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Entry, costs reduction, and competition in the Portuguese mobile telephony industry

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Abstract

We study the effect of entry on costs and competition in the Portuguese mobile telephony industry. We construct and estimate a model that includes demand, network, and cost equations. The latter accounts for inefficiency and cost reducing effort. Our results suggest that the entry of a third operator in 1998 led to significant cost reductions and fostered competition. We also show that failure to account for cost reducing effort leads to biased estimates of competition in the industry. Finally, we also find that our estimated price–cost margins are similar to hypothetical Nash margins, if firms are patient and have optimistic beliefs about the industry growth.

JEL classification: L13; L43; L93

Keywords: Mobile telephony; Entry; Competition; Efficiency; Empirical analysis

1. Introduction

We analyze the mobile telecommunications industry in Portugal. We first test whether cost reduction and competition were affected by the entry of an additional firm in 1998 and the liberalization of fixed telephony in 2000. Second, we focus on the pricing behavior of the firms. With a dynamic model, we shed light on whether firms cared for immediate profits, or whether they were more concerned with increasing their customer base during the period we study.

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A common practice in the empirical industry models that focus on oligopolistic frameworks is to assume that firms are efficient and costs are exogenous. This is in contradiction with a rich empirical tradition related to the measurement of efficiency through the estimation of production and cost functions (Aigner et al., 1977; Kumbhakar and Lovell, 2000). Moreover, the recent literature on incentives proposed a theoretical framework to account for the effect of cost reduction by firms, emphasizing the endogeneity of costs (Laffont, 1994). This literature suggests that the firms' endogenous effort depends closely on the constraints exerted by the competitive or regulatory environment it faces.

We construct and estimate an industry model that includes cross-price elasticities, and where firms choose both prices and cost reducing effort. The model consists of a system of equations that accounts for the demand, network, and the technology of each firm. Technology is described by a cost function that includes two non-observable parameters: the exogenous technical inefficiency of each firm and cost reducing effort. Cost reducing effort can be expressed by taking into account the competitive pressures impinging on the activity of each firm before and after the entry of a third firm or the liberalization of the telecommunications industry.

The Portuguese mobile telephony industry provides a suitable application for the framework we have in mind. In Portugal, the firm associated with the incumbent, *Tmn*, started its activity in 1989 with the analogue technology *C-450*. In 1991, the sectorial regulator, *ICPANACOM*, assigned two licenses to operate the digital technology *GSM 900*.¹ One of the licenses was assigned to *Tmn*. The other license was assigned to the entrant *Vodafone*. In 1997, the regulator assigned three licenses to operate the digital technology *GSM 1800*. Two licenses were assigned to *Tmn* and *Vodafone*. A third license was assigned to the entrant *Optimus*, which was also granted a license to operate *GSM 900*. Finally, the legislation of the *EU* imposed the full liberalization of the telecommunications industry at the end of the nineties. The liberalization affected essentially fixed line services. After 1998, any firm licensed by the sectorial regulator could offer fixed telephony services, either through direct access based on their own infrastructures or through indirect access available for all types of calls. In Portugal, the liberalization took effect in 2000.² Note that the entry of *Optimus* and the 2000 liberalization were independent and exogenous events, determined largely at the *EU* level.

After its inception in 1989, the Portuguese mobile telephony industry had a fast diffusion (Pereira and Pernias, 2004), which led to high and rising penetration rates. After entering the market in 1992, *Vodafone* gained revenue market share rapidly, as shown in Fig. 1. During the duopoly period, i.e., from 1992 to 1997, *Tmn* and *Vodafone* essentially shared the market. The entry of *Optimus* led to an asymmetric split of the market, which suggests that this event had a significant impact in the industry.

