The diffusion of mobile telecommunications services in the European Union

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Abstract:

We study the technological and regulatory determinants of the diffusion of mobile telecommunications services in the European Union, using a logistic model of diffusion. We find that the transition from the analogue to the digital technology during the early nineties, and the corresponding increase in spectrum capacity, had a major impact on the diffusion of mobile telecommunications. Countries which granted first licenses at later points in time show a significant but slow catching-up effect, implying international convergence only by around 2006. The impact of introducing competition has also been significant, during both the analogue and the digital period, though the effect was small compared to the technology effect.

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1. Introduction

Mobile telecommunications services have experienced drastic developments in recent years. Although the technology has been available since the early 1960s, its diffusion has become feasible on a large scale only after some basic innovations in semiconductor technology. The diffusion of mobile telecommunications services was affected both by further technological innovations, such as the transition from the analogue to the digital technology, and by regulatory decisions concerning spectrum licensing, competition and the co-ordination to a common technical standard.[1] The sector is now one of the most dynamic sectors in telecommunications. The number of new subscribers grew by 61 percent in 1998, yielding a European-average penetration rate of 23.5 mobile phone subscribers per 100 inhabitants. In Finland, the penetration rate has even reached 58 percent.

European policy documents emphasise both the role of technology and of regulatory decisions as key determinants in the speed of diffusion of mobile telecommunications services.[2] This paper aims to empirically evaluate the role of both factors. Using panel data on the whole history of the industry for all members of the European Union, we assess the relative importance of the following factors: technology (analogue vs. digital), the timing of the first licenses granted (and the speed of catching-up), and the introduction of competition. The impact of the existing fixed line network and GDP per capita are also considered.

We find that the transition from the analogue to the digital technology during the early nineties, and the corresponding increase in spectrum capacity, had a major impact on the diffusion of mobile telecommunications. Countries which granted first licenses at later points in time show a significant but slow catching-up effect, implying international convergence only by around 2006. The impact of introducing competition was also significant, during both the analogue and the digital period, though the effect was small compared to the technology effect.

A recent, related paper is by Parker and Röller (1997) on the U.S. mobile telephone industry. In a structural model, they focus in more detail on aspects of competition, but they abstract from the technological aspects and the timing of first licences. They find that the introduction of duopoly in U.S. states had a significant, though relatively small effect. This is consistent with our conclusion for the European countries, i.e. that the diffusion has been affected more by technology and the timing of the first licences than by the introduction of competition.

Section 2 presents the background technological and regulatory developments. Section 3 describes the econometric model of diffusion. Section 4 presents and discusses the empirical results. Section 5 concludes and provides implications for public policy.

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[1] See e.g. Garg and Wilkes (1996) and Rappaport (1996) for detailed descriptions.

[2] See for example the Green Paper by the European Commission, “Towards the Personal Communications Environment: Green Paper on a common approach to mobile and personal communications in the European Union: COM (94) 145 final, 27.04.1994.

2. The evolution of the market for mobile telecommunications services

2.1. Technological developments

In a mobile communications network, radio transmission replaces the physical connection between the user and the base station. The scarce resource required for radio transmission is the spectrum. Due to technological progress, capacity constraints from spectrum scarcity have been gradually reduced and transmission quality improved (Rappaport, 1996). The first generation analogue systems of the early 1980s use portions of the spectrum around 450 MHz. The exploitation of the spectrum was quite inefficient so that only few consumers could have a telecommunication conversation at the same time in a given geographical area. The second generation analogue systems, introduced during the second half of the 1980s, used a portion of the spectrum around 900 MHz. The higher frequency implied the need for setting up more base stations, but the denser layout of base stations over the territory permitted to better exploit the spectrum and to squeeze more users into the network.

