DISCUSSION PAPER SERIES

No. 2598

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INDUSTRIAL ORGANIZATION

Centre for Economic Policy Research

www.cepr.org

ISSN 0265-8003

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Discussion Paper No. 2598
October 2000

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CEPR Discussion Paper No. 2598

October 2000

ABSTRACT

The Impact of Mobile Phone Diffusion on the Fixed-Link Network*

There is currently little knowledge on the consequences of diffusion of cellular technology on the incumbent fixed-link telephony service. This paper addresses this issue by estimation of diffusion curves for both technologies, allowing for potential cross-effects, using data from a small European economy. The main findings are a negative effect of the mobile phone diffusion on the fixed-link telephony penetration rate. The effect is, roughly, a 10% decrease in the fixed-link penetration rate (in comparison with the absence of mobile phones). No effect on the reverse direction seems to exist. Mobile phone market growth seems to be determined essentially by technological advances.

JEL Classification: L96
Keywords: mobile phone diffusion and telecommunications

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* We thank participants in several seminars for useful comments and suggestions. All errors and deficiencies are our own. We gratefully acknowledge financial assistance by the European Commission under the TMR network contract number ERBFMRX-CT98-0203.This paper is produced as part of a CEPR research network on The Evolution of Market Structure in Network Industries, funded by the European Commission under the Training and Mobility of Researchers Programme (Contract No ERBFMRX-CT98-0203)

Submitted 19 September 2000

NON-TECHNICAL SUMMARY

Technological advances in recent years made mobile telecommunication services available at an unprecedented rate. The introduction of digital technology as well as a more liberal stance on spectrum licensing has led to a fast diffusion of mobile telephones. At the same time, the opening of traditional fixed-link telecommunications has been actively promoted in the European Union Member States. The European Commission led the way, imposing a schedule for telecommunication service liberalization. Although some attention has been devoted to the mobile telephony market, little is known about its impact on the fixed-link telephone service. This paper addresses this issue by estimation of diffusion curves for both technologies, allowing for potential cross-effects.

The effect of the mobile phone technology on the fixed-link operator is, by no means, clear. On the one hand, we have a substitution effect: some calls previously placed on the fixed-link network are diverted to mobile phones. Some subscribers of the fixed-link network may even opt for the mobile phone network only. This suggests a negative impact of mobile phone diffusion on the fixed-link telephony penetration rate. On the other hand, network externalities may increase the overall number of calls, and, by doing this, will also benefit the fixed-link operator. Moreover, divertion of calls from within the fixed-link network to situations where either the receiver or the caller (but not both) belong to the fixed-link operator is not necessarily disadvantageous to the fixed-link operator. This paper attempts to measure the net effect of mobile phones diffusion on the number of subscribers of the fixed-link telephony service using available data for a small European economy – Portugal. An advantage of using data from Portugal is that we can better trace the effects of mobile phones as, at the start of mobile telephony, the fixed-link diffusion was far from complete. This makes the exercise interesting for many other European countries.

The findings allow comment on recent developments in the telecommunications markets worldwide, and especially in the European Union. There has been a broad trend of liberalization and deregulation in telecommunications markets. In most countries, these markets were characterised by an incumbent monopolist. Often, there were also provisions on the so-called universal service obligations.

Due to the general environment favouring deregulation of telecommunications markets, the new mobile phone market has seen competition at relatively early stages of development. This contrasts with the previous development of the fixed-link telephone network. Faced with increasing competition both from the mobile market and from the opening of previous monopolies to other suppliers, incumbents have been forced to change tariff structures (rebalancing) to avoid cross-subsidization (namely, long-distance calls

subsidizing local calls). The last argument for protection of incumbent fixed-link operators lies in the universal service obligations, and how liberalization and growth of mobile phone markets may have decreased the ability of incumbent fixed-link companies to fulfil these obligations. Our work suggests that although fixed-link networks may experience a slowdown in their diffusion due to the growth of mobile telephony services, for the time being the effect is not very pronounced and may be more than compensated for by revenues from traffic generated by mobile-to-fixed (and vice-versa) calls. Thus, the growth of cellular telephony has been mainly a demand-creating effect for telecommunication services at large. Since competition has been a positive factor, fostering diffusion of mobile phone services, the general approach followed at the European Commission seems to bear positive effects, even though a full welfare analysis is beyond the scope of the present work.

It is also possible to derive some implications for less advanced countries where fixed-link network diffusion may still be an issue (namely, for Central and Eastern European Countries). Further development of the mobile phone market should not be hindered by fear of sharp unfavourable effects for fixed-link operators. Some negative effects may occur, but they are of a relatively small order of magnitude.

1. Introduction

Technological advances in recent years made available mobile telecommunication services at an unprecedented scale. The introduction of the digital technology as well as a more liberal stance on spectrum licensing has lead to a fast diffusion of mobile telephones. At the same time, opening of traditional fixed-link telecommunications has been actively promoted in the European Union Members States. The European Commission led the way, imposing a schedule for telecommunication services liberalisation. Although some attention has been devoted to the mobile telephony market, little is known about its impact on the fixed-link telephone service.

We intend to fill this gap. We use data from a European Union country, Portugal, thus examining an European experience. The available data allows us to trace the evolution from the point of introduction of cellular technology up to an almost equal number of subscribers in mobile phone and fixed-link services. In fact, at the end of our sample (last quarter of 1999), the number of mobile phone subscribers exceeded that of fixed-link telephone users. As such, it constitutes also a reference point for the likely evolution of the telecommunications market of other economies.

