2000; Gruber and Verboven, 2001). This is consistent with theoretical models suggesting that deregulation of entry generally gives incentives for cost minimisation and forces prices closer to the marginal cost level, which in turn speeds up diffusion.

Having outlined the initial conditions and important policy dimensions that prevailed at the outset of 2G, we will now discuss the determination of several dimensions of technological performance: entry, diffusion and prices.

III. Economics of entry, diffusion and pricing

i) Firm Entry

The first year of digital service provision varied greatly in our sample, despite the fact that technologies were internationally available and transferable. The degree of dispersion is shown in Figure 3. It is interesting to ask which factors, both demographic and regulatory, affected the timing of 2G introduction.

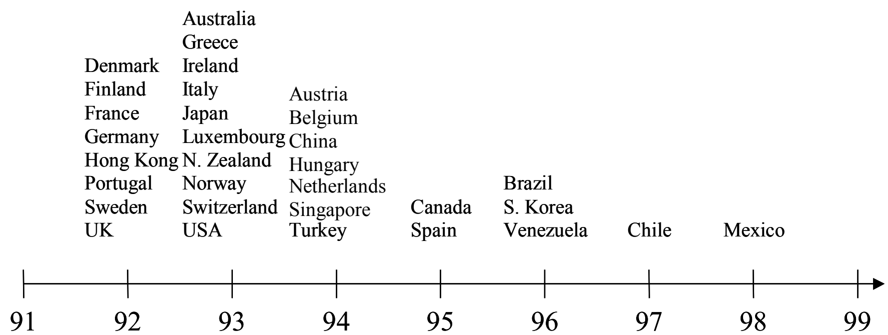

Figure 3: Timeline of 2G introduction dates

Firstly however, it is important to identify the agents that influence the decision to enter. In the vast majority of cases, the first entrant was the previously state-owned monopoly telephone provider, who often simultaneously held a (often the only) license for 1G (analogue) mobile telephony, which is likely to affect product introduction decisions. Early 2G operators were also often monopolists on some part of the fixed-line network (local, long-distance, or international services). Assuming that these existing technologies and digital mobile telephony are substitutes (as confirmed by Barros and Cadima (2000) or Liikanen et al. (2002)), revenues from the new technology would to some extent cannibalise existing rents from fixed- and first-generation services. At the same time, information about the state of 2G technology was often with the incumbent firms because potential new entrants had only limited experience and knowledge about the market and the technology. For example, the Norwegian Telecommunications

Authority NPT relied almost exclusively on Telenor, the incumbent operator, and handset producers like Nokia and Eriksson for information on the technological state of digital mobile telephony, which gave incumbents an opportunity to orchestrate or at least influence the date at which the new technology should start service. Prieger (2001) develops a model along these lines in which a regulated firm informs the regulator about the cost of delaying the introduction of a new product and finds that firms will strategically reveal their information (i.e. signal to the regulator) in order to achieve an optimal point of product introduction. Similarly, we therefore assume the decisions to introduce 2G mobile telephony were taken jointly by the regulators and the incumbent telecom firms.[2]

There is an extensive literature on the adoption of new technologies. In particular, the literature recognizes a tradeoff between waiting and possibly gathering more information about the technology in question or taking advantage of technological progress, and adopting early in order to preempt other entrants from entering (see, e.g. Fudenberg and Tirole (1985)). This effect is likely to be exacerbated in the presence of network effects, where the installed base of early entrants confers an added competitive advantage (Regibeau and Rockett (1996)). Berry (1992) and Bresnahan and Reiss (1990, 1991) develop models in which entry decision reveal information about the underlying profitability of the market, implying that entry will take place as soon as it is profitable.[3]

Dekimpe et al. (1998, 2000a, 2000b) have studied entry decisions in the ICT industry in detail. In Dekimpe et al. (2000a), they find that countries "learn" from similar countries

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[2] Indeed, a similar pattern can be recognized in the discussions on number portability between networks. Even though it has been a technological possibility for a long time, many countries are only introducing it now as a consequence of the long list of concerns brought forward by incumbents, who have most to lose from a decrease in switching costs for existing customers.

[3] Note that "soon" need not have a time interpretation. Bresnahan and Reiss (1991) derive different threshold market sizes that will trigger entry of an additional firm. In our case, however, the intuition is that the 2G market is becoming increasingly profitable and that it is only a matter of time until the first firm decides to enter.

about the expected profitability of the mobile telephony market, so that the timing of first entry resembles an epidemic model of technology diffusion. In Dekimpe et al. (2000b), this model is extended to include more country covariates and to study both the timing of the *implementation stage* (i.e. first usage of the technology) and the *confirmation stage* (i.e. full usage). Their results suggest that the factors influencing transition to the implementation stage are similar to the ones accelerating transition to the confirmation stage.

The timing of entry of 2G telephony may be influenced by regulatory as well as demographic factors. Below we discuss the factors we use in our empirical study.

