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ESTIMATION OF NETWORK EXTERNALITIES AND CRITICAL MASS IN THE MOBILE TELEPHONE MARKET: A PANEL DATA ANALYSIS OF THE OECD COUNTRIES

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Estimation of Network Externalities and Critical Mass in the Mobile Telephone Market: a panel data analysis of the OECD Countries

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Preliminary version

Abstract

This paper provides an empirical study on the extent of network effects for mobile telecommunications. We specify and estimate a model of consumer demand for mobile telephone calls, to identify the extent of network externalities and to prove that, with network effects, the demand curve is not downward sloping everywhere but it has an increasing part, verifying empirically the existence of the *critical mass* of the installed base of consumers. In order to do that we use a panel data of the 30 OECD Countries from 1989 to 2006 for estimating a quadratic relationship between price of 3-minute cellular call and the installed base of subscribers; we find strong network externalities effects on mobile telephone market which drive the demand curve for this network good to be upward sloping until the critical mass point is reached, and then, downward sloping.

JEL Classification: D12, L96
Keywords: Network Externalities, Mobile Telecommunication, Critical Mass

1. Introduction

Telecommunications growth is one of the economic and social most relevant aspects of recent years. Telecommunications growth means an ever larger number of users operators, connections and services. It means more and more bandwidth and longer periods of network utilisation.

Presently, the telecommunications sector is going through a revolutionary change. The rapid technological change in key inputs of telecommunications services and in complementary goods has reduced dramatically the costs of traditional services and have made many new services available at reasonable prices. Moreover, the sweeping digitization of the telecommunications and the related sectors contributed to the change. The underlying telecommunications technology has become digital and the consumer and business telecommunications interfaces have become more versatile and closer to multifunction computers than to traditional telephones.

Digitization and integration of telecommunications services with computers create significant business opportunities and impose significant pressure on traditional pricing structures, especially in voice telephony.

The telecommunication network is a typical one characterized by *direct network externalities* which play a fundamental role in the growth of this market (the concept of network externalities will be explained in Section 2). Economic literature showed that consumption network externalities could have an important implication for size and structure of the telecommunication market. Economides & Himmelberg (1995) define the concept of *critical mass:* the minimal non-zero equilibrium size (market coverage) of a network good or service (for any price); for many network goods, the critical mass is of significant size, and therefore for these goods smaller market coverage will never be observed. Once the critical mass is reached the network experiments an exponential growth.

After the seminal article of Rohlfs (1974), and the influential papers of Katz and Shapiro (1985) and Farrell and Saloner (1985), the theoretical studies on network effects became more and more rich; but, empirical works in this area are still poor. Greenstein (1993) conducts the first research in that stream. He shows that compatibility with the installed base matters in the choice of the mainframe computer system. Gandal (1994, 1995), in order to test the hypothesis that the software markets exhibit network externalities, estimates hedonic price equations for spreadsheets and data base management systems finding that the consumer's willingness to pay for software supporting a common file compatibility standard is increasing. Similar results are in the Brynjolfsson and Kemerer (1996) paper. Additionally, they find that a product's installed base increases the price of spreadsheets. But those authors use a specification of hedonic price model which, in our mind, should be used in market with direct network externalities and not with indirect one, as in the network of spreadsheets.

In the empirical part of the Economides and Himmelberg (1995) paper they estimate the demand for facsimiles in the U.S. over 1978-1991. The assumption that facilitates the estimation is that expected network size is a linear function of the past network size. Fulfilled expectations would then lead to a constant growth rate of the U.S. fax network, which is counterfactual and breaks the consistency of that structural model.

Others structural econometric works concerning network externalities include Gandal, Kende, and Rob (2000) for the CD industry and Rysmann (2002) for the Yellow Pages market. These authors concentrate on the indirect network effect and estimate two interrelated demand equations, for software and hardware, to model the complementarities between software and hardware.

While it is widely acknowledged that network effects are a key feature of telecommunications industries, and indeed that telecommunications networks provide perhaps the leading example of network effects, relatively few studies have analyzed the empirical importance and extent of network effects in the telecommunications market.

Empirical literature on mobile telecommunications concentrates on determinants of growth and competitiveness of the industry neglecting network effects in general. The study by Bousquet and Ivaldi (1997) is probably the first one which tests empirically for existence of network effects in the fixed-line telecommunications; the concept of network externality they use relies on received calls, which benefit subscribers without paying for them, rather than on installed base of subscribers. Next, Okada and Hatta (1999) specify demand for fixed-line and mobile telephone service adopting an Almost Ideal Demand System. They show that the number of mobile subscribers, as a quality measure for telephone service, has significant positive effect on share of telecommunications' expenditures – both mobile and fixed-line – in households' budgets. This result is an empirical evidence of network effects in demand for telephone service. Kim and Kwon (2003) show that consumers prefer mobile service providers with larger number of subscribers because of the intra-network call discounts and quality signaling effect. Directly related to our research is the study from Doganoglu and Grzybowski (2005) on network effects in the German mobile telecommunications market. They estimate a system of demand function for mobile subscribers in Germany in the period from January 1998 to June 2003 and find that network effects played a significant role in the diffusion of mobile services in Germany. Grajek (2003) specifies a structural model of demand for mobile telephone service and estimate this model for the Polish mobile telephone industry using quarterly panel data for the period 1996-2001; he provides empirical evidence on the extent of network effects and compatibility between networks in mobile telecommunications finding strong network effects, which give rise to upward-sloping demand, and, despite full interconnection of the mobile telephone networks, low compatibility.

This paper aims to contribute in filling the gap of the empirical literature by providing empirical study on the extent of network effects from mobile telecommunications. We specify and estimate a model of consumer demand for mobile telephone calls, for identifying the extent of network externalities and for proving that, with network effects, the demand curve is not downward sloping everywhere but it has an increasing part; this allows us to verify empirically the existence of the *critical mass* of the installed base of consumers.

This is one of the very few panel empirical analysis on the network externalities effects; it uses the variables in the World Telecommunication/ICT indicators database of 30 OEDC Countries from 1989 to 2006.

We estimate a dynamic panel data model using the one-step and two-step Arellano-Bond GMM estimator.

