Estimating network effects in mobile telephony in Germany

Toker Doganoglu [a,b], Lukasz Grzybowski [c,*]

[a] *Faculty of Arts and Sciences, Sabanci University, 34956 Orhanli-Tuzla, Istanbul, Turkey*
[b] *Center for Information and Network Economics, University of Munich, Akademiestr. 1/I, 80799 Munich, Germany*
[c] *Departamento de Fundamentos del Analisis Economico, Universidad de Alicante, Campus de San Vicente, 03080 Alicante, Spain*

Abstract

In this paper we analyze the demand for mobile telecommunication services in Germany in the period from January 1998 to June 2003. During this time, the subscriber base grew exponentially by about 700% while prices declined only moderately by about 41%. We believe that prices alone cannot account for such rapid diffusion and network effects have influenced the evolution of the industry. We put this view to the test by using publicly available data on subscriptions, price indices and churn rates. Using churn rates gave us approximate sales levels which enabled us to use standard methods to investigate the effect of network size on demands. Our estimates of a system of demand functions show that network effects played a significant role in the diffusion of mobile services in Germany.

JEL classification: L13; L96

Keywords: Mobile telephony; Discrete choice; Network effects

[*] Corresponding author.
E-mail addresses: toker@stat.uni-muenchen.de (T. Doganoglu), lukasz@merlin.fae.ua.es (L. Grzybowski).

1. Introduction

In the last decade, mobile telephony has been the fastest growing segment in the telecommunications industry. In June 2003, after a few years of exponential growth, there were more than 60 million subscribers to mobile telephony providers in Germany. Between January 1998 and June 2003 the total number of subscribers grew by about 700%. During the same period of time, the index of prices for mobile services calculated by the German Statistical Office fell by about 41%. Whether such a moderate price decrease can fuel the exponential change in the market size is a question that is yet to be answered.

At first glance, it is unlikely that prices alone can account for such a large increase in the user base. The introduction of prepaid cards and new services, such as the short message service (SMS) and wireless application protocol (WAP), together with the increasing attractiveness of handsets has played a very important role in the development of the industry. However, network effects may be another force that can rationalize such tremendous growth rates. A product that exhibits network effects becomes more valuable when more people use it. In our opinion, network effects influence the decision of consumers to subscribe to mobile services.

Network effects in mobile telephony may have different origins. In the first place, an increase in the number of mobile users increases communication options. In particular, the consumption of mobile services can be attributed to a single person and not to a household. This implies a much larger potential market size than in the case of fixed telephony. Second, in addition to voice telephony, mobile firms can offer several other services, such as SMS, MMS, WAP and email, which may themselves be subject to network effects. Finally, the spread of mobile services within an individual's social circle may exert social pressure inducing him or her to subscribe. For example, lack of mobile contact may lead to exclusion from spontaneous social events.

In this paper, we investigate whether network effects have an impact on the decision of consumers to subscribe to mobile telephony services in Germany. Our analysis is based on publicly available industry data, namely subscription levels, prices and churn rates for the period from January 1998 to June 2003 in monthly intervals. One of our main goals is to present a simple methodology which uses such limited information and can yet enhance our understanding of the evolution of the mobile industry.

The most easily accessible industry statistics in Germany, as in many other countries worldwide, are the subscription levels. Although interesting for describing the state of the industry, by itself this information is hardly useful in studying how consumer demand responds to changes in industry determinants. An important shortcoming is due to the fact that consumers often sign long term deals with their service providers, and hence do not engage in decision making every month. However, a simple first difference of subscription levels does not correspond to sales because a significant amount of consumers with expiring contracts leave their previous operator.

In this paper, we propose using churn rates to impute the fraction of switching consumers and approximate the number of locked in consumers – those who do not make subscription decisions. First difference of observed subscription levels and the number of locked in consumers should yield a good approximation for the number of new contracts sold. The second set of important variables we need are firm-specific prices. However, these are hard to find in a prepared form since the German Statistical Office provides only aggregate price indexes. Nevertheless, industry magazines and various Internet sites provide detailed information on the tariffs offered by each provider. These can be used to construct operator-specific price indexes.

We use installed bases, sales and prices along with several other control variables, to estimate a system of demand equations. A clear drawback of working with limited data is naturally the constraints it imposes upon the sophistication of the estimated model. We therefore use fairly standard methods and functional forms that have been successfully used in earlier literature on network effects. We explicitly state the economic and statistical assumptions, which are necessary for interpreting results of our simple estimation methodology as indicative of the strength of network effects in mobile telephony.

We use a standard aggregate nested logit model following Berry (1994). We assume that consumers first decide whether to subscribe to fixed telephony services only or to both mobile and fixed services. By normalizing with respect to the utility of fixed telephony services, one can impute the mean utility levels of subscribing to mobile telephony services via a simple transformation of observed market shares. We then posit a relatively straightforward linear utility for subscribing to mobile services and search for parameters that allow our linear model to best explain observed mean utility levels.

In modeling network effects, we use the lagged total share of subscribers in the population to proxy for network size. This assumes perfect compatibility between provider services and the lack of price-mediated network effects due to different on-net and off-net prices. We test the appropriateness of this specification in two ways. In the first extension, we allow own network size to have a different effect to the size of the other operators' network. We cannot reject the hypothesis that the network effects are not firm specific, which supports our formulation. The second extension tests whether the linear specification we use is appropriate. We re-estimated the model using a Box–Cox transformation of network size. We cannot reject the hypothesis that the network sizes affect utility in a linear fashion.