Standardization – i.e. whether to allow multiple 2G standards in the market or not – decreases the perceived uncertainty of market participants and therefore renders the future profitability of a market less volatile. For example, if a country allows for multiple technological standards, the first entrant may fear being leapfrogged by a later entrant with a superior technology, or it may decide to wait until the standardization problem is resolved. It seems plausible then that the standardization approach of a country affects the timing of market entry of the first 2G mobile service providers. More specifically, choice of a single technological standard is expected to have a positive influence on the likelihood of entry due to the decreased volatility of future cashflows.

An important regulatory factor that may have played a role in the incumbent operators' decision to enter the market for mobile services is the **degree of competition in fixed line services**. During the 1990s various countries opened up their fixed line services to competition. This was likely to reduce the incumbents' (expected) rents from fixed-line services and make the new market areas such as mobile services more attractive to them. Thus, we expect the degree of competition in fixed-line service to have a positive influence on the likelihood of entry.

The potential influence of the incumbent for the regulator may be weaker when the regulator is independent.[4] Firstly, conflicts of interest are avoided (governments often held shares in the incumbent operators), and it seems plausible that an independently appointed regulatory committee is more open to alternative means of gathering information. Since the delay of 2G introduction chiefly benefits the incumbent firms willing to avoid possible cannibalisation of their own service provision, an **independent regulator** is expected to accelerate the timing of 2G introduction.

Also, the expected future cash-flows from 2G services are expected to be larger, and high-quality services used more readily, if potential users are more **wealthy**. Thus, higher GDP per population signals a higher (expected) profitability of entrants, and consequently should facilitate the market entry.

Previous experience of an operator regarding mobile service provision in the 1G market may also have facilitated its entry to the 2G market. The reason for this is learning-by-using effects, i.e. the stock of knowledge and skills the operator has developed through building analogue mobile networks and providing 1G services. Learning-by-using effects increase the profitability of adopting technologies based on the previous vintages of technologies (similar evidence on the mobile market has been found by Liikanen et al. (2002), and for previous empirical evidence on Flexible Automation production, see Colombo and Mosconi 1995). Moreover, the size of the market for 1G services is likely to be an indicator of the future profitability of 2G market. Finally, since analogue mobile telephony was much less efficient in its spectrum use, capacity constraints in spectrum may have necessitated the transition to 2G. Therefore, we assume that the **installed user base of 1G users** is positively related to the probability of entry.

[4] The communications sectors of industrialized countries have basically two types of regulatory authorities: the independent regulatory authorities and government departments acting as regulators.

It is also important to account for the cost of setting up a network. Mobile networks operate through a network of transmission towers covering a limited geographical area (or cell). Therefore, setting up a network in a geographically more dispersed country will be relatively more costly than in a small, concentrated one. Therefore, **population density** may have a positive effect on the likelihood of entry. Another possible proxy for the (relative) fixed cost of setting up a mobile network is the **geographical area** of the country.

Finally, we expect countries to learn from previous adoption decisions. Since over time more and more countries will have adopted, we expect the hazard of entry to exhibit **positive duration dependence**.

ii) 2G Diffusion

Diffusion phenomena have been widely studied in the literature. However, there is often a focus on production technologies whose adopters are firms competing in the product market.[5] Most of the conclusions however also hold of end-consumer products such as 2G mobile. In particular, two important effects in the adoption of new technologies are the *network* and the *epidemic* effect.[6] Both say that as more consumers are using a technology, it will become more attractive for non-users to become users. Network effects exist if the product becomes more useful, e.g. due to lower intra-network calls, while epidemic effects arise from informational diffusion and reduction of uncertainty (Bikhchandani, Hirshleifer and Welch, 1992). In the

[5] Stoneman and Zettelmeyer (1993) is a rare exception. They estimate alternative models of diffusion for three consumer technologies in Germany and the UK.

[6] There is a large literature going back to Griliches (1957) that studies the epidemic effect in technological diffusion. Network effects have been identified by Koski (1999) in a diffusion setting, and by Saloner and Shepard (1995) in the context of first adoption of a new technology.

early stages of technological diffusion, we would therefore expect a positive relationship between **past adoptions** and diffusion speed.

Technological standardization has been shown in previous studies (Koski, 1999) to affect diffusion speed: A network technology's usefulness depends on the number of other users. A durable product will lose value if it turns out to be "orphaned", i.e. there are no future users. Consumers will factor this into their decision, and may therefore delay adoption until the winning standard becomes known. Therefore, we expect standardization to be positively related to the diffusion speed of mobile phones. We investigate the impact of standardization on diffusion from two perspectives. First, we explore how diffusion of mobile phones differs in countries were one 2G mobile standard was chosen from those supporting multiple 2G technologies. Second, we investigate whether and how the market share of the dominant standard influences diffusion speed.

The number of competitors on the market is expected to influence demand via prices but it may also have an independent effect on diffusion speed. In particular, market presence by multiple firms will lead to higher product awareness, and the likelihood of aggressive non-price competition increases, further influencing incentives to adopt. We then assume that **2G competition** is positively related to diffusion.