Under the hypothesis that the best proxy for the future installed base of the mobile telephone network is the past installed base, we estimate the network externality effect. Moreover, we estimate a quadratic relation between the price of 3-minute cellular call and the mobile cellular subscribers and we find that for the mobile telephone network a positive critical mass exists[1].

This paper wants to enrich the poor empirical literature on network externalities effect, analyzing the market where probably these network externalities are more present.

The paper is organized as follows: in Section 2 we define the network externalities and their source in TLC market; in Section 3 provide a brief description of the fixed and

[1] It should be interesting to see if the same result holds for fixed telephone call. We think probably it doesn't, because the network externality effect has been undone by the price regulation of the fixed telephone market.

mobile telephone market; in Section 4 we make a descriptive analysis and in Section 5 we present the empirical analysis and the results; Section 6 provides the concluding remarks and the lines for further investigations.

2. Network externalities and their source in telecommunication market

The literature on network effects usually distinguishes between two types of network externalities: *direct network externalities* and indirect *network externalities*. Direct network effects refer to the case where users directly benefit from the fact that there are large numbers of other users of the same network; that is, direct network externalities are generated through a direct effect of the number of agents, consuming the same good, on the utility function of agents themselves (through a creation of new goods that directly and positively affects the utility function of every participant to the network). The TLC network (fixed and mobile) is a typical one characterized by direct network externalities which, indeed, arises when the user can call a larger set of other users.

Indirect network externalities arise when the value of a good increases as the number, or varieties of complementary goods increases: the addiction of new varieties of one type of components affects positively but indirectly the utility of all participants through the reduction of prices. More generally, most markets with indirect network externalities are characterized by the presence of two distinct sides which benefit from the interaction among them. Typical examples are the PC market and the credit cards network.

The key reason for the existence of network externalities is the complementarity between the components of a network. There are several possible sources of network effects in mobile telecommunications. First, with rising number of users having subscribed to a network, it becomes more attractive for other people also to buy a mobile phone and subscribe to the same network. This is the "direct effect" as in fixed-line telecommunications: consumers value the installed base of subscribers, because they can satisfy more communication needs[2]. Second, network expansion drives the usage volume of people already using mobile telecommunication: we would expect the

[2] If the installed base of fixed-line subscribers is already huge, network effects could arise in mobile telecommunications when mobile customers can call the stationary numbers. However, short message service (SMS) – available only within mobile network – might help to generate the "traditional" network effects.

usage volume of existing subscribers increases with the total number of mobile telephone subscribers.

More recent economic literature (e.g. Granovetter and Soong, 1986; Becker, 1991; Lindbeck et al.,1999; Schoder, 2000) starts with the social interaction theory in order to show that another source of network externalities is a need of people to buy, consume, and behave like their follows; therefore we expect that consumption of mobile telephone service is influenced by such conformist behavior.

On-net call[3] discounts offer another explanation for network effects in mobile telecommunications. Blonski (2002) call this effect as "endogenous network externality": given that it is cheaper to call a mobile number from mobile telephone in the same network than from another network, larger mobile network implies - as before - lower monthly bill, hence higher attractiveness of mobile telephone service in general.

3. Description of the telephone market

The fixed telephone market borns as a monopolistic one. The justification was the presence of economies of scale and of density which have leaded to a natural monopoly. This natural monopoly was a public one in Europe and a regulated one in USA. In Europe the market liberalization started in 1988; in USA it started in 1984 for the *long distance* communications and in 1996 (with the Telecommunication Act) for the *local* communications.

The technology research and development contributed to reduce fixed costs and to shoot down the barriers to entry. This fixed telephone market has been always regulated, either with only one firm or with a plurality of firms, to guarantee an efficient service to everyone, independently from their revenue.

For the mobile telephone market the history has been different because there were not natural monopoly technology conditions but the number of firms in the market has been decided by the number of licenses offered by governments.

During the early 1980s analog cellular telephone systems were experiencing rapid growth in Europe, particularly in Scandinavia and the United Kingdom, but also in France and Germany. Each country developed its own system, which was incompatible with everyone else's in equipment and operation. This was an undesirable situation,

[3] On-net calls are calls made to the same network; off-net calls are calls made to other network.

because not only the mobile equipment was limited to operation within national boundaries, which in a unified Europe were increasingly unimportant, but there was also a very limited market for each type of equipment, so economies of scale and the subsequent savings could not be realized.

The Europeans realized this early on, and in 1982 the Conference of European Posts and Telegraphs CEPT, formed a study group called the Groupe Spécial Mobile GSM in order to study and develop a pan-European public land mobile system.

In 1989, GSM responsibility was transferred to the European Telecommunication Standards Institute (ETSI), and phase I of the GSM specifications was published in 1990, Commercial service was started in mid-1991 and by 1993 there were 36 GSM networks in 22 countries with 25 additional countries having already selected or considering GSM. Although standardized in Europe, GSM is not only a European standard. GSM networks are operational or planned in almost 60 countries in Europe, the Middle East, the Far East, Africa, South America and Australia. In the beginning of 1994 there were 1,3 million subscribers worldwide. By the beginning of 1995 there were over 5 million subscribers. The acronym GSM now aptly stands for Global System for Mobile communications.

Once introduced, mobile telecommunication in the US and Europe always was in strong demand. In the 1990's the rapid and sustained growth rate was accompanied by profound changes in the telecommunications markets. What once was the usual way to call someone changed from using the telephone booth or a fixed telephone line to using a personal phone kept in the pocket or in the handbag.

Using a phone increasingly meant using a mobile phone instead of a fixed, a change that started in 1993. Global mobile communication - in all EU member states - is subject to regulation by an independent national regulatory authority (NRA). For the broader market only the European Commission targets the wholesale market, hence the retail market is essentially a national market (EC, 2006).

4. Descriptive analysis

Figure 1 shows the mobile cellular telephone subscribers from 1989 to 2006. The data come from the ITU database. The graphic in the figure is constructed by calculating the mean of the mobile cellular telephone subscribers for the 30 OECD Countries[4] in every year (from 1989 to 2006). Our analysis begins in 1989 because before 1989 the data on mobile subscribers (and price) were not available given the absence of the cellular telephone market. The exponential growth of this market started from 1993-1994, when the GSM technology replaced the TACS technology and when consumers started using mobile phone instead of fixed one. As the figure shows, after 1993-1994 the demand for mobiles began to accelerate drastically. In 1997 it exploded to more than double the previous year, and in the following years the same; in 2004 the installed base had grown to more than 30 million subscribers.