The really fundamental improvement in the exploitation of the radio spectrum occurred with the transition from the analogue to the digital technology. Digital technology, introduced first in the same 900 MHz spectrum as analogue technology, uses the spectrum much more efficiently and is able to accommodate three to four times more customers (Garg and Wilkes, 1996). The most widely used first generation digital system is the European standard GSM 900 (Global System for Mobiles). Second generation digital systems work at the 1800 MHz frequency (DCS 1800), and can accommodate even more customers.

2.2. Regulatory developments

Several important decisions are taken by the governments: the technological standard (if any), the timing and number of licenses, and the procedures by which licences are granted. We focus here on the licensing policies, in particular the timing and the number of licences.

During the period of the first and the second generation of analogue technology, countries largely followed uncoordinated licensing policies. Most countries (except France, the U.K. and Sweden) granted a single monopoly license for the first generation analogue period (at 450 MHz). The common justification for the restricted number of licenses during this period was the scarcity of spectrum capacity. The limited number of possible users caused the problem that economies of scale would not be fully exhausted as the construction of a mobile telecommunications network requires huge up-front investments. As demand for mobile telecommunications services increased, pressure to grant additional licenses for mobile communication services increased. Several countries took advantage of the second generation analogue technology (at 900 MHz) to grant additional licenses. However, the licences often went to the operator that had already a 450 MHz license.

With the introduction of the digital technology, based on the GSM standard, the European Commission started to actively promote a co-ordinated approach with more competition. A Green Paper on the sector set out the E.U.' s policy orientations.[3] The E.U. Directive 96/2 formally instructed the member countries to grant at least two licenses for GSM 900 services and allow additional firms to enter DCS 1800.

In practice, the Scandinavian countries played a leading role in granting licenses for the analogue technology, with first licenses as early as 1981 in Sweden. Even during the digital technology area when countries were obliged to follow the E.U. Directive, the timing of first and second licences varied considerably. As will be shown below, the heterogeneity in the timing of the licenses had important implications for the diffusion path of technologies.[4]

2.3. Understanding the diffusion of mobile communications services

Both the technological developments and the role played by the governments in issuing licenses may have affected the diffusion pattern of mobile telecommunications services. The technological transition from the analogue to the digital technology permitted a drastic increase in the capacity of the radio spectrum. Under such conditions, even a monopolist (or a collusive industry) may find it profitable to reduce prices to attract new subscribers. The transition to the digital technology, leading to increased spectrum capacity, may thus explain *global* increases in the number of subscribers, common to all countries. In contrast, the timing of the first and second licenses granted by the local governments may explain why in some countries the diffusion occurred more rapidly than in other countries. Our central empirical question in the next sections is whether the diffusion of mobile services has been largely determined by the technology-driven capacity constraints, or whether, in addition, the timing of first licenses and the introduction of competition has played a significant role.

3. The econometric model of diffusion

We start from a version of Griliches' (1957) logistic model, in which the technology diffusion follows an S-shaped function. More specifically, let y_{it} denote the number of agents that have adopted the new technology in country i at time t. Let y_{it}^* denote the total number of potential adopters. The diffusion of the new technology follows the logistic function:

$$y_{it} = \frac{y_{it}^*}{1 + \exp(-a_{it} - b_{it} t)} \tag{1}$$

[3] See footnote 2: COM(94) 145 final, 27.04.1994.

[4] The regulatory delays in the introduction of new products such as mobile telecommunications services can be very costly. Hausman (1997) estimated that the delay in licensing mobile telecommunications in the US led to welfare losses for US consumers in the range of $31-50 billion a year.

Three important elements determine the shape of this function. First, there is the total number of potential adopters, y_{it}*. Second, there is the location or “timing” variable a_{it}. This variable shifts the S-shaped diffusion function forwards or backwards, without affecting the S-shape otherwise. Third, there is the variable b_{it}, which is a measure of the diffusion speed. This can be verified from differentiating (1) with respect to t:

$$\frac{dy_{it}}{dt}\frac{1}{y_{it}} = b_{it}\frac{y_{it}^{*} - y_{it}}{y_{it}^{*}},$$

which implies that b_{it} equals the growth rate in the number of adopters, relative to the proportion of agents who have not yet adopted the innovation. The second derivative of (1) is positive for $y_{it} < y_{it}^*/2$, and negative if the reverse holds. The diffusion of the number adopters thus follows an S-shaped pattern, with a maximum diffusion speed reached when half of the total number of potential adopters has adopted the new technology.