Clearly, since technology diffusion is the aggregate of a large number of consumers' cost-benefit decisions, we expect that **prices** are negatively related to diffusion. Finally, it seems intuitive to assume that the **wealth** of a country will influence its speed of diffusion; the demand for mobile services is likely to be greater in richer countries.

iii) Pricing

Comparing the mobile service price dynamics reveals that the prices charged in different countries vary dramatically. Our primary interest is to investigate how **within and between standards competition** and **competition between firms** have influenced 2G service pricing. On the one hand, it seems possible than when various incompatible technologies compete for the market share and the dominant position, price competition in mobile services intensifies as it is important for firms to gain an installed user base for the technology they have chosen. On the other hand, standardization means that the firms may benefit from economies of scale in production and service provision, and thus prices are lower than on markets with incompatible technologies. Thus, it is an empirical question to be resolved how **standardization** (and the market share of dominant 2G technology) influences prices. Competition generally results in lower prices. Having only two competitors on the market may, however, not reduce prices as much as competition between various firms. For instance, Parker and Röller (1997) show that prices in a duopolistic market structure are higher than predicted, but lower than the expected monopoly price. Their conclusion is that there may exist a certain level of cooperative price-setting, but no fully-fledged joint-profit maximization. A word on penetration, or predatory pricing: It is commonly accepted that the greatest barrier in getting consumers to purchase mobile phone services was the handset price. Therefore, in order to trigger a purchase, subsidized handsets (often even "sold" at zero cost) were by far the most frequent means of aggressive price competition, whereas service prices seemed much less predatory.

The size of the **installed user base** may also be related to mobile service prices. Greater number of users means higher potential benefits from scale economies in service provision and thus lower service prices.

The emergence of **pre-paid phone cards** opened up mobile telephony services to a new consumer segment, namely low-usage, low willingness-to-pay. It seems possible that mobile operators would have lowered their subscription service prices in the absence of pre-paid cards in order to attract consumers with higher price elasticity. This would imply that the emergence of pre-paid cards would allow operators to keep prices high or even increase them. On the other hand, pre-paid cards presented an attractive alternative to subscriptions and therefore may have exerted downward pressure on subscription prices. The net effect of pre-paid phone cards therefore is not quite clear, as we would expect both effect to counteract each other.

It is often said that independent regulators can regulate a market more efficiently due to several reasons. Wallsten (2001) points out that independent regulators are more likely to initiate regulatory reforms, and independent regulators are expected to experience less conflicts of interest, especially since lobbying efforts by mobile operators cannot be made via the government. Assuming that an independent regulator indeed creates a more favorable market environment, we expect prices to be lower and diffusion to be faster in countries with **independent regulators**.

IV. Estimation strategy and data

We will estimate three decisions: First, the governments' (and incumbent telephone providers') decision to introduce mobile telephony. Second, the pricing decision of firms as function of the level of competition in the market. Third and finally, we estimate the diffusion of mobile telephony in our sample countries. Because of the simultaneity of the second and third decision, we estimate both pricing and the diffusion equation simultaneously. By generating results on timing of entry, prices and diffusion, we thus give a rather complete picture of the evolution of the mobile telephony industry in different countries.

(i) Entry

We use a hazard rate model to identify independent variables that influence the timing of 2G entry. This also gives us the opportunity to experiment with alternative specifications of the baseline hazard – we experimented with exponential, Weibull, and Cox proportional hazard models. Since parameter values for the monotonously changing hazard rate in the Weibull specification are large in magnitude and strongly significant however, we select the Weibull specification and report results accordingly. We assume that 2G was only available and (potentially) commercially viable in the year prior to the first introduction (1991). All of our sample countries adopted 2G within the time period considered, which avoids problems of right-censoring.

Therefore, the hazard rate of country i in year t, given that it has not introduced 2G yet, is

$$h_i(t) = h_0(t) \cdot \lambda_i, \quad (1)$$

where $\lambda_{it} = \exp(x_{it}\beta)$ is a vector of covariates and $h_0(t) = \gamma t^{\gamma-1}$ in a Weibull specification. Values $\gamma > 1$ therefore imply positive duration dependence.

(ii) Diffusion and prices

We make a common assumption concerning the diffusion of mobile phones (see, e.g., Gruber and Verboven, 2001) that the fraction of the mobile phones adopted of the potential total number of mobile phones adopted in country i at time t follows a logistic growth curve

$$N_{it} = \frac{N^*}{1+\exp(-x_{2it}^{'}\beta_1 - u_{2it})}, \tag{2}$$

where N_{it}= the number of mobile phones in country i at time t and N* equals the network size of technology when its diffusion is complete[7]. A transformation of equation (2) produces the following model:

$$y_{2it} = \log(\frac{N_{it}}{N^* - N_{it}}) = x_{2it}\beta_2 + u_{2it}, \tag{3}$$

We assume that y_{2it} follows a normal distribution with mean 0 and variance σ_2^2.