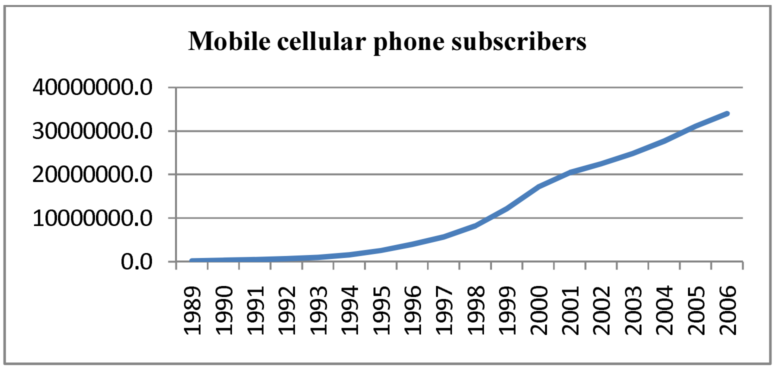

Figure 1

Interesting is Figure 2 which shows the mobile cellular subscribers over the population.

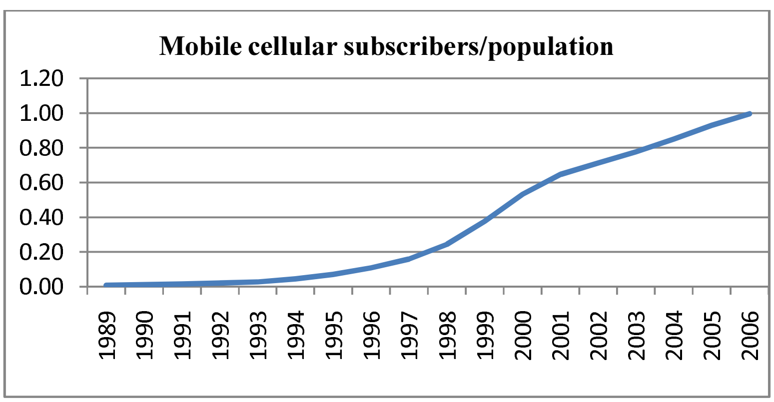

Figure 2

[4] The Countries are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxemburg, Mexico, Netherland, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, UK, US.

The data speak for themselves: the fact that 'everyone has a mobile phone' is not very far away. Actually there are countries that have a market penetration of more than 100 per cent because some individuals have multiple subscriptions, for example one at work and one for private use and temporary subscriptions in foreign countries. An important driver of demand is price decreases. Additional support to the strong market growth came from the Internet revolution and worldwide liberalisation, privatisation and deregulation of the telecommunication markets. The mobile phone has become a symbol of status and fashion, the use of a mobile phone is also a part of young people's consumption style, incidentally to a large part paid by their parents (Wilska, 2003).

The number of mobile network operators increased considerably as a result of two processes. The first is the liberalisation of fixed and mobile telephony which started in the 1980s; the second process is the incorporation and partial privatisation of the former incumbent public telecom operators in the 1980s and 1990s. As a consequence of competition, prices went down while traffic volumes increased.

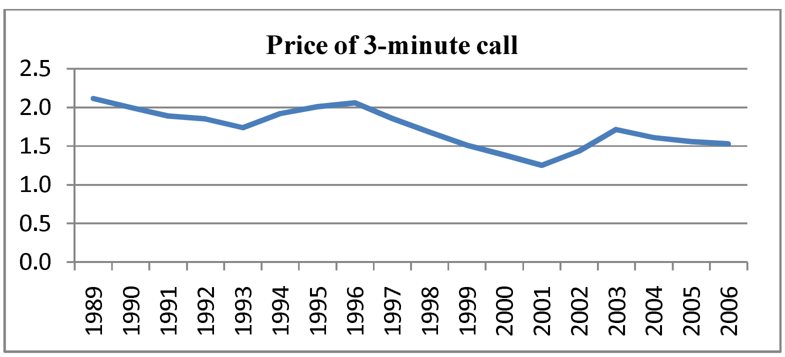

Figure 3

Look at the graphic of price[5] (Figure 3): price of 3-minute call has been sometimes growing sometimes decreasing as the installed base has been always increasing over the years (these are the nominal price; in the estimation we will use the real price).

Figure 4 gives some interesting statistics about how the telephone network grew in term of installed base for the high income Countries (which compose the panel for the estimation) in five years (from 2000 to 2005).

[5] We construct this graphic taking the mean of the 3-minute cellular call of the 30 OECD Countries for every year.