Our results suggest that network effects played a significant role in the diffusion of mobile services in Germany. In the absence of network effects, if prices remained as observed, the penetration of mobiles could be lower by at least 50%. Current penetration levels could be reached without network effects only if prices were drastically lower. Moreover, assuming that observed prices result from pure strategy Nash equilibrium, we compute marginal costs and total margins.[1] The price-cost margin for all network operators increased over time from about 13% in January 1998 to about 30% in June 2003. This increase is due to the fact that margins remained almost constant while the prices decreased.

The next section provides a short overview of empirical literature on network effects and the telecommunications industry. In Section 2, we present a brief history and current state of the mobile industry in Germany. The model we use for econometric analysis is presented in Section 3. Data description and estimation results follow in Sections 4 and 5, respectively. Finally, we conclude our analysis in Section 6.

[1] Clearly, the assumption of a static Nash equilibrium is highly likely to be incorrect given the dynamic evolution of demand. Nevertheless, this exercise provides a crude first-order approximation to total margins and their evolution and is therefore informative.

2. Literature

There is a growing body of literature that attempts to measure indirect and direct network effects in a variety of network industries. For instance, Gandal et al. (2000) study the diffusion of CD technology and find that the number of CD titles available has an impact on the consumer's willingness to adopt the CD player. Park (2003) analyzes the role of network effects in the standard war between VHS and Betamax video recording systems. Similarly, Ohashi (2003) estimates a random utility model and measures the role of network externalities in the diffusion of VCRs in the US between 1978 and 1986. Clements and Ohashi (2005) estimate indirect network effects in the US video game market between 1994 and 2002 using a nested logit model. Goolsbee and Klenow (2002) estimate a reduced form diffusion model for home computers and find that people are more likely to adopt computer technology in areas with a higher fraction of computer users.

There are a number of earlier papers that focus on estimating a hedonic price function for products showing network effects. Brynjolfsson and Kemerer (1996) use the hedonic pricing model to determine the impact of network effects, defined as compatibility with the dominant standard, on the prices of microcomputer spreadsheets. Similar approaches are employed by Hartman and Teece (1990), Gandal (1994), Economides and Himmelberg (1995), Moch (1995) and Gröhn (1999). For an excellent review of the theoretical and empirical literature on network effects and switching costs, we refer the reader to Farrell and Klemperer (2006).

The empirical studies that account for network effects in the telecommunications industry are relatively scarce. Most studies focus on the diffusion of telecommunications services and use reduced form regression and diffusion models. The presence of network effects has not usually been taken into account. For instance, Gruber and Verboven (2001) estimate a logistic diffusion model for the EU countries and find that regulation and technological progress are important for the growth of the mobile industry. Wallsten (2003) uses data on the telecommunications industry worldwide to analyze whether the sequence of reforms, such as establishing a regulatory authority and privatization of the incumbent, is of importance. Koski and Kretschmer (2005) analyze the effects of regulation and competition on the development of mobile telephony.

There are a few recent studies which explicitly acknowledge network effects in the telecommunications industry. Bousquet and Ivaldi (1997) estimate network effects in fixed-line telephony in terms of usage. Kim and Kwon (2003) use a consumer survey to analyze Korean mobile telephony and conclude that consumers prefer carriers that have larger consumer bases. Birke and Swann (2006) use household survey data to identify price-mediated network effects in mobile telephony in the UK.

The paper most similar to ours is Grajek (2003) which estimates the magnitude of network effects in the Polish mobile telephone industry during the period 1996–2001. He essentially adopts the model of Katz and Shapiro (1985) and assumes that mobile services are homogeneous and firms set equal hedonic prices. He adopts a quadratic network benefit function and allows the own and competitors' subscriber base to have a different effects on utility. He develops an estimating equation which explains the total subscriber base in each period. By estimating a system of such equations, he finds significant network effects which are mainly due to the own installed base, despite full technological compatibility between the networks of different firms. Our model differs from Grajek (2003) in a number of aspects. We model the services of different providers as differentiated products. More importantly, we posit a model of sales each period.

3. Mobile telephony in Germany

3.1. Development of the industry

The second-generation (2G) digital networks (GSM 900) started providing services in 1992.[2] Two licenses were granted – the first to the state-owned Deutsche Telekom Mobilnet which was later privatized and transformed into T-Mobile. The second license went to the first private mobile network operator Mannesmann Mobilfunk, which was later taken over by Vodafone. In 1993, a third license was granted to E-plus. This network began to operate on 1800 MHz one year later. Another license was granted in 1997 to Viag Interkom (later called O2) which started providing services in November 1998. In 1999, T-Mobile and Mannesmann-Vodafone were granted transmission rights on 1800 MHz as well.