The main objective of the current study is to evaluate the impact of mobile phone growth on the fixed-link network. The easiest way to evaluate the effect of some exogenous change in the penetration rate of fixed-link telephony is to consider some diffusion curve for the latter as a function of the former variable. As we are interested on the effect of mobile phone technology, one could just add this variable to the set of explanatory variables of the fixed-link penetration. However, this is clearly not satisfactory, as the mobile phone and fixed-link penetration rates are (potentially) interdependent. This advises us to model both processes simultaneously, a feature that has not been present in earlier works.

The closest works to ours are Gruber and Verboven (1999, 2000) and Gruber (2000). They look at the determinants of diffusion of cellular phone technology in the countries of the European Union. In particular, Gruber and Verboven (1999) aim at disentangling the effect of pure technological factors and of Government-led diffusion.

Gruber and Verboven (1999) allow for an effect of the fixed-link telephony on mobile communications speed of diffusion. For the European Union countries, in the period 1991-1997, the authors find a negative coefficient. This means a substitution effect between mobile and fixed-link networks. However, this ignores that the decision to use the fixed-link telephone is not independent of mobile communications development. In fact, the more adequate interpretation of Gruber and Verboven (1999) results is that countries with lower penetration of fixed-link network experienced higher growth of the cellular phone market. We are interested in the complementary question: what would have been the diffusion of the fixed-link network in the absence of mobile communications?

On the other hand, Gruber and Verboven (2000) extend the analysis to world data and look at a different set of issues. Gruber (2000) looks at diffusion of mobile telecommunications in Central and Eastern Europe, finding that countries which are late adopters have a faster diffusion rate. He also finds a positive effect on diffusion from increasing competition and from the size of the fixed-link network.

Our work is complementary to theirs, as we ask the question of how big is the impact of cellular phones on the existing fixed-link telecommunications service. Gruber and Verboven (1999, 2000) and Gruber (2000) take as exogenous the existing fixed-link network. In contrast, we allow for feedback effects. On the other hand, we do not focus on licensing procedures, setting of standards, timing of entry, etc.

While it is clear that a high penetration rate of fixed-link telephony is a good proxy to market demand for telecommunications services, it is also true that the number of current subscribers may not be independent of cellular phone diffusion.

Another difference that makes our study complementary to Gruber and Verboven (1999, 2000) and Gruber (2000) is the dimension used to trace the relevant effects. While the analysis of Gruber and Verboven (1999, 2000) and Gruber (2000) use cross-country differences to identify diffusion determinants, we focus on time evolution to clarify the interaction among the fixed-link and cellular phone diffusion technologies. This isolates country-specific effects, which have been found to be relevant in previous studies.

The mobile phone market has also received attention from Parker and Roller (1997), who address in detail the competition effects in the U.S. cellular telephone market. In particular, they find evidence of collusion, which explains a small, and significant, effect from the evolution of monopoly to duopoly. Roller and Waverman (2000) address the issue of the contribution of telecommunications infrastructure to economic growth. They find a critical mass effect. The critical mass effect implies that only when the number of subscribers of telecommunication services reaches a critical treshold it is possible to find statistically significant results. The highly significant role, in statistical and economic terms, of country-specific effects means that a good deal of differences across countries is still unexplained. Thus, country studies, exploring in detail the evolution of the telecommunications sector in a single country over time, provides complementar information to that obtained from cross-country studies.

In another direction, Jha and Majumdar (1999) evaluate the impact of mobile phone diffusion on the productive efficiency of the telecommunications service. They find a positive and significant effect.

It is useful at this point to contrast our findings with the results of Gruber and Verboven (1999). They find evidence that consumers perceive mobile telephony as a substitute product for the fixed-link telephone service. We also find evidence in accordance to it in terms of the number of subscribers. The effect is weaker than prior expectations, given the speed of cellular phone diffusion.

Despite the apparently natural effect of substitution in the number of subscribers between mobile telephony and fixed-link telephone services, the empirical evidence is not totally clear, as Ahn and Lee (1999) found demand for access to mobile phones to be positively related to fixed-link penetration.

As to the mixed empirical evidence of Gruber and Verboven (1999) and Ahn and Lee (1999), our analysis clarifies that a negative effect upon development of fixed-link telephony is still compatible with a seemingly positive correlation (as both penetration rates are still rising, a positive effect can be identified).

Before we proceed further in the analysis of penetration rates over time, it is instructive to see that, on a cross-country basis, cellular penetration has increased, but also fixed-link penetration progressed positively. Figure 1 shows, moreover, than in the countries with a more pronounced diffusion of mobile phones, fixed-link growth was lower. Thus, a sort of substitution pattern seems to exist.[1]