The prices for mobile services are determined by the demand for services, and by the competitive environment of the firm as follows:

$$f(P_{it} | x_{3it}, N_{it} > 0) = \prod_{i=1}^{n} \frac{1}{\sigma_3} \phi(\frac{P_{it} - \beta' x_{3it}}{\sigma_3}), \tag{4}$$

where x_{3it} is the vector of explanatory variables.

Equation (3) and (4) are estimated simultaneously by using the three stages least squares (or 3SLS) instrumental variable method, in which part of the explanatory variables may be pre-determined and all the parameters of the model are estimated jointly (see Berndt, et al., 1975).

Price and diffusion equations are estimated conditional on network size being greater than zero. As we use only observable data on diffusion and prices, the estimated coefficients of the explanatory variables may be biased due to differences in the timing of 2G entry among sample countries. To take into account this potential

[7] We bound the upper limits of the diffusion of the fixed and cellular telecommunications networks to be one main line and one cellular telephone per inhabitant, respectively.

sample selection bias, and to test its existence, we use Heckman's two stage sample selection method (1979). In other words, we use the inverse Mills ratio function of the probit residuals as an additional variable to explain variation in the diffusion speed of digital mobile phones and the prices for mobile telephony services.

Data

We are using a panel of 32 industrialized countries over the years 1991 to 1999. The data has been gathered from the following data sources: Prices and subscription number variables are from the EMC mobile telecommunications database, and demographic and infrastructure data is taken from the OECD Telecommunications Database 2001. Additional data on country characteristics was taken from the WDI World Bank database.

Dependent variables

Of interest in the entry equation is the time until a country starts offering 2G services. This could be estimated either using a spells specification, where a spell is defined as the length T that a country delays the adoption of 2G after the technology has become available. An analogous way, which we choose in this paper, is to model the probability that a spell will end between time t and $t+\Delta$. This is best examined by investigating the hazard rate $\lambda(t)$. Clearly, integrating the hazard function over all time periods $\tau < t$ will generate the *survivor function*, i.e. the probability that a spell will last at until t. Consequently, our dependent variable is the entry decision and the time at which entry took place. Since we have a panel of countries, a country-year gets value zero if entry has not yet taken place and one when the country enters, i.e. when the number of subscriber to a second-generation mobile technology is positive for the first time.

Information is given on the number of subscribers for each active digital network (technology) in the country – i.e. GSM, CDMA, TDMA and PDC. Variable DIFP, measures (log) the diffusion of mobile phones per population and is derived according to equations (2) and (3). The price variable (PRICE) is the (log) monthly cost of 120 minutes peak calls (in USD and PPP). The probit model correcting for potential sample selection bias is estimated by using the dummy variable DIGDMY – which is 0 when there are no digital wireless services available in a country and 1 if there are – as dependent variable.

Regulatory and competition variables

We include a set of dummy variables on the nature of domestic competition in a country. We use the dummy variable COMP that gets value 1 if there are *more than two* competing operators in the market for digital mobile telephony, and value 0 if there is no competition, as indicator for the competitiveness of the market. The dummy variable MULTIE is used for controlling competitive environment in the beginning of the market for 2G services in each country. It gets value 1 when there has been more than one entrant when 2G mobile service provision began, and value 0 if there was only one monopoly entrant during the first year of 2G operation. The dummy variable STAND distinguishes countries that have set one digital mobile telephony standard (variable gets value 1) from those of multiple standards (variable gets value 0). We also use variable SHARE, (log) market share of the dominant 2G standard, in our empirical investigation to further understand the role of standardization in mobile pricing and diffusion decision.

In explaining the timing of introduction of digital mobile telephony, we also use variables capturing the degree of competition in local markets: COMPF = (COMPLO+COMPLD+COMPI)/3, where COMPLO/COMPLD/COMPI = 1 if local/long-distance/international telecommunications services are opened up to competition, 0 otherwise. In the entry equation, we also construct a dummy variable (MORECOMP) that takes on value 1 if the country's competitiveness index (COMPF) is higher than the average competitiveness index in that particular year. This helps us identify the countries that are more competitive than their relative "peer group", i.e. the countries that have not yet introduced 2G.

The regulatory environment is captured by variable REGU that gets value 1 when the market is regulated by an independent regulatory authority and 0 otherwise.

Installed user base effect

The installed base at time t – 1, DIGP(t-1), is expected to have an effect on the speed of diffusion. This proxies the network effect of mobile phones - i.e. a mobile phone becomes more attractive when many people are already using it - on their diffusion. In the price equation, we use variable IBASE(t-1), the number of mobile phone users per population, to control for the network effect. We add variable PREPAID, (log) number of prepaid mobile customers, to evaluate the importance of the number of prepaid 2G users in the diffusion and price dynamics.

We also include the installed base of analog mobile phones at time t-1, ANAP(t-1), in order to capture the influence of the installed user base of analogue mobile telephone users for the timing of introduction of mobile telephony. We expect the relationship between these two variables to be positive as a) the analogue wireless technology was using the limited spectrum inefficiently, and thus the operators were getting closer to the capacity constraints of service provision when more consumers were using analog mobile phones, and b) there may be intergenerational network effects in the mobile telephone market (see Liikanen et al. (2002).