		Mobile cellular subscribers			*Prepaid*	*Population*	*As % of total*
		Total (000s) 2005	*per 100 inhabitants 2005*	*CAGR (%) 2000-2005*	*subscribers (%) 2005*	*coverage (%) 2005*	*telephone subscribers 2005*
151	Andorra	65	96.14	22.4	44.6	...	64.6
152	Antigua & Barbuda	86	105.55	31.3	...	...	70.8
153	Aruba	134	135.11	55.0	...	90.0	78.1
154	Australia	18'420	91.39	16.6	46.2	98.0	64.5
155	Austria	8'650	105.81	7.2	39.1	98.5	69.8
156	Bahamas	186	58.35	55.9	72.6	95.0	57.1
157	Bahrain	749	103.04	29.5	80.4	100.0	79.2
158	Belgium	9'460	90.00	10.9	63.9	99.0	66.5
159	Bermuda	49	76.63	39.3	...	...	...
160	Brunei Darussalam	233	62.27	19.6	...	...	73.5
161	Canada	17'017	52.51	14.3	22.5	97.0	45.0
162	Cyprus	719	86.09	26.9	53.9	100.0	63.1
163	Denmark	5'449	100.34	10.1	18.3	...	61.9
164	Faroe Islands	42	89.40	19.9	52.3	100.0	63.8
165	Finland	5'270	100.40	7.2	6.8	99.0	71.3
166	France	48'099	79.51	10.6	36.6	99.0	58.8
167	French Polynesia	87	33.98	16.9	37.9	97.0	62.0
168	Germany	79'200	95.78	10.4	50.8	99.0	59.0
169	Greece	10'260	92.27	11.6	59.8	99.6	61.9
170	Greenland	32	56.20	19.1	...	...	...
171	Guam	98	59.39	37.8	...	...	...
172	Hong Kong, China	8'693	123.47	9.8	43.8	100.0	69.6
173	Iceland	304	103.40	7.2	43.7	99.0	61.1
174	Ireland	4'270	102.94	11.7	75.8	99.0	67.5
175	Israel	7'757	112.42	12.0	27.6	99.0	72.5
176	Italy	72'200	124.28	11.3	90.9	99.8	74.2
177	Japan	96'484	75.33	7.6	2.8	99.0	62.4
178	Korea (Rep.)	38'342	79.39	7.4	...	99.0	61.8
179	Kuwait	2'380	88.57	38.0	80.4	100.0	82.3
180	Liechtenstein	28	79.03	22.4	18.8	...	57.9
181	Luxembourg	720	154.83	18.9	58.2	98.5	74.6
182	Macao, China	533	115.82	30.4	51.3	100.0	75.3
183	Malta	324	80.79	23.1	92.0	99.0	61.6
184	Monaco	17	48.76	4.3	55.1	...	33.6
185	Neth. Antilles	200	90.09	-	...	...	...
186	Netherlands	15'834	97.15	8.0	55.6	99.9	67.6
187	New Caledonia	134	56.65	21.9	79.7	*90.0*	70.8
188	New Zealand	3'530	87.61	18.0	70.0	98.0	67.1
189	Norway	4'754	102.90	8.1	36.5	...	69.3
190	Portugal	11'447	109.08	11.4	81.2	99.0	73.0
191	Puerto Rico	2'682	68.82	30.4	...	100.0	70.7
192	Qatar	717	92.15	42.8	76.8	99.0	77.7
193	Saudi Arabia	13'300	54.12	57.4	46.8	...	77.8
194	Singapore	4'385	100.76	9.8	36.7	99.9	70.4
195	Slovenia	1'759	89.44	7.7	43.9	99.4	68.3
196	Spain	41'328	96.81	11.2	49.2	99.0	69.3
197	Sweden	9'087	100.51	7.4	50.9	99.0	63.3
198	Switzerland	6'834	91.60	8.1	41.1	100.0	57.0
199	Taiwan, China	22'171	97.37	4.4	11.5	100.0	62.0
200	United Arab Emirates	4'534	100.86	26.0	88.4	100.0	78.6
201	United Kingdom	65'500	109.77	8.6	66.7	99.0	67.3
202	United States	213'000	71.43	14.2	7.3	99.0	54.8
203	Virgin Islands (US)	64	57.84	16.4	...	...	47.5
	High income	**857'618**	**84.73**	**11.1**	**35.8**	**99.0**	**61.7**
	World	**2'192'902**	**34.02**	**24.3**	**50.6**	**89.2**	**63.5**
	Africa	**136'246**	**15.22**	**54.7**	**92.1**	**67.8**	**83.2**
	Americas	**471'772**	**53.02**	**21.0**	**47.3**	**93.7**	**61.5**
	Asia	**879'494**	**22.98**	**29.6**	**37.7**	**91.1**	**59.5**
	Europe	**682'730**	**85.34**	**18.6**	**62.5**	**98.3**	**67.8**
	Oceania	**22'660**	**68.78**	**17.1**	**50.1**	**96.0**	**64.9**

Note: For data comparability and coverage, see the technical notes.
Figures in italics are estimates or refer to years other than those specified.
Source: ITU.

Figure 4

5. Econometric analysis and results

The explosive growth of the cellular network during the 90s was fueled by both realized and anticipated increases in the size of the installed base. Consumption goods with network externalities are often characterized by the existence of a *critical mass point.* That is, an equilibrium market for the good does not exist unless the installed base is greater that a minimum level. This is a general feature of goods that exhibit network externalities and it can be observed in a variety of market structures.

The theoretical model our work refers to is that of Economides and Himmelberg (1995). They present a model which allows to infer the effect of network externalities on consumer purchasing decisions. They assume that network externalities exist and attempt to model their consequences. The model assumes that the *net* value of a network good to an individual consumer depends on that consumer's income level, the size of the installed base, the price paid for it, and a random element that captures idiosyncratic tastes. For normal goods which do not exhibit network externalities, demand slopes downward; as price decreases, more of the good is demanded. This fundamental relationship may fail in goods with network externalities. For these goods, the willingness to pay for the last unit increases as the number expected to be sold increases. If expected sales equal actual sales, the willingness to pay for the last unit *may* increase with the number of units sold. Thus, for goods with network externalities, the (fulfilled expectations) demand-price schedule may not slope downward everywhere. In such markets, as costs decrease we may observe discontinuous expansions in sales rather than the smooth expansion along a downward sloping demand curve. The *critical mass* is defined as the minimal non-zero equilibrium size (market coverage) of a network good or service (for any price). The two authors argue that, for many network goods, the critical mass is of significant size, and therefore for these goods small market coverage will never be observed - either the market does not exist or it has significant coverage. The concept of critical mass formalizes the "chicken and the egg" paradox that logically arises in such markets, namely: many consumers are not interested in purchasing the good because the installed base is too small, and the installed base is too small because an insufficiently small number of consumers have purchased the good. Thus, consumers' expectations of no network good provision may be fulfilled. However, for a range of costs, expectations of positive level(s) of sales of the network good are also fulfilled. Often, there are multiple fulfilled expectations equilibria. Consumers and producers can coordinate to reach the equilibrium of the largest network size (the Pareto optimal one).

Economides and Himmelberg show that perfect competition, monopoly, and oligopoly of compatible goods exhibit the same critical mass size. Thus, in each of these markets the network starts with the same coverage and at the same marginal cost. The expansion of the network as marginal cost decreases follows slower rates for oligopoly and monopoly.

Based on this theoretical model we construct a structural model of demand for mobile telephone service.