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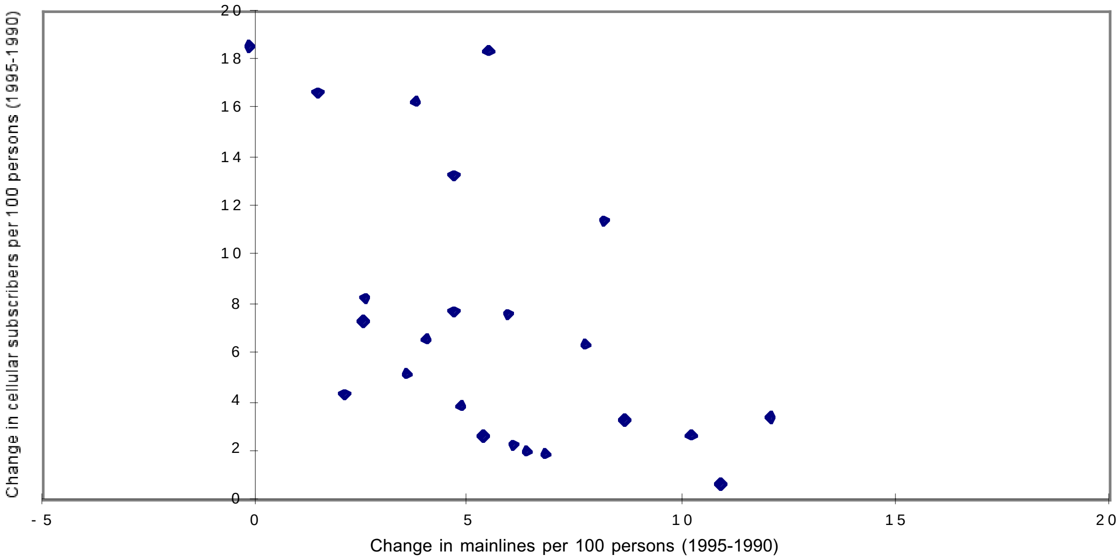
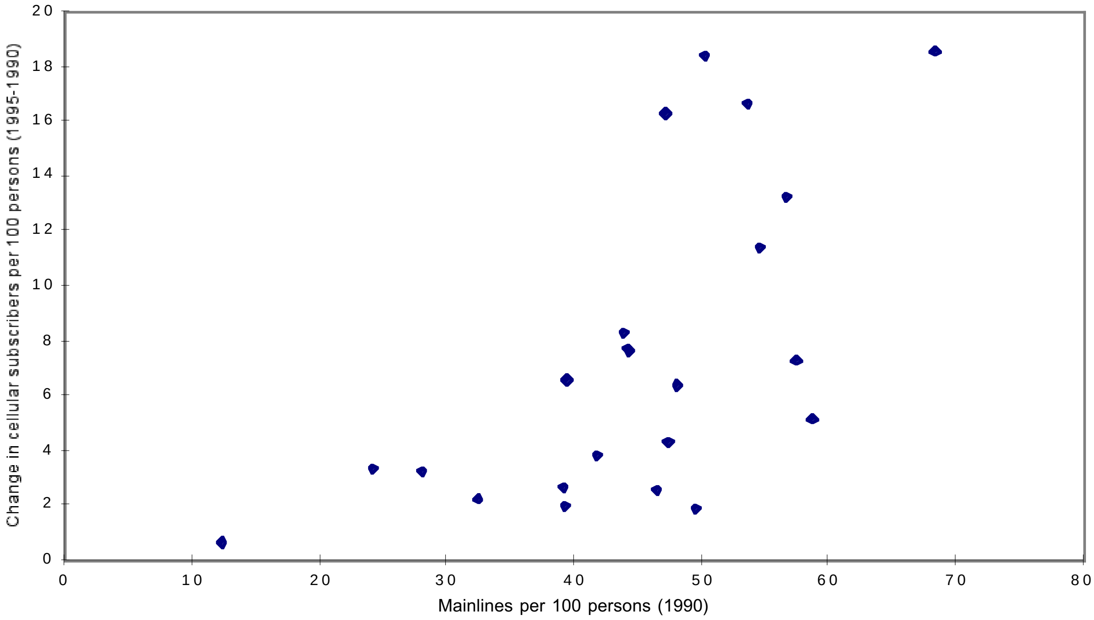
[1] This can be easily confirmed by way of a simple regression, which yields a statistically significant negative coefficient.

Figure 1: Changes in penetration rates



Source: Jha and Majumdar (1999), Table 1.

Figure 2: Growth of mobile phones and fixed-link telephone penetration



Source: Jha and Majumdar (1999), Table 1.

Probing a little bit further, Figure 2 presents the change in cellular subscribers vs. the stock of mainlines in 1990. A clear positive relation can be detected, thus justifying the finding of some "demand sophistication" in needs of telecommunications services, as a positive determinant of mobile phone diffusion. Those countries with a higher degree of penetration of fixed-link telephony, mobile phone technology experienced the highest growth rates. In a simple way, these are the main effects we believe have been detected in previous empirical studies. As it will be apparent below, our findings are complementary to the available cross-country evidence. We find a negative effect of the mobile phone diffusion on the fixed-link telephony penetration rate. No effect on the reverse direction exists.

The paper is organised as follows. Section 2 presents a preliminary exploration of the data. Next, Section 3 outlines the econometric model, reports data sources and econometric procedures. Section 4 presents the estimates. Finally, Section 5 concludes.

2. A preliminary exploration

In response to the introduction of the cellular phone technology, a slowdown in fixed-link penetration is expected. New generations of consumers entering the market perceive no advantage of the fixed-link over the cellular technology. In fact, the mobility associated with the latter gives a clear advantage at consumers' eyes. Thus, a negative impact is anticipated. Other effects absent, one may expect a stop, or even a decline, in the fixed-link penetration rate. However, the assumption of "no-other-effects" is probably unrealistic. For example, the recent explosion in internet growth seems to spur further diffusion of fixed lines, especially if based on digital technology. Internet traffic demands higher quality transmission and it is also a more "dense" traffic, as carrying images and sound over the telephone network is quite distinct from simple voice services. This makes important and interesting to look simultaneously at fixed-link and cellular telephony diffusion processes.

Like most innovations, telephones, either fixed or mobile, have not been adopted at the same time by all potential consumers. The adoption process takes time. There are several aspects that influence, in a decisive way, the diffusion and adoption of new telecommunications technologies, like the price of calls and equipment, and the level of competition in the marketplace.