Demographics

We control for the “wealth” of a country by variable *GPD/POP* that is (log) gross national product divided by population. In the entry equation, we also look at population density (POP_DENSITY) and the percentage of inhabitants living in urban areas (URBAN_POP).

Instruments

We use a constant term, all the predetermined and exogenous variables as instrumental variables in the system of price and diffusion equations. In addition, we use the (log) number of competitors in the digital mobile telephony (*NCOMP*) and the (log) standard deviation of the number of users of (incompatible) digital technology standards as instruments (*STDEV*). The number of competitors is correlated with the COMP dummy variable providing additional information regarding the competitive environment. The standard deviation of the number of users of digital technology standards is related both to standardization and the market share of the biggest mobile service operator. When a country has used a single digital mobile phone standard, STDEV variable gets value 0, i.e. there is no variation with regard to incompatible network sizes. Higher market share of the dominant standard is of course negatively related to STDEV, i.e. standardization requires that there is no variation concerning incompatible digital mobile networks. The variable STDEV thus captures uncertainty related to the leader digital technology in the future.

The list and descriptive statistics of all the variables used in the paper are shown in table 1.

V. Empirical findings

(i) Entry of 2G services

Our estimations results suggest that standardization (STAND) is an insignificant determinant of the timing of 2G entry. Even though the sign is positive, as expected, and robust across specifications, we cannot confirm our hypothesis that standardization decreases the uncertainty surrounding 2G entry and therefore makes entry likely to occur earlier. Similarly, independently regulated (REGU) countries entered slightly earlier on average, but this did not result in a significant coefficient. Both regulatory determinants therefore seem not to have a significant effect on the introduction of 2G technology in our sample.

The relative degree of competition (MORECOMP) in fixed-line telephone services is positive and significant at the 5% level in the initial specification (1) and significant at least at the 10% level in alternative models. We also use the competitiveness index (COMPFIX) in Specification 1c and obtain comparable results: Relatively more competitive fixed-line markets are likely to trigger earlier entry than their less competitive cohorts. This suggests that there is indeed a cannibalisation effect from 2G to fixed-line telephony.

Previous diffusion of analogue mobile telephony carries a positive and strongly significant sign in all of the specifications. This is in line with the findings by Liikanen et al. (2002) who take this as evidence for intergenerational network effects. As an alternative (or complementary) interpretation, there are indications that capacity in analogue telephones has reached its limit and that therefore the transition to a higher-capacity, superior-quality technology was accelerated in countries with relatively constrained networks.

The effect of a country's wealth is positive and significant in most specifications, suggesting that richer countries will introduce an advanced technology earlier. We found that linear GDP per head performs better than the log transformation (regressions with GDP/POP are not reported, but can be supplied by the authors)

We used several different proxies for the expected cost of setting up a 2G network. The (log) size of the country is not significant (model 1a), and the percentage of urban population (URBAN_POP) does not have a significant coefficient in Model 1b.

Finally, it should be noted that the duration dependence is positive and significant in all specifications, suggesting that there exists indeed some cross-national learning or an exogenous decrease in the cost of setting up a 2G network.

(ii) Diffusion and price dynamics

We estimate jointly the diffusion speed of 2G mobile and the pricing path in the different countries.[8] As a first step, we estimate the following simplified system of equations (MODEL 1):

$$DIGP_t = a_0 + a_1 PRICE_t + a_2 DIGP_{t-1} + a_3 (GDP/POP)_t + a_4 PREPAID_t + a_5 MILLS + \varepsilon_{it}$$

$$PRICE_t = b_0 + b_1 IBASE_{t-1} + b_2 (GDP/POP)_t + b_3 PREPAID_t + b_5 MILLS + \mu_{it}$$

The explanatory variables $DIGP_{t-1}$ and $IBASE_{t-1}$ are, as expected, highly correlated with the regulatory variables of our interest, particularly competition. Therefore, we

[8] Empirical findings concerning the timing of 2G entry are discussed above so we do not discuss here the estimation results of the probit model creating additional explanatory variable correcting potential sample selection bias, the inverse Mills ratio variable (MILLS), for the price and diffusion equations. We first estimated the random effects probit model to investigate whether the error terms of the probit equation are autocorrelated and consequently, the estimation results of the pooled probit model inconsistent. Our findings – no autocorrelation – suggest that it is sufficient to use the simple pooled probit approach.

isolate the effects of regulatory variables on diffusion and pricing by estimating the model that excludes price and installed base variables from the right hand side of the equation (MODEL 2):

$DIGP_t = a_{0'} + a_{1'}REG_t + a_{2'}DIGP_{t-1} + a_{3'}(GDP/POP)_t + a_{4'}PREPAID_t + a_{5'}MILLS + \varepsilon_{it}$

$PRICE_t = b_{0'} + b_{1'}REG_t + b_{2'}(GDP/POP)_t + b_{3'}PREPAID_t + b_{5'}MILLS + \mu_{it}$,

where REG is a vector of regulatory variables of our interest. In MODEL 2a) REG comprises standardization dummy (STAND), competition dummy (COMP) and dummy variable for independent regulator (REGU). MODEL 2b) includes COMP and REGU but we measure standardization by the market share of the dominant 2G standard (SHARE).