We estimate two models, the first one to analyse empirically the extent of network externalities in mobile telecommunications and the second one to verify the slope of the demand curve for this network good; that is, to verify the relation between the price of the mobile calls and the base of subscribers and to see if in the telephone market network externalities play a role and if this market (network) exhibit a positive critical mass.

Following Grajek (2002), we firstly estimate the equation

$$base_{i,t} = \alpha + \beta_1 base_{i,t-1} + \beta_2 base_{i,t-2} + \beta_3 base_{i,t-3} + \beta_4 p_{i,t} + \epsilon_{i,t} \qquad (1)$$

The dependence of the installed base (called “base” in equation (1)) of cellular subscribers on the installed base of the past years grasps the network externalities effects[6]. The hypothesis here is that the future (unobserved) installed base is approximated by the lagged network size: consumers care about the lagged network size in their decision about joining the network[7].

We expect that the (total) effect of the lagged installed base on the today’s installed base be positive and the price effect (called “$p_{i,t}$” in equation (1)) be negative.

This is the first part of the analysis. The second part consist in the estimation of the critical mass. From the theoretical point of view, this implies that the willingness to pay of consumers for the network good is upward sloping and, after the critical mass point, it becomes downward sloping: when the installed base is small, the positive effect of the

[6] Grajek (1992) inserts in the estimated equation the square function of the lagged network size to catch its non-linear influence on the willingness to pay of the consumers, e. g., diminishing positive marginal network effect. We think that this non-linear effect of the installed base is key in the calculation of the critical mass and it should be most correctly put in the equation of the willingness to pay. See below.

[7] In the estimated equation the lagged network size corresponds to the lagged dependent variable.

network size expectation on the willingness to pay of consumers is stronger than the negative effect of the network size; as soon as the installed base reaches the critical mass, the strength of the two effects is reversed and the inverse demand function slopes downward.

We can think of the price of the network good as an hedonic price, that is, as function of the installed base of subscribers, of the quantity of calls, of the coverage of mobile cellular network, and other factors (i.e., some sociological ones). We estimate the willingness to pay as a square function of the installed base of subscribers to grasp the non linear influence of this latter on prices and then, to verify if a critical mass point exists.

Therefore, the second estimated equation is

$$\ln (p)_{i,t} = a + b_1 \ln (base)_{i,t} + b_2 [\ln (base)]_{i,t}^2 + \beta_3 \ln (q)_{i,t} + e_{i,t} \qquad (2)$$

If a mobile cellular telephone market exhibit a positive critical mass point, we have to observe a positive sign of b_1 and a negative sign of b_2. We choose a log-log specification for the interpretation of the coefficient in term of elasticity[8].

Since the paper focuses on the demand side of the market and, in particular, on the identification of the network effects, we make the realistic assumption of the oligopolistic competition in mobile telecommunication market.

The data we used come from the ITU database; we take the values of the real prices of the 3-minute mobile calls[9] and the subscribers for the 30 OECD Countries from 1989 to 2006. We start from 1989 because before this year cellular almost didn't exist, as said above. We have chosen the OECD Countries because of the same evolution of the telephone market.

Equation (1) shows a dynamic panel data model which we estimate by using the Arellano-Bond techniques[10]. To balance the panel, missing values on price series were calculated with statistical methods.

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[8] We will describe every variable of the equation (1) and (2) in the follow.

[9] In the period studied, all providers used non-linear pricing in the form of multiple price plans, from which the customers self-select the most favourable one. A plan consists of a monthly fixed charge, a price per minute of usage and often includes some minutes free of charge. A usage price is further diversified according to the time of the day (peak/off-peak hours) and to the termination network (intra-network discounts).

[10] Linear dynamic panel-data models include p lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. By construction, the unobserved panel-level effects are

Firstly, look at the result of the estimation of equation (1) showed in table 1.

The dependent variable is the Mobile cellular telephone subscribers (Post-paid + Pre-paid), for Country i at time t; it refers to the use of portable telephones subscribing to a mobile telephone service and provides access to Public Switched Telephone Network (PSTN) using cellular technology. This can include analogue and digital cellular systems. This also includes subscribers to IMT-2000 (Third Generation, 3G). Given the compatibility of the different mobile operators in the same Country, we can consider the network size (the installed base) as composed by the sum of the number of subscribers of each network in every Country; this variable is called *base(M)*.

The real price we use as regressors are called "Price call"; "Price call" is the mobile cellular price of 3-minute local call (peak and off-peak) in US dollars, for Country *i* at time *t*. The price of a 3-minute peak and off-peak rate call refers to calls from a mobile cellular telephone to a mobile cellular subscriber of the same network[11].

We control for the real per capita gdp in US dollar (called "GDP") and for the population (called "pop"), both for Country i at time t.

In equation (a) of table 1 the parameters were estimated by using a fixed effect panel data estimation (it is not a dynamic model); equations (b), (c) and (d) uses Arellano-Bond GMM estimator. Equation (b) reports the coefficients of the one-step estimation considering the homoskedastic case. Only in the case of homoskedastic error term the Sargan test have an asymptotic chi-squared distribution; the chi-squared of the one-step Sargan test in the table reject the null hypothesis that the overidentifying restriction are valid, but is could be due to heteroskedasticity. For that reason we estimate the equation (c) with robust standard errors, and the values of the coefficient do not change. In the robust case we can compute the Arellano-Bond test for first and second-order autocorrelation in the first-differenced residuals that is showed in the table 2: referring

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correlated with the lagged dependent variables, making standard estimators inconsistent. Arellano and Bond (1991) derive a consistent generalized method of moments (GMM) estimator for the parameters of the model

$$y_{i,t} = \sum_{j=1}^{p} \alpha_j \, y_{i,t-j} + \beta_1 x_{i,t} + \beta_2 w_{i,t} + v_i + \varepsilon_{i,t}$$

where α_j are p parameters to be estimated, $x_{i,t}$ is a vector of strictly exogenous variables, $w_{i,t}$ is a vector of predetermined variables, β_1 and β_2 are parameters to be estimated, v_i are the random effects that are i.i.d. over the panel with variance σ^2_v and $\varepsilon_{i,t}$ are i.i.d. over the whole sample with variance σ^2_ε.