The effect of the mobile phone technology on the fixed-link operator is by no means clear. On the one hand, we have a substitution effect: some calls previously placed on the fixed-link network are diverted to mobile phones. Some subscribers of the fixed-link network may even opt for the mobile phone network only. This suggests a negative impact of mobile phone diffusion on the fixed-link telephony penetration rate. On the other hand, network externalities may increase the overall number of calls, and by this to benefit also the fixed-link operator. Moreover, divertion of calls from within the fixed-link network to situations where either the receiver or the caller (but not both) belong to the fixed-link operator is not necessarily disadvantageous to the fixed-link operator. We attempt to measure the net effect of mobile phones diffusion on the number of subscribers of the fixed-link telephony service. We use available data for a small European economy, Portugal. An advantage of using data from Portugal is that we can trace better the effects of mobile phones, as at the start of mobile telephony, the fixed-link diffusion was far from complete. This makes the exercise interesting for many other European countries. Of course, for countries that have, arguably, reached the peak of fixed-link diffusion, like Finland, a different empirical approach has to be tought of.

The issue of whether cellular telephones are a substitute or a complement to the fixed-link telephony service should, ideally, be addressed in traffic and revenues, in addition to the effect upon subscribers. Unfortunately, such information is not available to us.

Some basic facts about the time evolution of telephony services are worth describing, before a formal econometric analysis.[2] Looking at quarterly data since 1993, the penetration rate for the fixed-link telephony seems to follow a linear trend. At the same time, growth of the mobile phone market follows, apparently, an exponential trend (see Figure 3). We observe a slow start, followed by an acceleration period in the relative size of cellular vs. fixed-link networks. By the end of 1999, the number of mobile phone subscribers exceeded, for the first time, that of the fixed-link network. However, the current trend is not sustainable as a general description of mobile phone diffusion. It would imply a penetration rate of 152% by the end of year 2001. This is clearly unrealistic. It would mean more than doubling current number of phones in a year. Even the more advanced countries at the end of the diffusion curve are now reaching values close to 100% penetration rates (e.g. Finland). The more recent values disclosed, second quarter of 2000, indicate that mobile phone subscribers are about 5.2 million, a penetration rate of (roughly) 52% in July 2000.

The (almost) linear trend for the fixed-link telephony strongly suggests that diffusion of this technology is already reaching the upper tail of the S-shaped process.

The tradition in the analysis of technology diffusion has been to assume S-shaped functions.[3] That is, a slow start is followed by a rapid increase in the number of adopters of the new technology. After reaching some critical mass, the rate of adoption decreases again, as the set of potential new users is exhausted. The S-shaped processes can be justified by economic theory in several ways. See Geroski (1999) for a recent overview of the literature on technology diffusion.

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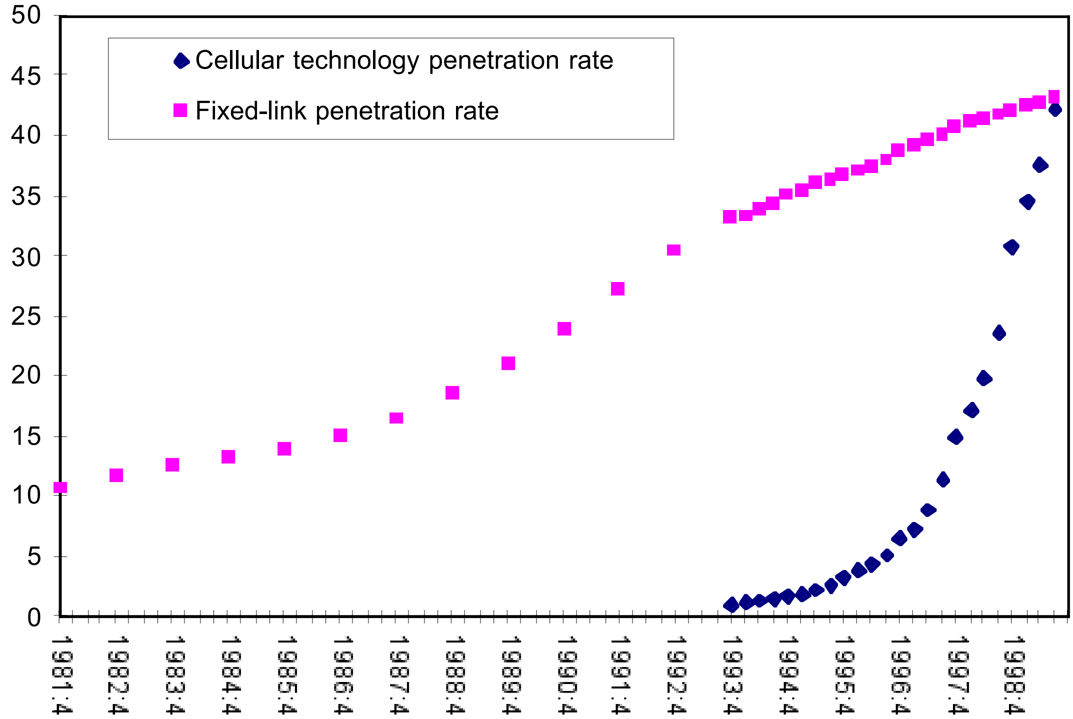
[2] A more in-depth analysis of the Portuguese telecommunications market can be found in Cadima (1999).

[3] See, for example, Chow (1967) for an early example.

Figure 3: Penetration rates of mobile and fixed-link networks



These preliminary data explorations have important implications for our analysis. In particular, they are at the root of two unconventional procedures that we will use.

First, to econometrically trace the diffusion curve of the fixed-link penetration rate, using the available quarterly data has very clear shortcomings. More information on the other phases of diffusion is called for. As there is no quarterly data available prior to 1993, we take the option of combining quarterly and yearly data. This combination of series of different frequency will increase precision in the identification of the diffusion process for the fixed-link telephone service. Second, given the unrealistic trend for steady-state penetration rate in the mobile phone, an exogenously set upper limit will be imposed (more on this below).