Comparing the estimation results of the model for diffusion and prices with and without correcting for the potential bias arising from differing entry dates suggests that endogenous entry affects both diffusion and pricing dynamics. First, various coefficients are estimated more accurately when the variable MILLS is incorporated into the equations. Second, the MILLS variable appears to be statistically significant in both the price and diffusion equation.

The estimation of MODEL 1 suggests that the prices of mobile service are, according to the economic theory, negatively and statistically significantly related to the diffusion of mobile phones (see Table 3). The positive and statistically significant coefficient of variable DIGP(-1) indicates that the slope of the diffusion curve is, indeed, positive or that the installed user base further facilitates diffusion. In the price equation, the installed user base effect is negative indicating that greater number of mobile telephone users is related to lower service prices. This finding is consistent with the assumption of the existence of scale economies in wireless service provision. A country's wealth, however, is negatively related to mobile service prices. This result is puzzling, and we suspect that wealth is correlated with a variable of interest that is related to lower prices. For example, in our sample richer countries are often more equally distributed countries. It is thus possible that the relevant demand for 2G mobile telephones is actually less price elastic in countries that are poorer on average, simply because only a wealthy subset of consumers would contemplate adopting 2G. Alternatively, GDP per head may be related to variables on telecom infrastructure we cannot control for. For instance, if fixed-line telephones were closer substitutes in wealthier countries, the price pressure on 2G mobile would be higher, leading to lower prices. The isolation of these two possible explanations is the subject of ongoing research.

The estimation results of MODEL 2a and 2b suggest interesting interactions between competitive environment and diffusion and price dynamics. First, we find that standardization facilitates the diffusion of mobile phones. This result suggests that technological compatibility increases the expected user value of mobile services, and this transpires at the aggregate level as a greater diffusion. The estimation results of MODEL 2b show that the market share of a dominant 2G technology (SHARE) is similarly positively related to diffusion. Interestingly, when we estimate the model without MILLS variable, i.e. do not control for sample selection bias, we find that standardization does not explain statistically significantly variation in the diffusion of 2G mobile phones. This empirical finding is consistent with the estimation results of Gruber and Verboven (2001). It thus seems that the statistical significance of standardization variable in the diffusion equation depends crucially from controlling for the 2G market entry.

Interestingly, we find that the standardization also has a direct, statistically significant positive influence for mobile service prices but the market share of dominant technology, instead, does not explain well variation in the price variable. It thus seems that competition between incompatible standards results in more intense price competition, whereas firms implement less aggressive pricing strategies when competition takes place within a single standard. This seems logical as in the case of incompatible technologies, the user value of a single technology and its future success - and thus the future profit opportunities of a mobile service provider - greatly depends on the order of magnitude of its installed user base. Aggressive price competition is one means to aim at rapidly increasing the customer base.

The coefficient of the estimate of competition variable (COMP) gets expected and statistically significant signs in the price and diffusion equation. In other words, competition decreases mobile service prices and facilitates mobile diffusion. We also estimated a model that included a dummy variable that got value 1 when there were at least two firms entering the wireless market of the country during the first year of 2G service provision.[9] Whether or not the 2G market was competitive from its very beginning does not seem to affect notably the aggregate diffusion of mobile phones but it has a clear negative influence for prices. It seems that the monopolistic position of early entrants lead to less aggressive pricing strategies than those exercised by the simultaneous first entrants. We therefore find no evidence for penetration pricing in the 2G market.

The variable DIGP(-1) was used to capture the installed user base effect in the diffusion equation. The estimated coefficient of the variable is 0.35 and statistically significant. This means that during the sampled time period the installed user base effect has prominently facilitated the growth of digital mobile telephony.

[9] The estimation results regarding multiple entry dummy are not reported in this paper but are available from the authors.

The estimation results also capture the expected relationship between the level of wealth, or GDP per population, and diffusion and prices. Generally, it seems that the wealth is positively related to diffusion, as expected, but negatively related to prices, possibly due to the correlation of GDP per head with other important variables. This result corresponds to the negative relation found in the empirical study reported in a recent OECD publication (Boyland and Nicoletti, 2000).

V. Conclusions

Our empirical exploration provides a more complete picture of the market dynamics of digital mobile telephony than the previous studies that have typically estimated econometric models that ignore the role of endogenous decisions of service providers in the observed market behaviour. The incorporation of endogenous supply side decisions regarding market entry and pricing to the model explaining the diffusion of digital mobile telephony allows us to distinguish the effects of within-standard and within-firm competition on the observed diffusion phenomenon.