In 2000, the German government auctioned licenses for third-generation mobile networks (UMTS) that allow data to be transferred at much higher rates in order to satisfy the demands of multimedia applications. A total of DM 99 billion was paid by six companies for the rights to develop 3G networks: Group 3G (Quam), T-Mobil, Mannesmann-Vodafone, Auditorium, Mobilcom Multimedia and O2. These companies were established by consortiums of large multinational telecommunications companies and existing GSM network operators. Network development and the introduction of the 3G communications standard on the German market was expected to take place in 2002–2005. One of the license winners, Quam, entered the market in November 2001 by signing roaming agreements with other network operators. It acquired about 200,000 consumers but subsequently went bankrupt one year later.[3]

3.2. Market structure

Network operators may sell services to consumers directly or indirectly through independent service providers (ISPs). In general, an ISP resells airtime on a third party's mobile network by providing billing and customer care services under its own brand name. In Germany, network operators can commercially decide whether to sign an ISP agreement. According to the German Telecommunications Act the agreements between network operators and ISPs have to be non-discriminatory and assure fair competition between retailers. Typically, the tariffs offered by ISPs reflect tariffs of the network carriers.

In 2003, there were four network operators – T-Mobile, D2 Vodafone, E-Plus and O2 – and about twelve ISPs in Germany. Only O2 has not reached an agreement with ISPs. Out of these firms, only eight had significant market shares – network operators: T-Mobil (29.9%), D2 Vodafone (27.7%), E-Plus (9.3%), O2 (6.3%) and ISPs: Debitel (12.7%), Mobilcom (6.5%), Talkline (3.2%), Drillisch (2.4%). The remaining ISPs accounted for only about 2.0% of subscribers.[4] The market share of ISPs has decreased over time.

[2] 2G networks were preceded by the analog network provided by the state-owned monopolist Deutsche Bundespost-Telekom which was switched off in year 2000.

[3] *Source:* "Connect" magazine, http://www.xonio.de.

[4] *Source:* www.RegTP.de.

Because of data limitations and the aforementioned market structure, we assume that consumers can only choose among network operators. Subscribers to ISPs are included into the consumer bases of the respective network operators.

Since the introduction of 2G networks, the mobile industry has experienced dramatic growth rates. At the end of 2003, the number of mobile subscribers reached 64.8 million, which implies a penetration rate of 78.3%. The distribution of market shares between the four network operators has remained stable in the last few years, with T-Mobile maintaining about 40.6%, D2 Vodafone – 38.1%, E-Plus – 12.7% and O2 – 8.6% as of the third quarter 2003. Clearly, as the high market shares of T-Mobile and Vodafone suggest, early entry played a critical role for the size and growth of the consumer base. Late entrants E-plus and O2 applied innovative pricing policies but did not manage to enlarge their market shares substantially. For instance, since July 1999, O2 has been offering the Genion tariff. Under this tariff users pay fixed-line rates for calls within at least one hundred meters around their declared home location and a lower city tariff within the city area. Since December 1998, E-Plus has been providing a range of time and more tariffs with free minutes and prices independent of call destination.

4. Empirical model

We model demand for mobile subscriptions using a discrete-choice model, as discussed in Anderson et al. (1992) and Berry (1994). We use the estimation strategy proposed by Berry (1994) and invert market-share equations to find the implied mean levels of utility for each alternative. We then posit a functional form for this utility in terms of observed and unobserved variables. The unobserved variable serves as our econometric error term and is interpreted as the mean value of consumer valuation of unobserved product characteristics, such as product quality. Some components of the unobserved characteristics can be captured by dummy variables.

We assume that all consumers have access to a fixed line. In the first stage they decide whether to continue using a fixed telephone alone or to buy a mobile as well. In the second stage, consumers choose a network operator. This is a standard nested logit structure, where one branch is degenerated and no further choices are made. The utility of an outside option for consumer i at time t is denoted by U_{i0t} and may vary in time due to its dependence on the prices of fixed-line services. The utility derived by consumer i from using a fixed-line together with mobile services of network operator j can be written as

$$U_{ijt} = U_{i0t} + r_j - \alpha p_{jt} + V(z_t^e) + \xi_{jt} + \zeta_{gt} + (1-\sigma)\epsilon_{ijt}, \tag{1}$$

where r_j is the stand alone value, p_{jt} represents service price and $V(z_t^e)$ is the expected network benefit, which we discuss in detail in the next subsection. The variable ζ_{gt} is a common value for all products in group $g = \{0, 1\}$ and has a distribution dependent on σ, with $0 \leqslant \sigma < 1$. The nest $g = 0$ stands for fixed-line alone and $g = 1$ represents the choice of mobile telephony plus fixed line. By normalizing with respect to the utility of the outside option, the choice of alternatives becomes independent of the determinants of the fixed line utility. The consumer's tastes for products within the nest may be correlated. When the choice of alternatives in the nest is independent, which implies that $\sigma = 0$, nested logit is reduced to a simple logit. Finally, ξ_{jt} accounts for the population average of the unobserved utility of operator j and ϵ_{ijt} is the idiosyncratic taste variable, which has a double exponential distribution.[5]

As with Berry (1994), we invert observed market shares to compute mean utility levels for each product and treat them as observed. Using the observed utility level and our specification in (1), we arrive at the following estimation equation

$$\log(s_{jt}) - \log(1 - s_t) = r_j - \alpha p_{jt} + V(z_t^e) + \sigma \log(\bar{s}_{jt|g=1}) + \xi_{jt}, \tag{2}$$

where s_{jt} represents the share of operator j in the total number of consumers that make decisions about subscription and $s_t = \sum_j s_{jt}$. The share of operator j in the total sales of mobile services is denoted by $\bar{s}_{jt|g}$. The unobserved utility, ξ_{jt}, serves as the econometric error term.