The objective of our work is threefold. First, we test whether the entry of *Optimus* in 1998, or the full liberalization of the telecommunications industry in 2000, gave firms stronger incentives to reduce costs. Note that economic theory has no simple prediction about the relation between

¹ Both of the licenses for *GSM 900* and for *GSM 1800* were assigned through public tenders, following the *EU* Directives 91/287 and 96/2, respectively. The first Directive instructed member states to adopt the *GSM* standard, and the second to grant at least two *GSM 900* licenses and to allow additional firms to use *GSM 1800*. System *GSM 900* operates on the 900 MHz frequency. System *GSM 1800* operates on the 1800 MHz frequency.

² The liberalization was promoted by, among others, the Council Directive 90/387/EEC, the Commission Directive 90/388/EEC, Council Resolution 93/C213/01, and the Commission Directive 96/19/EC. The official date for the liberalization was 1998. Portugal, like other countries, benefited from a derogation (Commission Decision 97/310/EC).

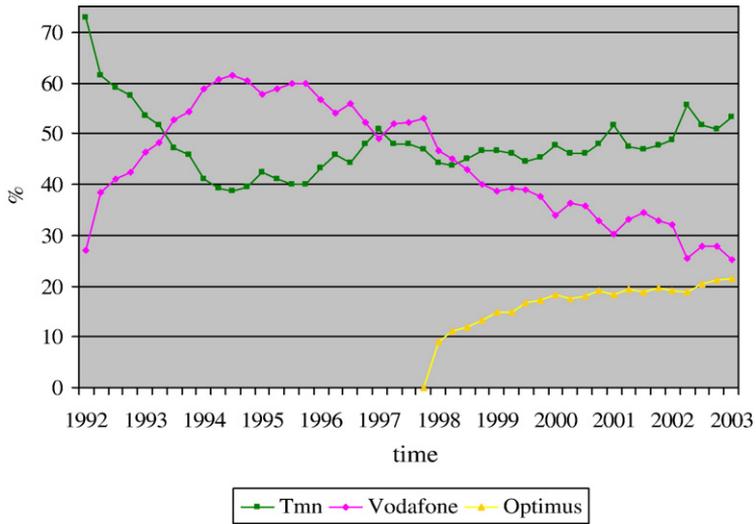


Fig. 1. Revenue market shares.

the number of competitors in a market and incentives to reduce costs.³ We construct a cost function that accounts for the firms' cost reducing effort and test several scenarios of incentive pressures against each other, in order to identify which fits the data better. We show that cost reducing effort increased significantly after the entry of *Optimus* in 1998, while the 2000 liberalization had only a mild impact on cost reduction.⁴

Second, with several tests, we show that our model improves upon a simple cost function with no inefficiency and no effort. We discuss alternative explanations for cost reduction after the entry of *Optimus*, such as preemptive behavior by the incumbents or spillovers effects at the industry level, and explain why we discard them.

Third, given these estimates, we retrieve cost and demand parameters to construct marginal costs, and therefore price–cost margins. The results show that the standard model underestimates the toughness of competition. Using an original dynamic pricing framework, we test whether price–cost margins correspond to a non-cooperative Nash behavior under alternative hypothesis, where firm either have a myopic or a long-run perspective. We find that estimated price–cost margins are similar to hypothetical Nash margins, if firms are patient and have optimistic beliefs about the industry growth. As a by-product, network effects and switching costs are also identified as playing an important role in this industry.

The remainder of the paper is organized as follows. Section 2 presents the cost, network, and demand systems. Section 3 proposes a model of firms' cost reduction activity. Section 4 presents

³ The likely effect of the entry is a decrease in prices. If in addition the quantity produced by each firm increases, then firms have more incentives to invest in marginal cost reducing effort. If, however, the quantity produced by each firm decreases, firms have less incentives to invest in cost reduction. See Pereira (2001) for a model where lower prices can be associated with higher or lower investment in cost reduction.

⁴ Note that, on the one hand, more competition in fixed telephony should have pushed the prices of this service down, and reduced the substitution between fixed and mobile telephony (Barros and Cadima, 2000; Rodini et al., 2003). On the other hand, the liberalization involved a tariff rebalancing which increased the telephone subscription fee and the price of local calls. It is therefore unclear what the impact of the full liberalization of the telecommunications market in Portugal should have been.

an empirical evaluation of such activity. Section 5 evaluates the competitive forces in the industry, which entails determining the pricing rules set by firms. Section 6 proposes a welfare analysis. Finally, Section 7 concludes.