3. Variables, data and procedures

To characterise the diffusion process at work and the (possible) interactions between mobile and fixed-link telephone services, we adopt a two-equation model. The (very) small sample size advises a parsimonious modelling of effects.

The first equation describes the diffusion process of the cellular telephony penetration rate (*CTPR*). We take the diffusion process to depend, besides a time trend, on the size of the fixed-link network, measured by its penetration rate in the same period (*FLPR*), on the 'price' variable (*ARPS*), on income, proxied by real GDP per capita, (*GDP*), on seasonal effects (*TRIM*) and on the introduction of competition (*COMP*). The seasonal effects variable, *TRIM*, is an index that intends to capture peak demand for mobile phones in the last quarter of the year, due to Christmas sales. The competition variable, *COMP,* intends to capture the acceleration of penetration due to the start-up of a third mobile phone provider. It is a proxy for effects other than price, like the advertising surge that occurred a little before and after entry of the third operator in the mobile telecommunications market.

We take the penetration rate of the fixed-link telephone service as dependent on several elements. Since we are dealing with a diffusion curve, time is obviously present. Focusing on demand-side determinants of telephone penetration, it comes naturally to mind the role of price and income, and measures of both are considered (*PRICE* and *GDP*, respectively). In terms of substitution pattern with mobile telephony, we include both the level of penetration of cellular phones (*CTPR*) and the price of their services (*ARPS*). A recent development may have changed the trend regarding the fixed-link telephone services: the internet. Internet provision is mainly provided to households through the fixed-link network. People may not disconnect the fixed-link line in order to access internet services, and in some cases, second household lines are being bought for this purpose.

Thus, penetration rates of the fixed-link telephony services may experience a new upturn. Of course, this may be a sufficiently new phenomenon to not be adequately captured in our empirical framework. Nonetheless, we opt for including it, measured by the number of internet users (*INTERNET*). In addition, we allow for seasonal effects (*TRIM*).

The data available covers the period 1981 up to the fourth quarter of 1999. Prior to 1994, data are on annual frequency. From 1994 onwards, quarterly data are available. We use all the information available. The main implication is that the time index jumps on multiples of four until 1994, to account for series frequency differences.

The penetration rate in the fixed-link telephone service is computed as the number of lines over the population. Information on the number of lines is provided by the incumbent monopolist, *Portugal Telecom*. Population figures were obtained from *INE* - *Instituto Nacional de Estatística* (the official statistical office). Notice that we normalised the number of lines by the total population and not the total number of households. This implies a saturation point typically below 100% (as the typical household has an average number of members slightly above 2, and rarely more than one fixed-link phone).

The mobile phone penetration rate is obtained in a similar way. The total number of cellular phone subscribers was obtained from ICP - *Instituto de Comunicações de Portugal* (the Portuguese regulatory body for telecommunications).

As to the price variable for mobile phone services (*ARPS*), it was computed as the revenues over the quarterly average number of subscribers of one cellular phone operator (quarterly data for the other main operator was not available to us), divided by the CPI. This means that we use a relative price of mobile telecommunications. The CPI was obtained from *INE*.

Unfortunately, we do not have information allowing for computation of prices per unit of time or per call, on a quarterly basis. The assumption of a close association of both operators' prices is not a strong one. It clearly holds on annual data, and for other measures of price.

The variable *TRIM* accounts for quarterly effects, according to average growth in each quarter, and normalised for the first quarter value. The option to use a seasonal index and not quarter dummies is due to the need of saving degrees of freedom for the econometric analysis.

The competition variable *COMP* accounts for entry of a third licensed operator in the mobile phone market. It takes value one after entry of the third operator, zero otherwise. Entry occurred in the last quarter of 1998.

A cautious treatment of the price variable in the fixed-link telephone service (*PRICE*) is in order. Given the heterogeneity of calls, it is not obvious what is the relevant price. The natural candidate is a weighted average of several prices. However, the required information is too demanding, especially for older periods. We face two problems to build a price index for the fixed-link telephony service. The first one is the lack of data prior to 1993; the second problem is the tariff rebalancing (from 1998 onwards), which induced changes in the pattern of calls. Given these constraints, we constructed a price index for the telephone service which includes a monthly charge (access fee) plus user charges according to the 1997 average pattern of calls (type and duration of calls).

The time period covered goes from 1981 to the last quarter of 1999.[4] Until 1993, only annual data are available. From this year on, quarterly data are used. The diffusion process of cellular technology takes off essentially after the licence to the second operator was issued. Thus, only from 1992 onwards can we find a visible number of mobile phone subscribers. We only consider the mobile phone market after it reaches 1% of penetration rate. This implies that data on the mobile phone diffusion process is all of quarterly frequency. On the other hand, the fixed-link service diffusion will be defined to a considerable extent by annual data. We have 37 observations for the fixed-link penetration rate equation and 26 for the mobile phone equation.

The first step in the econometric procedures for estimation is to specify the functional forms. As two diffusion processes are under consideration, after some experimentation, we adopt the logistic function for the diffusion process of the fixed-link network and the Gompertz function for the diffusion of the mobile phones. The basic difference between the logistic and Gompertz functionals is that in the latter we observe a higher initial adoption value, which seems to fit the observed mobile phone diffusion pattern.