Econometric specification

The total number of potential adopters, y_{it}*, is assumed to evolve proportionally to the total population, POP_{it}. Hence, we specify:

$$y_{it}^{*} = \gamma POP_{it}$$

where γ is the proportion of the population that eventually will adopt a mobile. In principle, one may allow economic determinants, such as income, to influence the total market potential. In practice, the parameter γ proved difficult to estimate, related to the fact that the more mature stages of diffusion have not yet been reached in most countries.

The timing variable a_{it} is specified as:

$$a_{it} = \alpha_i^F + \alpha^D DIG_{it} \qquad (2)$$

where DIG_{it} is a dummy variable equal to one if country i has already introduced the digital technology at time t, and 0 otherwise. The α_i^F are fixed effects for each country i, and capture an adoption lag (or lead) relative to a base country. The parameter α^D captures the instantaneous effect of the introduction of the digital technology. Below, we formulate hypotheses about possible restrictions that may hold for α_i^F and α^D.

The speed of diffusion is specified as:

$$b_{it} = \beta_i^F + \beta^D DIG_{it} + \beta^{CA} CMPA_{it} + \beta^{CD} CMPD_{it} + z_{it}\beta \qquad (3)$$

where β_i^F are country-specific fixed effects reflecting the autonomous diffusion speed, and β^D captures the effect of the presence of the digital technology on the diffusion speed. Two competition dummy variables are included, $CMPA_{it}$ and $CMPD_{it}$, which equal one if there are at least two distinct operators for the analogue and digital technology, respectively.[5] Note that in all cases the first operator of the digital technology was already a supplier of analogue technology so that the introduction of digital technology did not imply additional competition by itself. The vector z_{it} refers to demand variables: income, measured by gross domestic product per capita, GDP_{it}; and the number of mainlines per capita, $MNLINE_{it}$. The latter captures the size of the fixed network and may have a positive or a negative effect depending on whether mobile communications are complements or substitutes for a fixed connection.

Testable restrictions

The timing of adoption is specified in a more restrictive way than the speed of adoption since the variables $CMPA_{it}$, $CMPD_{it}$, and z_{it} only enter (3), and not (2). In contrast, the digital technology variable DIG_{it} and on the country-specific fixed effects enter both (2) and (3) unrestrictedly. It is however possible that these variables have closely related effects.

First, consider the effect of the introduction of the digital technology, DIG_{it}. Let T_i^D be the time at which the digital technology is introduced in country i. A testable restriction is whether, at time T_i^D, there is only an increase in the speed of diffusion (β^D>0) or whether there is also a discontinuous upward jump. The absence of a jump at T_i^D implies:

Restriction 1 (no jump): $\alpha^D + \beta^D T_i^D = 0,$

whereas an upward jump implies the expression is positive.

Second, consider the country-specific fixed effects. Recall that the α_i^F capture the time lag (or lead) relative to a base country, whereas the β_i^F capture the differences in the autonomous diffusion speed. An interesting hypothesis is whether a country that adopts relatively late also experiences a faster rate of diffusion. This may be the case for several reasons, such as declining cost of investment through calendar time, international learning, etc... To the extent that this is indeed the case, there is international convergence, or catching-up by the late-comers. A simple way to measure the degree of convergence, is as follows:

Restriction 2 (simultaneous international convergence): $\beta_i^F = - \lambda\alpha_i^F.$

[5] These variables may be viewed as a proxy for price for which we have no data at our disposal for all periods and countries. The price for adopting mobile telecommunications services includes an initial connection fee, a monthly rental charge and a tariff per minute of usage. Furthermore, a whole menu of different tariff structures is usually offered to consumers.