[11] Given the compatibility of network in the same Country and among Countries, we can consider the price of 3-minute call from a mobile cellular telephone to a mobile cellular subscriber of the same network as a good proxy of the price of call from a mobile cellular telephone to a mobile cellular subscriber of a different network (even to a fixed telephone network).

to equation (c), we reject the null hypothesis of no first-order autocorrelation in the differenced residuals but we cannot reject the null hypothesis of no second-order autocorrelation. First-order autocorrelation in the differenced residuals does not imply that the estimates are inconsistent but second-order autocorrelation would imply that the estimates are inconsistent. Since the rejection of the null hypothesis of the Sargan test may indicate the presence of heteroskedasticity, we perform the Arellano-Bond two-step estimator to improve efficiency whose results are showed in equation (d)[12]; the signs and the significance of the coefficients does not change but the two-step Sargan test says that we can no longer reject the null hypothesis that the overidentifying restriction are valid. For the equation (d) too, we compute the Arellano-Bond test for first and second-order autocorrelation in the first-differenced residuals that is showed in the table 2: we reject the null hypothesis of no first-order autocorrelation in the differenced residuals but we cannot reject the null hypothesis of no second-order autocorrelation.

As expected the sign of the price coefficient is negative and significant in every estimation. It is interesting to compare the price effect on the installed base in regression (a) and (b). Equation (a) assumes no network effect in demand for mobile telephone; equation (b) does it. The price effect in (b) is smaller than in (a) because of the network effects. Looking at the coefficient of the lagged installed base (base(M)), we can notice that network effects are present and highly significant; the total network effect ($\beta_1 + \beta_2 + \beta_3$) is positive meaning that effectively consumers care about the installed base of subscribers in their decision of joining the telephone network. The effect of the GDP and population is positive and significant.

Table 3 shows the results of the estimation when the dependent variable is the fixed + mobile phone subscribers (called *base(T)*); we specify this dependent variable because with a cellular phone one can call either mobile or fixed phones. The same result holds considering both the mobile and the total installed base[13].

In table 4 we report the Arellano-Bond test for first and second-order autocorrelation in the first-differenced residuals relatives to equation (c) and (d) of table 3: we reject the null hypothesis of no first-order autocorrelation in the differenced residuals but we cannot reject the null hypothesis of no second-order autocorrelation.

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[12] Arellano and Bond recommend using the one-step estimator for inference on the coefficients because the two-step standard errors tend to be biased downward in a small sample.

[13] We can interpret only the sign of the coefficient of price and not its value because of the difference in the unit of measure between the price and the subscribers base, as one can see in the figures above.

Table 5 shows the results of the estimation of equation (2).

Look at the variables we used.

$ln(Pcall)_{i,t}$ is the natural logarithm of the "price call" as defined above. $ln(q)_{i,t}$ is the natural logarithm of the number of mobile telephone calls. We didn't find this data on the ITU database, but we derived it from the Revenue from mobile communication in US dollar[14].

$ln(base(M))_{i,t}$ is the natural logarithm of the base (M) as defined above.

We introduce a lag of the dependent variable and we control for the natural logarithm of the real per capita gdp in US dollar (called ln(GDP)). Since we focus on the identification of network effects, we restrict pricing behaviour of the providers by assuming that competition in the mobile telephone industry results in setting equal hedonic prices across brands over time for every Country. This assumption seems natural, as consumers' preferences are not brand specific. As a consequence, in each instance of time consumers are indifferent toward brands.

The error term is interpreted as the mean value of consumer's valuations for unobserved product characteristics, such as product quality, etc.

To estimate the dynamic equation (2) we use the Arellano-Bond GMM estimator.

Look at the results in table 5. We present different estimation. In equation (a) there is not the $ln(q)_{i,t}$ and the estimations are robust. In equation (b), (c) and (d), $ln(q)_{i,t}$ is treated as an endogenous variable; we introduce one lag of this variable. The chi-squared of the Sargan test in equation (b) reject the null hypothesis of overidentifying restrictions, then we estimate equation (c) with robust standard errors and equation (d) by the two-step Arellano-Bond estimator; the corresponding Sargan test is reported (in equation (d) we cannot reject the null hypothesis), and table 6 shows the Arellano-Bond test for zero autocorrelation in first-differenced errors: we reject the null hypothesis of no first-order autocorrelation in the differenced residuals but we cannot reject the null hypothesis of no second-order autocorrelation.

[14] Revenue from mobile communication is the revenues from the provision of all types of mobile communications services such as mobile cellular, private trunked radio and radio paging. We derive the number of telephone call by dividing this revenue for prices of 3-minute call. Then this is just a proxy of the quantity of calls.

Equation (e) present an estimation using as regressor the natural logarithm of the total base of subscribers, which we called *ln(base(T),* instead of *ln(base(M))*[15]. In every equation the coefficient are highly significant.

The estimation of the coefficient of the installed base of subscribers shows that a critical mass point in the mobile TLC market exists. Indeed, the coefficient of *ln(base(M))* is positive and the coefficient of $[ln(base(M))]^2$ is negative meaning that the (natural log of the) inverse demand function for this network good slopes upward and, once a critical mass is reached, it slopes downward. The same results holds if we consider the natural logarithm of the total base of subscribers (ln*(base(T)*). When the installed base of cellular phone subscribers is small, the positive effect of network externalities on the willingness to pay of consumers is strong and the demand function slopes upward; once the critical mass point is reached, the negative effects of a huge installed base on the willingness to pay emerges leading the demand function for the "telephone" good to slop downward.

The coefficient of the $ln(q)_{i,t}$ is negative and highly significant; if we take its inverse, it expresses the elasticity of the demand of mobile call with respect to the price of the call.

The coefficient of the $ln(GDP)_{i,t}$ is the elasticity of price with respect to the per capita income; it is positive and significant, meaning that if the per capita GDP grows of 1% the price of cellular call grows of the 0,23% (taking the value in equation (a) for example).

We showed that a critical mass point in the TLC mobile market exists, such as in other markets characterized by network externalities. Then, keeping in mind that when the network reaches the critical mass point, its growth is becoming faster, network good producers should have to adopt some strategies to influence the expectation on consumers about the future faster network growth to be able to reach the critical mass point as soon as possible.