The specification of utility function (1) is representative of consumers with sufficiently low (zero) switching costs and of new consumers. Otherwise, the utility function may depend on the previous choice due to switching costs, for instance. Because we lack precise data on the number of switching consumers and their choices of network operators, we have to make simplifying assumptions. We assume that there are three types of consumers. Consumers with sufficiently low switching costs and new consumers choose network operators, while consumers with high switching costs are locked-in and continue using the same mobile services. Hence, locked-in consumers are assumed to be out of the market and are excluded from computed market shares. We approximate the number of locked-in consumers using data on accumulated subscriptions and churn rates.[6] This approximation implicitly assumes that all consumers with zero switching costs change network operators. Consequently, we assume that the share of consumers with zero switching costs is determined by the firm-specific churn rate λ_{jt}. One can thus approximate the sales of an operator j in period t by the difference between the observed number of subscribers and the number of locked in consumers: $y_{jt} = Z_{jt} - (1 - \lambda_{jt})Z_{jt-1}$ where Z_{jt} stands for the number of subscribers. In this case the number of locked-in consumers is large. On the other hand, if we calculate market shares assuming that all consumers can react to price changes each month, that is when $\lambda_{jt} = 1$, we get higher estimates of price elasticities and network effects. These estimates are sensitive with respect to the value of λ_{jt} because when it increases, the share of consumers choosing mobiles increases relative to the share of outside option.

The total number of consumers who can make subscription decisions is given by $m_t = M_t - \sum_j (1 - \lambda_{jt})Z_{jt-1}$, and represents our market size. The term M_t is the population in period t. Only consumers aged over 16, that is 84% of total population, are considered.[7] Thus, the share of subscribers of network operator j in the total number of consumers that

[5] The only firm characteristics in the model are prices, stand alone values and unobserved qualities. The other potential choice determinants, such as coverage and reception quality, were constant throughout the time of this study. An exception is O2, which had smaller network coverage immediately after entry in November 1998 but is excluded from this analysis for the reasons discussed in the next section. According to tests carried out by the telecommunications magazine "Connect" from 30.11.2000, the networks are hardly distinguishable as regards coverage and reception quality.

[6] For any given period of time, the churn rate equals the number of subscribers who discontinue their use of mobile services divided by the total number of users. We are very grateful to Jan Kranke for providing us with data on approximate quarterly churn rates for network operators in Germany. We calculate monthly data by linear approximation.

[7] The estimation results are robust with respect to small variation in market definition.

can make subscription decisions is given by $s_{jt} = y_{jt}/m_t$. The share of the outside good is computed as $s_{0t} = 1 - s_t = 1 - \sum_j s_{jt}$.[8]

4.1. Network effects in mobile telephony

So far we have not specified how consumers form expectations about network size and how the network benefit function is formulated. Most of the empirical and theoretical literature on network effects assumes linear network benefits. Swann (2002) examines the assumptions on communications needs which are necessary for the utility function to be either linear or s-shaped in network size. He argues that an s-shaped utility function in network size is more realistic for an average consumer and that this shape may differ for pioneers, medium adopters and late adopters. In the time period considered in this study, the mobile telephony market in Germany was in its fastest growth phase. Thus, the network benefits should be well approximated by a simple linear function $V(z_t^e) = \beta z_t^e$. We provide a test which supports the linear specification compared to a more general model where the network benefit function is assumed to have a Box–Cox form.

We employ a very simple rule for the formation of expectations. We assume that consumers think that the network penetration in the previous period will continue in the current period. When the market reaches a steady state, such formation of expectations will be fulfilled. Networks are fully compatible and their users may freely communicate with each other. Thus, expected penetration is represented by the sum of lagged installed bases divided by the size of population, $z_t^e = \sum_j Z_{jt-1}/M_{t-1} \equiv z_{t-1}$. A new subscriber to any of the networks brings the same marginal utility.

Clearly consumers derive network benefits from a fixed-line network as well. In the last decade, however, changes in the number of subscribers to fixed-line telephony were negligible. Given our assumption regarding the linear network benefit function and the linear form of utility function in (1), any network benefits from the fixed lines are cancelled when we normalize with respect to the outside option. Furthermore, there may also be asymmetric own and cross-network effects due to differences in on-net and off-net prices. We tested for this possibility, and found that our data does not support network effects with different magnitudes.

5. The data

The data on mobile subscriptions was collected from the Internet site run by the German regulator – RegTP. Subscription data is available from June 1992, but we have restricted this analysis to the period for which we were able to collect prices. As a result, we have 66 monthly observations from January 1998 to June 2003. Because of the late entry of the fourth network operator O2 in November 1998 and its small market share at the end of the period analyzed (8.6%), it may be difficult to estimate demand for this

[8] Some assumptions about the number of people taking decisions is unavoidable. Even if information about the number of expiring contracts were available, there is no way to obtain information on the number of consumers with zero switching costs. In order to compute sales, and hence market shares, we adopt the algorithm based on the churn rates. We believe that it is easier to argue that the number of locked in users of mobile services is relatively high.

operator. In this study we have only estimated demands for three main network operators, which cover about 91% of the market: T-Mobile, D2 and E-Plus.