Restriction 2, if true, implies that any country i and j would converge to the same number of adopters (holding all other variables constant) at time $t = 1/\lambda$. Hence, the inverse of the parameter λ may be interpreted as the time at which countries converge. Although this restriction may be overly restrictive (since countries presumably do not converge at the same time, if they converge at all), it does capture convergence in a parsimonious way.

Data description

The study is based on annual data and covers all 15 member states of the EU. The data on the number of subscribers at the end of each year and time of introduction of mobile telecommunications technologies is from *Mobile Communications* for the period 1992-1997 and from International telecommunications Union (World Telecommunications Indicators) for the period 1984-1991. The data are broken down by technology for each country. Data on GDP/head is from the OECD. Data on the number of fixed mainlines are from the International Telecommunications Union (World Telecommunications Indicators).

4. Empirical Results

The diffusion model is estimated using non-linear least squares, after adding an error term to (1). The empirical results are presented in Table 1. Specification (i) estimates the country-specific diffusion speeds (β_i^F) unrestrictedly. Specifications (ii) and (iii) impose the convergence Restriction 2. Specifications (iii) includes GDP_{it} and $MNLINE_{it}$. It was never possible to reject Restriction 1, implying that the introduction of the digital technology did not cause a jump in the number of adopters.[6] A precise estimate of the parameter γ, referring to the total market potential, could not be obtained. The reason for this is that most countries are still at the early stages of diffusion, so that there is little information about the mature part of the diffusion curve.[7]

We start with a discussion of the parameter estimates of specification (i). The diffusion speed parameters, β_i^F, have an estimated value (averaged over all countries) of about 0.30, implying a maximum "autonomous" growth rate of about 15 percent at the inflection point. The coefficient for the variable DIG_{it} measures the role of the transition from analogue to digital technology in speeding up the diffusion of mobile services. The estimates show that the technology effect is relatively large, with an estimate of 0.13. Combined with the result

[6] For more detailed empirical results, see Gruber and Verboven (1998). The t-values for the hypothesis of Restriction 1 were 0.59, 0.66 and 0.30, in specification (i), (ii) and (iii), respectively. The parameter estimates are similar when Restriction 1 is not imposed, while the standard errors of some parameters are larger.

[7] In a pooled version of the diffusion model, with $\beta_i^F = \beta^F$, there is potentially more information about the shape of the diffusion curve, since some countries may have reached phases closer to maturity. A pooled regression estimates γ to be equal to 0.62, with a standard error of 0.05, implying that there will be 62 mobile subscribers per 100 inhabitants in the long term, which is slightly higher than most industry forecasts.

that Restriction 1 could not be rejected, one may describe the transition from the analogue to the digital technology as smoothly though sharply accelerating the diffusion of mobile communications. The transition implied a drastic increase in spectrum capacity, apparently inducing even monopolists to cut prices to attract a larger amount of adopters. Even independent of increased capacity, the digital technology may have stimulated the diffusion, because of the advantages (e.g. roaming) associated with the common GSM standard.

The effect of introducing a second competitor, measured by the coefficients of the variables $CMPA_{it}$ and $CMPD_{it}$, is also significant. The magnitude of this effect is, however, much smaller than the technology effect. Note that the introduction of a second competitor has been of greater importance during the analogue than during the digital period. This is possibly due to the considerably higher prices during the analogue period. Moreover, in many countries analogue mobile telecommunications services were supplied by a monopoly with a prolonged exclusive licence. In contrast, with digital services, it was known at the outset (from the EU Directive) that a monopoly, if present, would be granted only over a very limited period.