Using the estimated coefficient of the quadratic relation between the log of the price of call and the log of the installed base of telephone network (both mobile and total) we draw a simulated price only taking account of the network externalities effect on the willingness to pay of consumers. In order to do that we find the (log of the) price of call in this way

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[15] For equation (e) we compute the Arellano-Bond one-step robust estimation. We insert in table 5 just one estimation with *ln(base(T)* as regressor because the result of all other estimation (as the Arellano-Bond one-step and two-step estimation) are the same.

$$\ln (Pcall)_t = 0.289\ln (base(M))_t - 0.0058[\ln (base(M))]_t^2$$

and

$$\ln (Pcall)_t = 0.65\ln (base(T))_t - 0.019[\ln (base(T))]_t^2$$

where $ln(base(M))_t$ (and $ln(base(M))_t$) is the cross section mean (of Country) of the mobile (total) installed base of subscribers for every year (from 1989 to 2006). Figures 5 and 6 present the simulation.

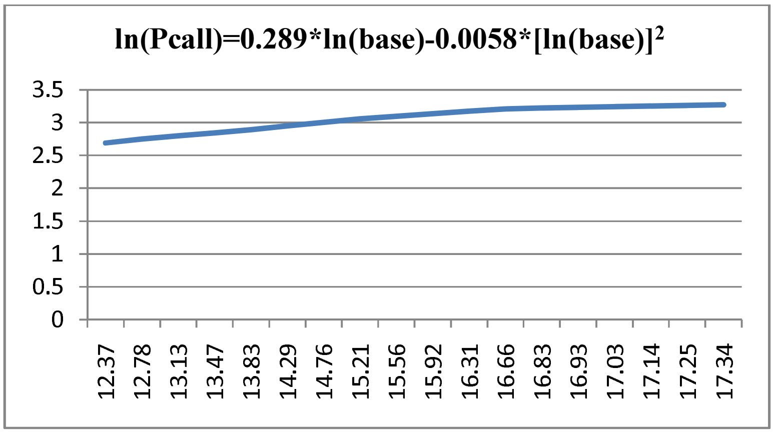

Figure 5

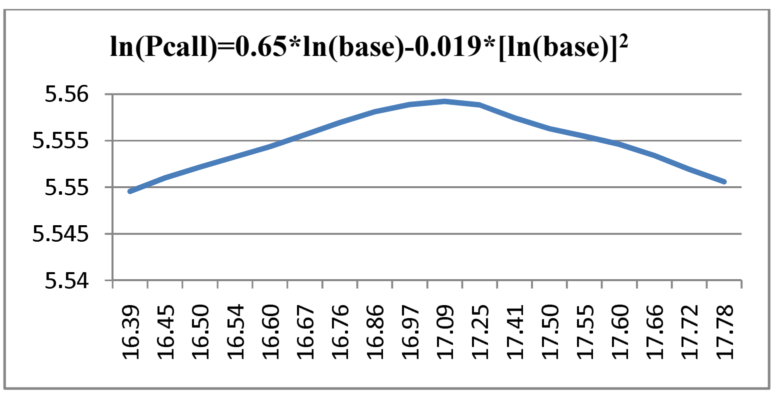

Figure 6

Figure 6 clearly shows the slope of the demand function for this particular network good; the critical mass point is reached when the log of the mobile installed base is about equal to 17.

Figure 5 shows that if price of call was function only of the installed base of subscribers, when this latter increases price increases (grasping the network externalities effect) but after a certain level of the installed base, the growth of price slows. Moreover, comparing the two figures at low levels of the installed base of users, the price grows more as the total installed base grows than as the mobile installed base grows, meaning that the network externalities effects are stronger when the installed base is wider. Clearly the price of call that we observe during the years are also affected by other factors than the installed base, as the quantity of calls, the coverage of mobile cellular network, some fashion factors, etc.

It is also interesting to notice the level of the elasticity of price call with respect to the installed base in each Country. To do that we calculate the mean (per years) of subscribers (mobile subscribers and total subscribers) for each Country, we have taken the natural logarithm, and the elasticity came from this formula

$\varepsilon = b_1 + 2b_2 \ln{(base)_i}$ [16]

See table 7

Table 7		
	Elasticity base(M)	Elasticity base(T)
Australia	0.106131493	0.018944796
Austria	0.114363439	0.05015336
Belgium	0.113792382	0.04484218
Canada	0.106356531	0.001902109
Czech Republic	0.113311977	0.052487118
Denmark	0.118722845	0.058925513
Finland	0.117796538	0.062169823
France	0.094804244	-0.02434961
Germany	0.089632137	-0.03847577
Greece	0.112836021	0.040441323
Hungary	0.115729781	0.058729237
Iceland	0.15196416	0.170515225
Ireland	0.123357003	0.081534651
Italy	0.090311719	-0.02565574
Japan	0.084858544	-0.05133373
Korea (Rep.of)	0.096575072	-0.01222784
Luxembourg	0.145336212	0.153632302
Mexico	0.098196097	0.002508883
Netherlands	0.10774139	0.02416608
New Zealand	0.125586436	0.083120353

[16] For example, the value of 0.106131493 for the Australia in the first column of table 7 is obtained as 0.289+2*-0,0058*ln(base(M)).

Norway	0.119627734	0.067779078
Poland	0.104609881	0.019577159
Portugal	0.111735171	0.045782448
Slovak Republic	0.124890761	0.088980367
Spain	0.096785097	-0.00607472
Sweden	0.111598929	0.036744222
Switzerland	0.116784012	0.048322878
Turkey	0.09904663	-0.00100354
United Kingdom	0.091071052	-0.02845582
United States	0.077225264	-0.0850554

The column of "Elasticity (base(M))" has been obtained using the estimated coefficient of the regressor *ln(base(M))* from equation (c) in table 5, while the column "Elasticity (base(T))" has been obtained using the estimated coefficient of the regressor *ln(base(T))* from equation (e) in table 5. For every Country, the elasticity of "price call" with respect to mobile installed base (always positive) is greater than the elasticity of "price call" with respect to total installed base (where positive). The percentage variation in the price of calls is more sensitive to a percentage variation in the mobile installed base than in the total installed base meaning that the network externality effect is decreasing as the installed base becomes wider.