For the purpose of this study we need firm-specific prices. We collected tariff information from the price listings published in telecommunication magazines and on the Internet in the time period January 1998–June 2003.[9] We applied the methodology used by the statistical office to compute firm-specific indices.[10] First we assume infrequent usage behavior and calculate expected monthly bills for all tariffs provided by network operators. In addition to what the statistical office does, we assume some randomness in calling behavior. Hence we randomize the number and length of phone calls as well as the distribution of calls among destination networks and time zones. The distribution among destination networks is proportional to the market shares. Moreover we account for price discrimination between on-net and off-net calls, which is omitted in the computation of official indices. We simulate 200 bills for each tariff and compute the mean values to compare tariffs. Out of the set of tariffs offered by each network operator, we pick the tariff which delivers the lowest bill. The cheapest tariff for the infrequent user is the one which determines the subscription decision of the marginal consumer.

The price indices computed in this way are correlated with the official price indices provided by the statistical office. Fig. 1a presents changes in the minimum tariffs for an infrequent user during the time period of this study. Apart from prices, firms also compete in handset subsidies and often provide handsets for free. For instance, in June 2003, T-Mobile offered six different handsets for the price of 1 Euro, D2 – 10 handsets, E-Plus – eight handsets and O2 – seven handsets.[11] Network operators try to recoup the initial investment in consumers through a stream of future payments.

5.1. *Instrumental variables*

To account for the endogeneity of prices and the within group shares we use instrumental variables. We have to find instruments which are correlated with prices and within group shares, but uncorrelated with the unobservable demand shocks. The error terms may be autocorrelated due to the character of data. Thus the usage of lagged endogenous variables, such as lagged consumer base, could be problematic.

Standard candidates for instruments are proxies for cost factors. For instance, Evans and Heckman (1984) estimate the total cost function in fixed-line telephony using prices of materials, the price of capital and the wage rate. In this study we use only one cost factor as an instrument: the cost of telecommunications equipment. It is publicly available through the German statistical office. The correlation coefficient of prices for mobile

[9] *Source:* magazine "Connect", http://www.teltarif.de.

[10] The German statistical office computes four monthly price indices for mobile services. First, three consumer profiles are defined based on the consumption intensities: infrequent, average and frequent users. Typically, network operators provide a set of tariffs for each profile. For all tariffs within each profile, an expected monthly bill is calculated. Consumers are assumed to be perfectly informed about the range of tariffs available each month on the market and choose the cheapest one. In this way, three profile indices are created which are further used to calculate aggregate weighted price index for mobile services. Tariffs consist of many price factors, such as on-net, off-net, fixed-line, time zones, billing intervals and so on, but the statistical office uses only the most important ones in the calculation. See Statistisches Bundesamt Wiesbaden (1999).

[11] *Source:* "Connect" magazine, June 2003.

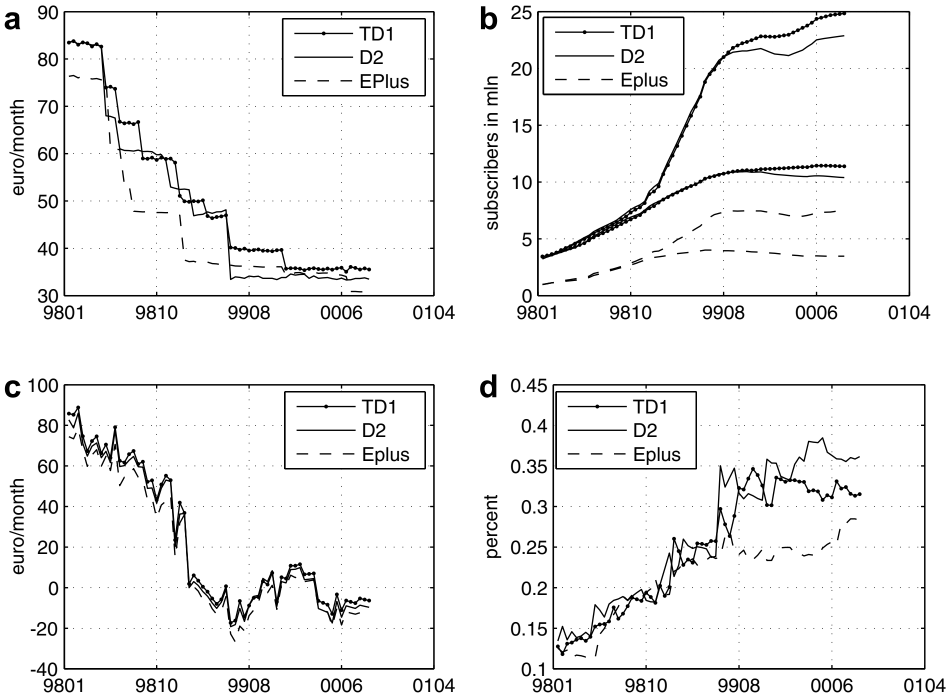

Fig. 1. (a) Lowest monthly bill for an infrequent user. (b) Industry growth with and without network effects. (c) Price levels required to reach subscriptions with network effects. (d) Margins $(\rho - c)/p$.

services with the hourly wages index in the telecommunications industry is almost zero and there are no other cost variables publicly available.

We also use a dummy for Christmas sales as an instrument, which is an explanatory variable in the model. Firms tend to offer special Christmas deals resulting in peak mobile sales in November and December. Apart from that, at the start of the year, due to the preparation for the international telecommunications fair – CeBIT, firms used to make announcements of new tariffs. This fair is held in Hannover in early March. Thus we also use a dummy for the first quarter as an instrument.