To check for the robustness of our estimates, we experimented with alternative definitions of the competition variable. To incorporate possible preemptive behaviour, we specified the competition variable to equal one from the year preceding actual competition. We also considered a specification allowing for a different effect when competition was introduced simultaneously rather than sequentially. We finally estimated a regression with a separate dummy variable for duopoly and triopoly market structures. None of these specifications altered our conclusion of a significant, though relatively moderate competition effect as compared to the technology effect. The results point out that the technological changes appear to have been dominant during the studied period, and that the effects of introducing competition should at present not be exaggerated.

The relatively small competition effect is consistent with the findings in Parker and Röller (1997), who focus on competition in more detail, but abstract from dynamic aspects such as technological developments and the timing of first licenses. They study various aspects of competition in the U.S. mobile telecommunications market, such as the degree of collusion, cross-ownership and multimarket contact. They find that the duopoly structure of regional markets leads to prices significantly higher than under the noncooperative Cournot duopoly outcome, and significantly though not substantially smaller than under monopoly outcome.

A final insight from specification (i) arises from plotting the country-specific timing effects α_i^F against the country-specific diffusion effects β_i^F in Figure 1. This graph reveals the following striking finding: there is a strong relationship between the timing of adoption and the subsequent speed of adoption. Countries that start adopting at a later date also experience a faster growth. One may thus speak of a catching-up effect of late-coming countries. This may be attributed to several factors. First, the cost of infrastructure investment and the cost of subscriber equipment (the handset) are decreasing over time, enabling the late coming countries to grow faster. Second, using the frequent interpretation of the diffusion speed parameter as a "learning" parameter, the catching up effect may be attributed to international learning spillovers. Finally, quality of mobile telecommunications services is increasing: with GSM wide-ranging international roaming is possible and consumers have a larger incentive to adopt, since they benefit more from international network externalities.

Given the strong relationship between the timing and diffusion speed fixed effects, it is natural to consider a more restricted regression. Restriction 2 imposes one possible relationship. The results are presented in specification (ii) of Table 1. A quasi-likelihood ratio test showed that (i) is statistically superior, though only marginally. As Figure 1 indicated, the parameter λ is very precisely estimated. The inverse of λ is approximately 22. Since the data set starts in 1984, this implies that international convergence in the number of adopters would be reached around the year 1984+22=2006. Therefore, countries which issued spectrum licenses rather lately, due to whatever local political reasons, eventually catch up. Nevertheless, the delay is quite substantial, especially in light of the large welfare losses from delayed adoption as reported by Hausman (1997) for the U.S., see footnote 4.

Now consider specification (iii) in Table 1, which includes the parameter estimates for GDP_{it} and $MNLINE_{it}$. The parameter estimate of $MNLINE_{it}$ is significantly negative, indicating that consumers perceive mobile communications services as a substitute for the fixed network. Mobile telecommunications were conceived in the early years as a complementary service to fixed telecommunications, mainly for business people and wealthy persons. However, as mobile telecommunications become a widely spread service and tariffs comparable to fixed telecommunications, substitution effects may become predominant. The parameter estimate of GDP_{it} is positive, although not significant. This is due to the high degree of multicollinearity between $MNLINE_{it}$ and GDP_{it}, also known as the Jipp-curve. Most other parameter estimates are robust with respect to the inclusion of these variables, with the exception of the autonomous diffusion parameter, β^F, which becomes considerably higher. This is because $MNLINE_{it}$, which increased throughout the sample period, had a significant negative effect on the diffusion, which was taken over by β^F in (i) and (ii).

5. Conclusions

This paper studied the determinants of the diffusion of mobile telecommunications services in the European Union in a logistic model of technology diffusion. We find that the transition during the early nineties from the analogue to the digital technology, and the corresponding increase in capacity, has had a major impact on the diffusion of mobile telecommunications. Apparently, the technological developments induced even monopolist operators to reduce their prices and attract more adopters. In addition, countries which granted licenses at a later point in time show a rather slow catching-up. Finally, the impact of introducing competition was significant, during both the analogue and the digital period, though the effect was small compared to the technology effect.