Our empirical investigation suggests that both the development of the market for fixed line telephony and analogue wireless or 1G service provision have played an important role in determining the timing of 2G entry in industrial countries. Operators have been more eager to introduce 2G services in countries that have had relatively more competitive markets for wire line services and a greater installed user base of 1G mobile phone users. Thus, consumers have not only benefited directly from lower service prices arising from competition but - given that the first entrants were often the previous wire line monopolies - also from new, innovative communications service provision that has been encouraged by competitive market environment.

Cross-country differences in within and between standards competition and competition between firms have also greatly influenced 2G diffusion patterns. Standardization or technological compatibility has clearly facilitated diffusion of digital mobile phones. Nevertheless, it seems to be also positively related to wireless service prices. Between standards competition apparently triggers more aggressive price competition than competition that takes places within a single standard. Though consumers may loose benefits from technological compatibility when market are led to decide upon the degree of standardization, they may benefit from lower service prices.

Our empirical investigation further suggests that consumers in the countries that have been relatively more advanced in liberalizing the market for telecommunication services have not only benefited from the earlier launch of digital mobile services but also from competition in the wireless service provision resulting in lower digital mobile service prices. Service price have been affected by competition particularly when there have been at least two entrants *at the time of introduction* of 2G services. The monopolistic position of early entrants, instead, has lead to less aggressive pricing strategies. We find that, consequently, competition is also related to the faster diffusion of digital mobile telephones.

It would be interesting to see whether the diffusion dynamics in the markets for other network products and services follow similar patterns to those suggested by our study. Further empirical studies might particularly illuminate the question whether our empirical results concerning the influence of within-firm and within-standard competition for the diffusion of 2G mobile telephones are characteristic of the diffusion dynamics of network technologies more generally.

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Table 1. Descriptive statistics

Variable name	Description	Mean (standard deviation)
DIGP	(Log) Number of mobile phones/Number of people *not* having mobile phone in each country	-2.88592 (2.05835)
PRICE	(Log) monthly cost of 120 minutes peak calls (in USD and PPP)	6.85683 (2.59222)
STAND	Dummy variable that gets value 1 if country has one 2G standard, 0 otherwise.	0.80405 (0.39827)
SHARE	(Log) market share of dominant 2G standard	-0.052775 (0.17496)
COMP	Dummy variable that get value 1 if there are more than 2 competitors in mobile service provision, 0 otherwise.	0.43243 (0.49710)
MULTIE	Dummy variable that get value 1 if there are more than one entrant during the first year of 2G service provision, 0 otherwise.	0.75000 (0.43448)
REGU	Dummy variable that get value 1 if telecom sector is regulated by independent regulatory authority, 0 otherwise.	0.29730 (0.45862)
GDP/POP	(Log) gross domestic product divided by population	9.84004 (0.64968)
PREP	Number of pre-paid mobile customers	0.26501 (11.25429)
COMPF	(COMPLO+COMPLD+COMPI)/3, where COMPLO/COMPLD/COMPI = 1 if local/long-distance/international telecommunications services are opened up to competition, 0 otherwise.	0.49054 (0.49217)
MORECOMP	Dummy variable that gets value 1 if COMPF of a country is higher than average, 0 otherwise.	0.19658 (0.03690)
LANAP(-1)	(Log) number of analogous/1G mobile phones per population at time t-1.	-5.18839 (2.46821)
IBASE	(Log) number of digital/2G mobile phones at time t-1.	14.45970 (1.54484)
L_AREA	(Log) area in square kilometers	5.43203 (0.05184)
URBAN_POP	Percentage of people living in urban areas	24.8130 (0.81223)

Table 2. Estimation results of the entry model

	1	1a	1b	1c
STAND	1.54984 (.65511)	1.56519 (.66659)	1.47801 (.58364)	1.88621 (1.00498)
REGU	1.63461 (.63350)	1.69733 (.69425)	1.68885 (.70553)	1.77881 (.71593)
MORECOMP	2.21141** (.89180)	2.09526** (.83665)	2.23854* (.98283)	
COMPFIX				2.51784* (1.32051)
L_ANA_DIFF	1.11846** (.04544)	1.12781** (.05224)	1.11766** (.04572)	1.11131** (.04209)
GDP_HEAD	1.000034* (.00002)	1.00004* (.00002)	1.00004** (.00002)	1.00003* (.00002)
L_AREA		1.05536 (.09593)		
URBAN_POP			.98684 (.01134)	
γ	2.75231** (.31795)	2.77302** (.34297)	2.80720** (.34589)	2.72370** (.30887)
Log Likelihood	-17.243212	-17.08731	-16.82822	-17.289913

Note: ** denotes significance at the 5% level, * denotes significance at the 10% level

Table 3. Estimation results of the 3SLS model: MODEL I (country dummies included but not reported)