The time trend, which accounts for the technological innovation in mobile telephony, may be a component of the cost function as well. It could be interpreted as a constant upgrade in the quality of services and handsets. Furthermore the entry of Viag, which took place in November 1998, could have decreased market prices and shuffled market shares. We also use the numbers of tariffs offered by network operators as instruments. Potentially, the variation in the number of tariffs should affect within group shares.

Unfortunately we miss any other firm-specific variables. We use the following set of instruments $W_t = [1, christmas_t, quart1_t, capital_t, time_t, viag_t, tariffs_{jt}]$. Our identifying assumption is the mean independence of the demand shocks in (2) with the set of instruments, i.e. $E(\xi_{jt}|W_t) = 0$.

6. Estimation results

The demand for mobile subscriptions is dependent on service prices, the lagged total installed base and a dummy for Christmas sales. The coefficients for price and network benefits are assumed to be the same for all three networks. However, the Wald test rejects the equality of demand intercepts (see Table 1).

First, demands are estimated using ordinary least squares (OLS) and two stage least squares (2SLS) with the set of instruments discussed in the previous section. The estimation results are presented in Table 1. According to the Hausman specification test, the null hypothesis of the exogeneity of prices may be rejected at a significance level of 10%. The Breusch–Godfrey test indicates autocorrelation of the error terms in all three demand equations. We account for the problem of endogeneity and autocorrelation by estimating the parameters using general method of moments (GMM) with the Newey–West estimator for the covariance matrix of the moment conditions.

We also estimated two different versions of the model to check the robustness of our results. The first extension considers differential magnitudes of own and cross-network effects. Estimating demand functions that include both own and cross-installed bases as explanatory variables turns out to be impossible due to the high correlation of subscriptions. Hence we fix the estimate of the own network effects to the value from our preferred specification (column III in Table 1) and test whether the cross-network effects are significantly different. In this case the estimate of cross-network effects is given by $\beta_0 = 1.72$ (column IV in Table 1). The Wald test statistic of 4.44 implies that we cannot reject the equality of own and cross-network effects at a significance level of 1%.[12] Therefore, network effects resulting from the total installed base seem to be a justified assumption.

Our second extension considers a possible nonlinearity of the network benefit function. Similar to Clements and Ohashi (2005), we use a Box–Cox transformation of the lagged penetration of mobiles and specify the modified network benefit function as $V(z_t^e) = \beta \frac{(1+z_{t-1})^{\lambda}-1}{\lambda}$. This transformation allows for our linear specification when $\lambda = 1$ and logarithmic when $\lambda = 0$. Once again, due to a collinearity problem, we are not able to estimate β and λ simultaneously. Again we fix the coefficient of network effects β and estimate λ. The hypothesis that $\lambda = 1$ cannot be rejected, which supports the use of a linear network benefit function (Wald test statistics of 0.42). Also Clements and Ohashi (2005) cannot reject the hypothesis of a linear specification for indirect network effects.

The estimates of all parameters are significant, as presented in Table 1. In particular, σ is estimated to be 0.80, which implies a relatively high correlation of choices within the nest. We calculate the elasticities of demand to interpret the estimates of coefficients for price and network effects. The own and cross-price elasticities of demand in the nested logit model are specified as

$$E_{p_{kt}}^{s_{jt}} = \begin{cases} -\frac{\alpha}{1-\sigma} p_{jt}\left[1 - \sigma \bar{s}_{jt|g=1} - (1-\sigma)s_{jt}\right] & \text{if } k = j, \\ \frac{\alpha}{1-\sigma} p_{kt}\left[\sigma \bar{s}_{kt|g=1} + (1-\sigma)s_{kt}\right] & \text{if } k \neq j, \end{cases}$$

[12] Note that when we computed firm-specific price indices, we took the difference in on-net and off-net prices into account. Thus, any price-mediated network externality is already captured in the price indices.

Table 1
Nested logit – T-D1, D2 Vodafone, E-plus

Parameter name estimates	OLS estimates (t)	2SLS estimates (t)	GMM estimates (t)	GMM own net estimates (t)	GMM Box–Cox estimates (t)
r_{d1}	−2.62 (−8.77)	−2.83 (−8.40)	−2.92 (−21.68)	−3.03 (−37.77)	−2.84 (−27.13)
r_{d2}	−2.69 (−9.24)	−2.89 (−8.81)	−2.98 (−22.46)	−3.08 (−40.14)	−2.90 (−28.14)
r_{e1}	−2.96 (−8.68)	−3.21 (−7.43)	−3.28 (−30.34)	−3.32 (−40.71)	−3.24 (−38.30)
β	1.34 (6.09)	1.40 (5.17)	1.47 (10.23)	1.47	1.47
β_0				1.72 (14.49)	
α	−2.46 (−8.40)	−2.27 (−6.44)	−2.16 (−15.14)	−1.98 (−21.55)	−2.28 (−17.44)
Christmas	0.31 (4.78)	0.31 (4.85)	0.33 (4.84)	0.36 (4.89)	0.33 (4.88)
σ	0.85 (6.57)	0.79 (3.49)	0.80 (23.34)	0.89 (29.49)	0.76 (20.78)
λ					0.82 (3.03)
MSE T-Mob	0.1073	0.1090	0.1098	0.1105	0.1081
MSE D2	0.1193	0.1196	0.1199	0.1200	0.1190
MSE E-Plus	0.1002	0.1000	0.1000	0.1004	0.0995
N * Obj.	20.80	6.1479	12.2979	11.9607	12.3651
Hausman		12.55			
$Pr > \chi^2$		0.0840			
Wald			171.29	4.44	0.42
$Pr > \chi^2$			0.001	0.035	0.51

where s_{jt} is the share of network operator j in sales at time t and $\bar{s}_{jt|g=1}$ is the within group share. Table 2 presents the average elasticities for GMM estimates for period January 1998–June 2003.