The results involve a wide range of policy issues – including the role of technology, the timing of first licenses, and the introduction of competition. The importance of improvements in technology appears clear and hard to underestimate. The role of the timing of first licenses demonstrates that early countries have a fairly long persisting lead (until the year 2006). As indicated by other studies, the welfare costs associated with such a persistent delay may be quite high. Finally, the relatively small estimated effect of competition is consistent with evidence for the U.S., but should be put in perspective. First, the sample covered mainly movements to duopoly. The effects of more competition remain to be seen as third or even more licenses are being issued. Second, even if competition has a relatively small effect on the adoption decision by consumers, this does not imply similar effects on the usage decision.

These qualifying statements call for various interesting directions in future work. Detailed price data (which is not an obvious task) may be collected to achieve further results on the differences between monopoly behaviour and competition. The role of the local policies followed in the various countries may be studied in further detail to obtain additional insights on the differences in adoption levels and speeds across countries. Finally, the evolution during the next 10 years, when the industry will have reached a stage closer to maturity, will yield interesting new data against which the results of this paper can be confronted.

6. References

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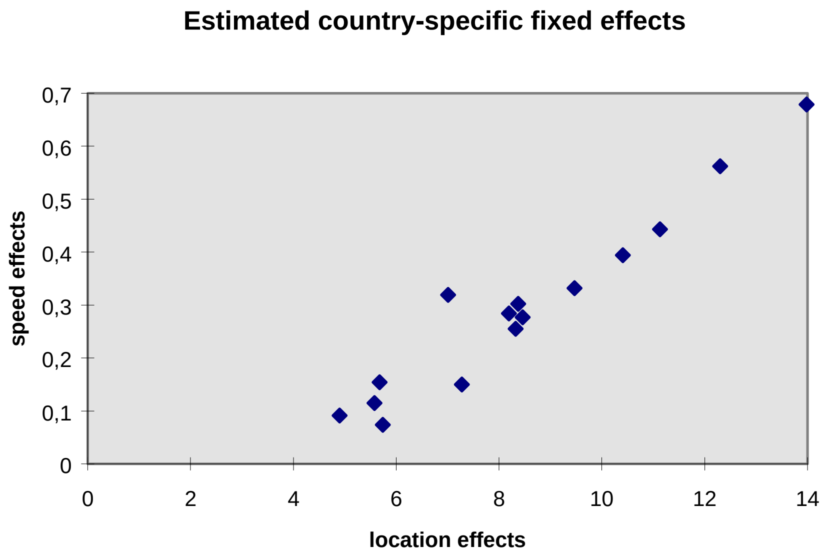
Table 1. Results for diffusion equation (1)

	(i)	(ii)	(iii)
Fraction of population, γ	1.394* (0.441)	1.198* (0.405)	2.002 (1.179)
Location fixed effects, α_i^F	YES	YES	YES
Diffusion speed parameters			
fixed effects, β_i^F	YES	NO	NO
autonomous diffusion speed, β^F	0.295* (0.067) [a]	0.381* (0.037)	0.631* (0.051)
convergence parameter, λ		0.046* (0.005)	0.043* (0.004)
digital technology, β^D	0.130* (0.033)	0.162* (0.042)	0.106* (0.041)
Analogue competition, β^{CA}	0.023* (0.010)	0.025* (0.013)	0.020* (0.011)
Digital competition, β^{CD}	0.014* (0.005)	0.011* (0.006)	0.008 (0.005)
GDP_{it}			0.942 (0.749)
$MNLINE_{it}$			-0.334* (0.070)

[a] Fixed effects β_i^F, averaged over all countries. Country-specific fixed effects in (i) are plotted in Figure 1. Standard errors are in parentheses. A star indicates the coefficient is significant at 95% confidence level.

Figure 1



location effects: α_i^F (in absolute value)

speed effects: β_i^F