Parameter	Estimate	Standard Error	t-statistic	P-value
DIFFUSION EQUATION				
C	2.83944	3.31600	.856284	[.392]
PRICE	-.288761	.080259	-3.59786	[.000]
DIGP(-1)	.335772	.064318	5.22053	[.000]
GDP/POP	-.447401	.316179	-1.41503	[.157]
PREPAID	.022079	.045341	.486948	[.626]
Y93	-1.47634	1.40662	-1.04956	[.294]
Y94	.322010	1.19269	.269986	[.787]
Y95	.457498	1.17372	.389785	[.697]
Y96	.950949	1.13657	.836686	[.403]
Y97	.611012	.495071	1.23419	[.217]
Y98	.875605	.399543	2.19151	[.028]
MILLS	1.30413	.476769	2.73536	[.006]
PRICE EQUATION				
C	43.9035	4.15340	10.5705	[.000]
IBASE	-.580544	.181165	-3.20450	[.001]
GDP/POP	-3.18646	.415109	-7.67620	[.000]
PREPAID	.059997	.054637	1.09811	[.272]
Y93	-.354224	1.49596	-.236787	[.813]
Y94	.407294	1.45383	.280152	[.779]
Y95	1.45175	1.46181	.993114	[.321]
Y96	1.92323	1.43389	1.34127	[.180]
Y97	1.09415	.664684	1.64613	[.100]
Y98	1.18752	.591112	2.00895	[.045]
MILLS	1.54327	.593303	2.60115	[.009]

NOBS=148

Table 4. Estimation results of the 3SLS model: MODEL IIa) (country dummies included but not reported)

Parameter	Estimate	Standard Error	t-statistic	P-value
DIFFUSION EQUATION				
C	-9.51807	2.49990	-3.80738	[.000]
STAND	.483481	.215055	2.24817	[.025]
COMP	.668447	.305684	2.18673	[.029]
REGU	.018970	.318389	.059582	[.952]
DIGP(-1)	.352764	.068946	5.11655	[.000]
GDP/POP	.511409	.223569	2.28748	[.022]
PREPAID	.046145	.035422	1.30273	[.193]
Y93	-.107776	1.16100	-.092831	[.926]
Y94	1.52657	1.10187	1.38543	[.166]
Y95	1.47316	1.05818	1.39217	[.164]
Y96	1.91151	1.03247	1.85140	[.064]
Y97	1.17376	.593359	1.97816	[.048]
Y98	1.24198	.531622	2.33622	[.019]
MILLS	1.45544	.552968	2.63205	[.008]
PRICE EQUATION				
C	36.9409	2.67805	13.7939	[.000]
STAND	1.62317	.396118	4.09768	[.000]
COMP	-.615446	.261106	-2.35707	[.018]
REGU	.291526	.261878	1.11321	[.266]
GDP/POP	-3.33597	.272162	-12.2573	[.000]
PREPAID	.010291	.039956	.257551	[.797]
Y93	-.420473	1.02152	-.411615	[.681]
Y94	.169110	1.06295	.159095	[.874]
Y95	.808607	1.09557	.738067	[.460]
Y96	.984464	1.06685	.922775	[.356]
Y97	.646527	.521302	1.24022	[.215]
Y98	.699983	.476206	1.46992	[.142]
MILLS	.973603	.427466	2.27761	[.023]

NOBS=148

Table 5. Estimation results of the 3SLS model: MODEL IIB) (country dummies included but not reported)

Parameter	Estimate	Standard Error	t-statistic	P-value
DIFFUSION EQUATION				
C	-10.4597	2.90701	-3.59809	[.000]
SHARE	1.61714	.558118	2.89748	[.004]
COMP	.725352	.340220	2.13201	[.033]
REGU	-.141609	.361507	-.391719	[.695]
DIGDP(-1)	.327061	.077032	4.24580	[.000]
GDP/POP	.586783	.258849	2.26689	[.023]
PREPAID	.080421	.052779	1.52372	[.128]
Y93	.525265	1.59337	.329657	[.742]
Y94	2.25794	1.53915	1.46700	[.142]
Y95	2.30609	1.53259	1.50470	[.132]
Y96	2.76060	1.50600	1.83306	[.067]
Y97	1.53074	.796444	1.92197	[.055]
Y98	1.58770	.695060	2.28427	[.022]
MILLS	1.76372	.713760	2.47103	[.013]
PRICE EQUATION				
C	40.6770	3.17145	12.8260	[.000]
SHARE	1.15818	.915774	1.26470	[.206]
COMP	-.925286	.257274	-3.59650	[.000]
REGU	.882542	.425593	2.07367	[.038]
GDP/POP	-3.56609	.342986	-10.3972	[.000]
PREPAID	-.029499	.062586	-.471330	[.637]
Y93	-1.47829	1.46987	-1.00573	[.315]
Y94	-.893449	1.51402	-.590117	[.555]
Y95	-.204958	1.55531	-.131779	[.895]
Y96	-.079343	1.51204	-.052474	[.958]
Y97	.183013	.607691	.301160	[.763]
Y98	.398891	.516569	.772193	[.440]
MILLS	.834592	.444436	1.87787	[.060]

NOBS=148