The functional forms for the penetration rate of the cellular technology and of the fixed-link telephony are:

$$CTPR_t = \beta_0 + (\mathrm{K} + X_t \mathrm{B}_1 - \beta_0)\exp(-\exp(Z_t \mathrm{B}_2)) \qquad (1)$$

$$FLPR_t = \frac{\Theta_1 W_t}{1 + \exp(\Theta_2 V_t)} \qquad (2)$$

where X, Z, W and V are sets of variables and B_1, B_2, β_1, Θ_1, and Θ_2 are sets of coefficients. The parameter K is an exogenously specified value for the long-run value of the penetration rate. It should be noted that the long-run penetration rate approximates $K+XB_1$.[5]

In set X we include the variables that may affect the penetration rate: income (*GDP*), own price (*ARPS*), the degree of competition in the market (*COMP*)

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[4] There are some data for the first quarter of 2000. Unfortunately, not for all variables. Estimation excluding the variables for which there is no information for 2000 yields very similar results.

[5] These are not the only functional forms possible. In particular, one may think that the fast diffusion of mobile phones advises the inclusion of determinants of the diffusion rate and not of the penetration rate. Earlier versions of the paper contemplated this possibility. Estimates for the effect on the fixed-

and the penetration rate of the fixed-link telephony (*FLPR*). In the diffusion components, *Z* (=*V*), we include a time trend (*TIME*) and the seasonal effects (*TRIM*), plus a constant. The set *W* includes income (*GDP*), own price (*PRICE*), internet users (*INTERNET*), the cellular telephony penetration rate and the price of cellular phone services (*ARPS*), and a constant term.

The equation for the cellular telephony penetration rate has an unusual format. The reason for this option is the following. Under a different version of equation (1),[6] one obtains unreasonable upper limits for the cellular phone penetration rate (in the range of 127% to 730%).[7] The econometric procedure is capturing mainly the exponential part of the diffusion process. It seems that the high-growth stage in the diffusion process has just been finished (see Figure 3). Relying mainly on data from this part of the process results in estimation problems. The solution to this problem consists in the imposition of an exogenous anchor on the upper limit of mobile phone subscriptions.

The first step in the computation of this estimate consists in drawing a distinction between the business and the individual markets.[8] In this market segmentation, it is reasonable to assume that business consumers use the equipment during business hours, while residential consumers will use the service mainly at the off-peak periods (after work and weekends). The business market can still be divided into four submarkets, according to the needs of usage of mobile phone: mobile workers, mobile managers, semi-mobile workers and non-mobile workers.

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link telephony from cellular market development are similar. These estimates are available from the authors upon request.

[6] Of the form $CTPR_t = \beta_0 + X_t B_1 \exp(-\exp(Z_t B_2))$, where *X* includes a constant term.

[7] In economic terms, this means something like a number of mobile phones between 13 million and 73 million for a population of 10 million people.

[8] See Knott and Bilgin (1998).

Based on current population structure, GDP levels and active workers figures, we define penetration rates for each of these sub-markets: 100% in each of the three sub-markets of business users and 75% in the last one. Given a workforce of 4.7 million workers, the predicted upper limit in this market segment is 4.2 cellular phones.

The residential market penetration rate is determined by income levels, the price of the handset and the price of calls. We may still distinguish retired people (above 65 or retired), young (above 15 years old), children (between 8 and 15 years old) and unemployed. To the age structure of population, we make use of the last census (1991) information. We assume that 30% of children, 100% of young people and 50% of unemployed will have mobile phones. These values are based on marketing studies, as well as on the experience of other countries (for example, the penetration rate in Finland in the young group is 100%).

Taking together all these elements, the estimated upper limit is 70%. That is, $K = 0.7$. Our exogenously estimated level of mobile phone penetration is above the estimate of Gruber and Verboven (1999), which is about 60%. Using the latter does not change the results, and is, in our view, an under-estimate in the Portuguese context (and probably in other European countries as well, like Finland).[9]

These two equations determine simultaneously both penetration rates, unless some of the cross-effects are non-significant. The research approach has to deal with small number of observations and the existence of different frequency data in one of the equations. The likelihood function takes into account that prior to 1993 there was no cellular telephony market. Full information maximum likelihood estimates, allowing for

[9] The specification allows for higher or lower values, depending on the magnitude and significance of effects. The current situation of some European countries, like Finland and Iceland, suggests that the 70% upper limit is an attainable one.

contemporaneous error correlation across equations, are reported in the next section.

4. Results

The estimates are presented in Table 1. They show that introduction of further competition (that is, licensing of a third mobile phone operator) fostered mobile phone penetration. The negative coefficient for the variable *Time* means that penetration has been rising over time, as one expects from a diffusion process. Income per capita seems to bear no relation with the growth of mobile telephony market. The fast development of this market has been essentially independent of income growth. Curiously enough, the seasonal effects are not statistically significant across the board, although they are intended to capture a strong end-of-the-year effect, mainly in the mobile telephony market.

On the other hand, the price effect is either non-significant or negative. Non-significance is probably due to the fact that the time trend captures the sharp decline in prices of telephone services *and* of handsets, the latter not being included in our measure of prices (whenever the price variable is excluded or statistically non-significant, the magnitude of the *TIME* variable increases considerably).

The feedback effect of the fixed-link network development on the mobile phone diffusion turns out to be non-significant. The evolution of the fixed-link network had no bearing on the development of mobile phones penetration. This is not surprising as mobile phones diffusion is more likely to be driven by other elements. The rate of technological innovation in the manufacturing of handsets has produced more reliable, lighter and cheaper phones. Competition among manufacturers has also contributed for a decline in prices of handsets. Such innovation pace has been, probably, the most important single fundamental drive of mobile phone diffusion. This may also justify the non-significance of the (relative) price variable.[10] We conclude that technological innovation was the essential driver of mobile phone diffusion.