For instance, a 1% price increase by T-Mobile resulted in 4.48% decrease in its sales and in 2.22% increase in the sales by D2 and E-Plus. We also calculate the elasticity of demand for mobile services in total, which is given by

$$E^{s_t}_{p_{kt}} = -\alpha s_{jt}(1 - s_t)\frac{p_{kt}}{s_t}.$$

The values in the last column in Table 2 are interpreted as follows: on average in the period January 1998–June 2003, a 1% price increase by T-Mobile resulted in 0.52% decrease in total sales of mobiles. This is the outcome of two opposite effects – a decrease in sales by T-Mobile and an increase in sales by the other network operators. Similarly, a 1% price increase by D2 and E-Plus led to a decrease in total sales by 0.52% and 0.19%, respectively. The elasticity of demand for mobile services in respect to the past installed base is specified as

$$E^{s_t}_{z_{t-1}} = \beta z_{t-1}(1 - s_t).$$

Table 2
Demand elasticities – prices and past consumer base

	T-Mobile	D2	E-Plus	Mobiles s_t
T-Mobile	−4.48	2.22	2.22	−0.52
D2	2.19	−4.20	2.19	−0.52
E-Plus	0.79	0.79	−5.04	−0.19
Network effect				0.69

If the previous period total installed base increased by 1%, current period sales would surge on average by 0.69%. This indicates strong network effects. If there were no network effects, the industry growth would be stimulated only by price changes. As presented in Fig. 1b, the penetration level in the absence of network effects could be at least 50% lower, compared to the current case. This is due to the fact that prices remained almost constant in the second part of the period analyzed. Network effects also have an impact on the equilibrium prices, which is ignored in projections. In the absence of network effects, the current penetration level could be reached only if prices were significantly lower. Fig. 1c suggests that prices would have to fall to zero or even lower. These projections indicate the importance of network effects for the growth of the industry. There was also a significant Christmas effect which resulted in an increase in demand for mobile subscriptions during the months of November and December.

Furthermore, assuming that observed prices are the result of a pure strategy Nash equilibrium, we can make use of the first-order equations to retrieve information about marginal costs. This assumption ignores the effects of current prices on future profits, which potentially leads to overestimated margins. The estimates of margins may be interpreted as an upper bound. Following Berry (1994), using first-order conditions for the nested logit model, the marginal cost may be written as

$$c_{jt} = p_{jt} - \left[\frac{(1-\sigma)}{\alpha} \Big/ [1 - \sigma\bar{s}_{jt|g=1} - (1-\sigma)s_{jt}]\right]. \tag{3}$$

Using the estimates of α and σ from the demand side we may calculate the changes in marginal cost and margin for each network operator over the time period analyzed. Fig. 1d shows changes in the total margins calculated as $(p_{jt} - c_{jt})/p_{jt}$. The price-cost margin for all network operators increased over time from about 13% in January 1998 to about 30% in June 2003. This increase is due to the fact that the margins remained almost constant while the prices decreased. At the end of the period margins differed across network operators with E-plus having the lowest value of about 28%, T-Mobile roughly 31% and D2 approximately 36%.

This paper employs the standard aggregate nested logit model and the results therefore depend on the limitations of the empirical model. For instance, the nested logit model has the property of independence of irrelevant alternatives within the nest, which implies that all cross-price elasticities with respect to the price of certain product are the same. Also cross-price elasticities of demand within the nest denoted by $E^{s_{jt}}_{p_{kt}}$ and the elasticity of demand for mobile services in total given by $E^{s_t}_{p_{kt}}$ depend on market shares s_{jt} and therefore are the smallest for E-Plus. Unfortunately, given data limitations we cannot use a more flexible framework, such as the random coefficients model. Also, we cannot estimate own and cross-price elasticities using a system of linear demands (having three prices in each equation) because of high price collinearity. Any restriction on price coefficients in linear demand system would also impose restrictions on elasticities.

7. Conclusion

In this paper we analyze the role of network effects in the mobile telecommunications industry in Germany. We find that network effects have a significant impact on consumers' decisions regarding subscriptions to mobile services. We are able to disentangle the impact of price and network effects on subscription demand and estimate reasonable price elasticities. For instance, on average in the period January 1998–June 2003, a 1% price increase by T-Mobile resulted in 4.48% decrease in its sales and in 2.22% increase in the sales by D2 and E-Plus. Furthermore, a 1% price increase by T-Mobile resulted in 0.52% decrease in total sales of mobiles, which is the outcome of two opposite effects – a decrease in sales by T-Mobile and an increase in sales by the other network operators. Similarly, a 1% price increase by D2 and E-Plus led to a decrease in total sales by 0.52% and 0.19%, respectively. If the previous period total installed base increased by 1%, current period sales would surge on average by 0.69%. If there were no network effects, the penetration of mobiles at the end of the period analyzed could be at least 50% lower. Current penetration levels could be reached only if prices were drastically lower. Furthermore, by estimating the price coefficient and assuming Nash equilibrium in prices we could provide measurements of marginal costs.