6. Concluding remark

In this paper we construct a demand model to estimate the network externality effect on the mobile telephone network. We used a Arellano-Bond dynamic panel data estimation to prove that the network effects play a role in this market and that a critical mass point exists. The line of further research will be to see if the results hold when we enlarge the sample by including other Countries, for example, the developing ones, and when we use other variables to better specify the model (as the coverage of mobile network). Moreover it would be interesting to test the same model using data on fixed telephone to see if the network externalities effects on price of fixed call have played a role even under the regulatory regime of those prices.

Table 1

base(M)	(a)	(b)	(c)	(d)
Price call	-113534000** (-1,9)	-709435.8* (-4,16)	-709435.8*** (-1.70)	-710222.2* (-138.37)
$base(M)_{i,t-1}$		1.526031* (30.15)	1.526031* (13.95)	1.525967* (1061.19)
$base(M)_{i,t-2}$		-.8027342* (-9.64)	-.8027342* (6.23)	-.801896* (-485.42)
$base(M)_{i,t-3}$		.2352647* (4.77)	.2352647* (4.02)	.2348561* (314.65)
$GDP_{i,t}$	108,1* (4,3)	23.34107** (2.13)	23.34107** (2.06)	23.05594* (26.78)
$Pop_{i,t}$	4,1* (14,8)	.4523715* (8.31)	.4523715* (5.75)	.4495634* (8.59)
N.obs	540	420	420	420
R^2	0,8			
Sargan test		chi2(130) = 376.0474		chi2(130) = 26.36288

In parentheses of equation (a) are Student's *t*-test values; in parentheses of equation (b), (c) and (d) are standardized normal *z*-test values. * significant at 1% level; ** significant at 5% level; *** significant at 10% level. Equation (a): fixed effects robust estimation; equation (b): Arellano-Bond one-step estimation; equation (c): Arellano-Bond one-step robust estimation; equation (d): Arellano-Bond two-step estimation.

Table 2

	(c)		(d)	
Order	z	Prob > z	z	Prob > z
1	-2.3047	0.0212	-1.8104	0.0702
2	-.39443	0.6933	-.31663	0.7515

Arellano-Bond test for zero autocorrelation in first-differenced errors.
H0: no autocorrelation

Table 3

base(T)	(a)	(b)	(c)	(d)
Price call	-1433167** (-1,98)	-939110.8* (-4,41)	-939110.8*** (-1.77)	-936016* (-166.55)
base(T)$_{i,t-1}$		1.517947* (30.03)	1.517947* (15.68)	1.517555* (1516.60)
base(T)$_{i,t-2}$		-.7972921* (-9.65)	-.7972921* (-5.75)	-.7965172* (-755.86)
base(T)$_{i,t-3}$		.2140276* (4.42)	.2140276* (3.45)	.2137982* (403.85)
GDP$_{i,t}$	121.8868* (4,2)	29.5709* (2.57)	29.5709*** (1.65)	28.82115* (30.94)
Pop$_{i,t}$	5.143772* (24.32)	.4928688* (7.12)	.4928688* (5.99)	.4911874* (136.72)
N.obs	540	420	420	420
R^2	0,7			
Sargan test		chi2(130) = 369.6251		chi2(130) = 25.75858

In parentheses of equation (a) are Student's *t*-test values; in parentheses of equation (b), (c) and (d) are standardized normal *z*-test values. * significant at 1% level; ** significant at 5% level; *** significant at 10% level. Equation (a): fixed effects robust estimation; equation (b): Arellano-Bond one-step estimation; equation (c): Arellano-Bond one-step robust estimation; equation (d): Arellano-Bond two-step estimation.

Table 4

	(c)		(d)	
Order	z	Prob > z	z	Prob > z
1	-2.5843	0.0098	-2.0199	0.0434
2	-.3125	0.7547	-.20002	0.8415

Arellano-Bond test for zero autocorrelation in first-differenced errors.
H0: no autocorrelation

Table 5

ln(Pcall)	(a)	(b)	(c)	(d)	(e)
$\ln(Pcall)_{i,t-1}$	.6326689 * (8.13)	.6411105 * (19.32)	.6411105 * (12.24)	.6006689 * (17.51)	.7529412* (12.36)
$\ln(base(M))_{i,t}$	.1943668* (2.56)	.2894437 * (6.65)	.2894437 * (3.74)	.3286822 * (5.21)	.6504694*** (1.81)
$[\ln(base(M)]^2_{i,t}$	-.0100213* (-3.18)	-.005838* (-3.57)	-.005838 * (-2.69)	-.0067776 * (-3.09)	-.0194735*** (-1.75)
$\ln(q)_{i,t}$		-.6364054 * (-22.71)	-.6364054 * (-4.54)	-.6508482 * (-24.55)	-.5635423* (-4.31)
$\ln(q)_{i,t-1}$		.3673682 * (10.76)	.3673682 * (3.89)	.3589892 * (15.15)	.4768291* (3.76)
$\ln(GDP)_{i,t}$	.2336447 * (2.48)	.2649247 * (6.62)	.2649247 * (5.76)	.2914349 * (10.00)	.1099759*** (1.60)
N.obs	480	480	480	480	480
Sargan test		chi2(252) = 355.1507		chi2(252) = 27.50719	

In parentheses are standardized normal *z*-test values. * significant at 1% level; ** significant at 5% level; *** significant at 10% level. Equation (a): Arellano-Bond one-step robust estimation; equation (b): Arellano-Bond one-step estimation, the $\ln(q)_{i,t}$ is the endogenous variable; equation (c): Arellano-Bond one-step robust estimation, the $\ln(q)_{i,t}$ is the endogenous variable; equation (d): Arellano-Bond two-step estimation, the $\ln(q)_{i,t}$ is the endogenous variable; equation (e): Arellano-Bond one-step robust estimation with dependent variable ln(base(T)), the $\ln(q)_{i,t}$ is the endogenous variable.

Table 6

	(a)		(c)		(d)	
Order	z	Prob > z	z	Prob > z	z	Prob > z
1	-2.821	0.0048	-2.801	0.0051	-2.6694	0.0076
2	1.4662	0.1426	.46038	0.6452	.41834	0.6757

Arellano-Bond test for zero autocorrelation in first-differenced errors.
H0: no autocorrelation

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