Table 1

Cellular penetration rate equation					
Const. (β_0)	0,018	0,013	0,019	0,020	0,020
	9,96	*10,69*	*9,88*	*10,51*	*10,60*
Const. in Z	8,529	6,071	8,470	8,686	8,648
	29,68	*14,20*	*30,04*	*31,94*	*32,11*
ARPS	0,228	-5,762			
	0,15	*-3,57*			
TIME	-0,122	-0,082	-0,122	-0,125	-0,125
	-25,88	*-11,18*	*-28,98*	*-30,67*	*-30,87*
FLPR		2,475			
		0,619			
COMP	0,137	0,129	0,144	0,138	0,142
	8,99	*8,02*	*8,64*	*9,02*	*9,35*
GDP		-0,283			
		-0,28			
TRIM	-0,025	-0,032			
	-1,34	*-2,97*			
Fixed-link penetration rate equation					
Const. in W	-0,021	-0,022			
	-0,24	*-0,22*			
CTPR	-0,070	-0,068	-0,077	-0,091	-0,127
	-1,86	*-1,12*	*-3,02*	*-2,53*	*-4,13*
Const. in V	0,427	0,425	0,527	0,589	0,676
	0,91	*0,81*	*6,53*	*5,10*	*6,98*
TIME	-0,036	-0,044	-0,036	-0,032	-0,032
	-10,85	*-1,40*	*-10,03*	*-6,91*	*-7,49*
GDP	0,350	0,350	0,339	0,319	0,349
	11,79	*11,96*	*15,55*	*10,20*	*12,89*
PRICE	-0,785	-0,810	-0,715	0,483	
	-1,64	*-1,47*	*-2,31*	*1,27*	
ARPS	0,408	0,417	0,341		
	5,55	*5,40*	*4,68*		
INTERNET		-0,673			
		-0,02			
TRIM	0,042	0,044			
	1,48	*1,40*			
LogLikelihood	290,521	310,605	285,941	277,717	277,051

Note: Robust standard errors in italics.

[10] Estimates with an absolute price measure provide the same qualitative results.

We turn now to the evolution of fixed-link subscribers. One might think that penetration in the fixed-link telephony has reached its maximum level, further growth being very difficult to achieve. We believe this is not necessary the case. The penetration rate of the fixed-link telephony is, in our data, below average values in OECD countries. This suggests the existence of some potential for growth of telecommunication services.

The growth in the fixed-link telephone service will be likely to continue due to the introduction of competition in fixed-link provision from January 1st 2000 onwards and to Internet-related increase in demand. As to the second, motive, Internet usage is facing an explosion in the number of users. Provision of connections to internet service providers relies essentially on communications through the fixed-link network. The growth of the fixed-link service will be anchored, at least partially, on the growth of second lines per home, for internet purposes.

We find some reassuring regularities in our estimates. First, as economic theory would predict, income per capita as a positive effect on fixed-link telephony penetration rate. Since telephone penetration has been going on for some time, and at a relatively slow pace, it allows for income effects to become noticeable (unlike what seems to occur at the mobile phones market). The own price effect is negative but not statistically significant in general. Two reasons concur for this. On the one hand, our proxy for price might be a weak proxy. On the other hand, prices of fixed-link telephony have not been, during the early stages, the main constraint on telephone diffusion. Presumably, the (lack of) efficiency of the incumbent operator is satisfying all the requests for new lines delayed effective adoption (in the eighties it was not uncommon for consumers to face a few months waiting period). [11]

Other effects are also reasonable. We find an overall positive effect of time (again, the negative coefficient is associated with a positive effect). No seasonal effect is found.

Finally, the recent surge in internet provision may have spurred a renewed interest in the fixed-link service. According to our data (internet users appear from 1994 onwards, but only after 1997 their number exceeds 100 thousand users), there is not a visible effect associated with it, yet.[12]

We are particularly interested on the effect of the cellular phone technology on the penetration rate of the fixed-link telephone service. We capture this effect by two variables: a direct effect associated with variable cellular phone penetration rate and an indirect effect through the cross-price variable. Both effects are statistically significant and point to the same qualitative feature: a negative impact (a negative effect associated with the cellular phone penetration rate and a positive cross-price coefficient).

This means that a slowdown in the diffusion of fixed-link telephones resulted from introduction and growth of cellular technology. Up to now, there was no decrease in the total number of fixed-link subscribers, as inertia, switching costs (change of phone number, essentially) and high levels of interconnection costs implies that current subscribers do not quit the fixed-link telephone service, even if they hold also a mobile phone. As old subscribers leave the market and new generations of consumers arrive, it is likely that we will see stronger effects unfolding over time. This transition is, however, made at the rhythm of demographic changes. These are by nature much slower to operate than the drastic technological evolution we have observed in recent years.

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[11] Gruber (2000) finds a significant role for waiting time in mobile phone demand in Central and Eastern Europe Countries.

[12] The negative sign is not a worry as it is highly sensitive to model specification. For example, exclusion of GDP per capita renders a positive coefficient associated with the internet variable, but still statistically non-significant.

To obtain an estimate of the order of magnitude of the effect, we re-estimate the model supressing the cross-price variable.[13] The new estimates are robust in the sense that the magnitudes of remaining coefficients (other than the cellular phone penetration rate impact in the fixed-link equation) do not change much. The only exception is the own-price effect, which appears as non-significant. Its exclusion, however, does not produce major changes in estimated coefficients. The effect on the fixed-link penetration rate is, roughly, around 0.1. That is, if the mobile phone penetration rate would be 70% (of the population), the impact on the fixed-link network is estimated to be 7% lower than in the absence of the cellular phone market. In terms of subscribers, this amounts to about 700 thousand less subscribers (in a population of 10 million people). At the current level of mobile telephony penetration rate (46.72% in the last quarter of 1999), and taking the impact of 0.09, we find a decrease in the fixed-link penetration rate of 4.2 percentage points, roughly 10% of the current level of fixed-link subscribers.[14]

This magnitude is smaller than one might have forecasted if a strong substitution effect between fixed and mobile phones exists.. This suggest that most of mobile phone expansion has not been only at the cost of fixed-link telephone service. Both telephone services seem to serve distinct needs; they are not perfect substitutes from the consumers' point of view, at least for the time being.