Besides the limitations mentioned in the former section, the discrete-choice model fits well to the analysis of mobile telephony where each consumer subscribes exactly to one network. The other advantage of nested logit model is that it leads to linear demand functions and could be easily applied for antitrust analysis. In the presence of constraints on data and timing of the analysis, which is almost always the case, an application of standard empirical framework is unavoidable.

As suggested by this study, network effects are an important aspect of antitrust analysis in mobile telephony. They influence consumers' subscription decisions to mobile services. By ignoring network effects, that is, by attributing the whole dramatic changes in demand to decreases in prices, we could overestimate price elasticities and underestimate margins. Thus, we could end up drawing incorrect conclusions about the competitiveness of the industry.

Acknowledgements

We are grateful to two anonymous referees and to the editor Tommaso Valletti for valuable comments. We would like to thank Volkswagen Stiftung, Munich Graduate School of Economics and the CEPR RTN Competition Policy in International Markets for the generous financial support which made this research possible. All errors are ours.

References

Anderson, S., De Palma, A., Thisse, J.-F., 1992. Discrete Choice Theory of Product Differentiation. MIT Press, Cambridge, MA.

Berry, S.T., 1994. Estimating discrete-choice models of product differentiation. RAND Journal of Economics 25 (2), 242–262.

Birke, D., Swann, P., 2006. Network effects and the choice of mobile phone operator. Journal of Evolutionary Economics 16 (1/2), 65–84.

Bousquet, A., Ivaldi, M., 1997. Optimal pricing of telephone usage: an econometric implementation. Information Economics and Policy 9 (3), 219–239.

Brynjolfsson, E., Kemerer, C., 1996. Network externalities in microcomputer software: an econometric analysis of the spreadsheet market. Management Science 42, 1627–1647.

Clements, M.T., Ohashi, H., 2005. Indirect network effects and the product cycle: video games in the US, 1994–2002. Journal of Industrial Economics 53 (44), 515–542.

Economides, N., Himmelberg, Ch., 1995. Critical Mass and Network Size with Application to the US Fax Market. Discussion Paper no. EC-95-11, Stern School of Business, New York University.

Evans, D., Heckman, J., 1984. A test for subadditivity of the cost function with an application to the bell system. American Economic Review 74 (4), 615–623.
Farrell, J., Klemperer, P., 2006. Coordination and Lock-In: Competition with Switching Costs and Network Effects. Competition Policy Center. Paper CPC06-058.
Gandal, N., 1994. Hedonic price indexes for spread sheets and a test of network externalities. RAND Journal of Economics 25 (1), 160–170.
Gandal, N., Kende, M., Rob, R., 2000. The dynamics of technological adoption in hardware/software systems: the case of compact disc players. RAND Journal of Economics 31 (1), 43–61.
Goolsbee, A., Klenow, P.J., 2002. Evidence on learning and network externalities in the diffusion of home computers. Journal of Law and Economics 45 (2), 317–344.
Grajek, M., 2003. Estimating Network Effects and Compatibility in Mobile Telecommunications. WZB Discussion Paper SP II 2003-26.
Gröhn, A., 1999. Network Effects in PC Software: An Empirical Analysis. Mimeo, National Bureau of Economic Research, Cambridge, MA.
Gruber, H., Verboven, F., 2001. The diffusion of mobile telecommunication services in the European Union. European Economic Review 45, 577–588.
Hartman, R., Teece, D.J., 1990. Product emulation strategies in the presence of reputation effects and network externalities: some evidence from the microcomputer industry. Economics of Innovation and New Technology 1, 157–182.
Katz, M., Shapiro, C., 1985. Network externalities, competition and compatibility. American Economic Review 75 (3), 424–440.
Kim, H.S., Kwon, N., 2003. The advantage of network size in acquiring new subscribers: a conditional logit analysis of the Korean mobile telephony market. Information Economics and Policy 15 (1), 17–33.
Koski, H., Kretschmer, T., 2005. Entry, standards and competition: firm strategies and the diffusion of mobile telephony. Review of Industrial Organization 26, 89–113.
Moch, D., 1995. Ein hedonischer Preisindex für PC-Datenbanksoftware: Eine empirische Untersuchung. In: Harhoff, D./Müller, M. (Hrsg.): Preismessung und technischer Fortschritt, Baden Baden.
Ohashi, H., 2003. The role of network externalities in the US VCR Market, 1978–86. Journal of Economics and Management Strategy 12 (4), 447–494.
Park, S., 2003. Quantitative analysis of network externalities in competing technologies: the VCR case. The Review of Economics and Statistics 86, 937–945.
Statistisches Bundesamt Wiesbaden, 1999. Neuberechnung des Verbraucherpreisindex für Telekommunikationsdienstleistungen auf Basis 1995. Sonderdruck aus Wirtschaft und Statistik.
Swann, P., 2002. The functional form of network effects. Information Economics and Policy 14 (3), 417–429.
Wallsten, S.J., 2003. Of carts and horses: regulation and privatization in telecommunications. Journal of Policy Reform 6 (4), 217–231.