5. Final remarks

At a more general level, our results indicate that introduction of new technologies may induce a sizeable negative effect upon previous generation technologies. The effect falls short of perfect and instantaneous

[13] Which has a high correlation with the cellular telephony penetration rate.
[14] The magnitude of the estimated impact is smaller than the prediction for the US by Hodges and Vanston (1998). They forecast that 25% of fixed-link lines may be lost by 2005, although growth in data access lines may mitigate this.

substitution, meaning that older technologies still play an important role for some time.

One important qualification to our results relates to the absence of any effect related to traffic generated or impact on economic profitability of the fixed-link network. These two dimensions are obviously important to fully address the issue of how mobile phones are changing the telecommunications landscape and affecting fixed-link incumbent operators. In particular, traffic generation may, or may not, reverse our finding of a negative impact associated with mobile phones. If the main effect is divertion of traffic from fixed-link telephones to within-mobile network calls, then the negative effect is reinforced. However, if most diversion pattern is from within fixed-link network calls to mobile phone to/from fixed-link, then it can be positive or negative depending on interconnection arrangements. Finally, whenever mobile phones diffusion creates demand for telecommunication services and some of it ends/starts in the fixed-link network, a positive effect (complementarity) is present. It is worth mentioning that while the number of subscribers increased by 5.3% relative to the previous quarter, the growth in mobile traffic was at 9% in minutes and at 7% in number of calls. Therefore, traffic is growing at a faster pace, confirming a past trend. In 1999, the number of mobile subscribers had a growth of 52% while minutes and number of calls increased by 74% and 47%, respectively. These figures reinforce the conjecture that the impact of mobile phones on the fixed link may be positive after accounting for traffic effects. Accounting for traffic effects is by no means a trivial exercise, and is quite demanding on the data needed to identify the several possible effects. Data availability precluded us from extending the analysis in such direction. We believe that future research should be devoted to it, as well as to confirming our findings related to the number of subscribers.

Our findings allows us to comment on recent development in the telecommunications markets worldwide, and especially in the European

Union. There has been a broad trend of liberalisation and deregulation in telecommunications markets. In most countries, these markets were characterised by an incumbent monopolist. Often, there were also provisions on the so-called universal service obligations.

Due to the general environment favouring deregulation of telecommunications markets, the new mobile phone market has seen competition at relatively early stages of development. This contrasts with the previous development of the fixed-link telephone network. Faced with increasing competition both from the mobile market and from opening of previous monopolies to other suppliers, incumbents have been forced to change tariff structure (rebalancing) to avoid cross-subsidisation (namely, long-distance calls subsidising local calls).[15] The last argument for protection of incumbent fixed-link operators lies in the universal service obligations, and how liberalisation and growth of mobile phone markets may have decreased the ability of incumbent fixed-link companies to fulfil these obligations. Our work suggests that although fixed-link networks may experience a slowdown in their diffusion due to the growth of mobile telephony services,[16] for the time being the effect is not very pronounced and may be more than compensated by revenues from traffic generated by mobile–to–fixed (and vice-versa) calls. Thus, the growth of cellular telephony has been mainly a demand-creating effect for telecommunication services at large. Since competition has been a positive factor, fostering diffusion of mobile phone services, the general approach followed at the European Commission seems to bear positive effects, even though a full welfare analysis is beyond the scope of the present work.

[15] A cross-country analysis of rebalancing and competition effects in the fixed-link network service can be found in Barros and Seabra (1999).

[16] Let alone the discussion of whether such universal service obligations would be better met by other means.

We can also derive some implications for less advanced countries,[17] where fixed-link network diffusion may still be an issue (namely, for Central and Eastern Europe Countries). Adding to the findings of Gruber (2000), which states that competition, simultaneous entry and the size of the fixed telecommunications network favour mobile phone diffusion, we may say that further development of the mobile phone market should not be hindered by fear of sharp unfavourable effects for fixed-link operators. Some negative effect may occur, but is of relatively small order of magnitude.

[17] Although we use data for Portugal only, the stage of development of telecommunication services during the sample period is similar to that faced by many of the Central and Eastern Europe Countries (except for the existence of mobile telephony, which did not exist in a commercial way up to the 90s.

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Appendix – Descriptive statistics and correlation matrix

	Mean	Std Dev	Minimum	Maximum
CTPR	0.13328	0.14402	0.010200	0.46724
FLPR	0.38177	0.029132	0.33100	0.42370
ARPS	0.072274	0.024493	0.033881	0.10729
PRICE	0.063026	0.0052559	0.055627	0.070700
INTERNET	8.55102	11.45995	0.00000	47.43890
GDP	1.43501	0.097249	1.27941	1.59600

Correlations	*CTPR*	*FLPR*	*ARPS*	*PRICE*	*INTERNET*	*GDP*
CTPR	1,000					
FLPR	0,860	1,000				
ARPS	-0,928	-0,933	1,000			
PRICE	-0,650	-0,303	0,541	1,000		
INTERNET	0,958	0,799	-0,851	-0,592	1,000	
GDP	0,891	0,995	-0,945	-0,362	0,836	1,000

Note: all statistics for the period 1993-1999 (quarterly data).