2. Building blocks of the model

In what follows, we specify a model of the firms' behavior that encompasses two important aspects of our problem. We are interested in representing the firms' cost reducing activity and pricing decisions, as well as the interconnection between these two aspects. This entails defining first a three-part structure that includes cost, network growth, and demand equations.

2.1. Demand and network growth

We refer to the three firms in the market by their order of entry, e.g., Tmn is firm 1, and index them with subscript $i=1, 2, 3$. We index time through subscript t . The demand of firm i on period t depends on its price p_{it} and a vector of the competitors' prices \mathbf{p}_{jt} . Moreover, we account for the consumers' income r_t , the size of its network, i.e., numbers of subscribers, in the previous period n_{it-1} , and a time trend t . The inclusion of the size of the network in the previous period could be justified by two non-mutually exclusive reasons. The first reason involves network economies. The consumers' marginal valuation of the service depends on the number of other consumers who belong to the network. However, consumers only observe with lag the size of the firms' networks.⁵ The second reason involves switching costs or consumer inertia. An increase in a firm's price relative to the prices of its rivals induces consumers to leave the firm. However, if consumers have switching costs, they will not respond immediately, but only over time. The time trend accounts for changes in preferences or consumer awareness. Denote by y_{it} the traffic, i.e., minutes of communication, supplied by firm i in period t . Each firm faces a demand of the form:

$$y_{it} = D_i(p_{it}, \mathbf{p}_{jt}, r_t, n_{it-1}, y_{it-1}, t|\alpha), \quad (1)$$

where α is a vector of parameters to be estimated and where the lagged network size term y_{it-1} is included in order to capture short-run dynamics. Two comments are in order. First, we do not impose any pattern of substitution between the firms' products. In particular, we do not impose that the products are homogeneous. Second, we assume that firms charge linear prices. This hardly involves any loss of generality, since 80% of the subscribers have prepaid cards.

We also assume that the size of firm i 's network in period t depends on its price p_{it} , a vector of the competitors' prices \mathbf{p}_{jt} , the consumers' income r_t , the size of its network in the previous period n_{it-1} , and a time trend t . Thus, each firm faces a network function of the form:

$$n_{it} = N_i(p_{it}, \mathbf{p}_{jt}, r_t, n_{it-1}, t|\gamma), \quad (2)$$

where γ is a vector of parameters to be estimated. The lagged network size term n_{it-1} is included in order to capture short-run dynamics. The network function will be useful in Section 5 where we disentangle short-run from long-run pricing decisions. Eqs. (1) and (2) give a dynamic structure to the model in the sense that a firm's demand in period t depends on its price of the previous period.

⁵ Network interconnection obligations mitigate, but do not eliminate network economies. Differences between intra and inter network calls resurface the value for a consumer of belonging to a large network as well as the strategic advantage for a firm of owning a large network.

2.2. Costs

We now turn to the cost side of the model. To produce a volume of traffic y_{it} , firm i requires quantities of labor, l_{it} , materials, m_{it} , and capital, k_{it} . Denote by $\omega_{l_{it}}$, $\omega_{m_{it}}$, and $\omega_{k_{it}}$ the price of labor, materials, and capital, respectively.

Denote by c_{it} the observed operating cost of firm i . An important feature of our model is that the actual operating cost may differ from the minimum operating cost. Inefficiency may prevent firms from reaching the required output level y_{it} at the minimum cost, and this may result in upward distorted costs.⁶ However, firms can undertake cost reducing activities to counterbalance their inefficiency. They can engage in process research and development; managers may spend time and effort in improving the location of inputs within the network, in particular reorganizing the position of base transceiver stations, antennas, supporting towers, and base station controllers, and upgrading the mobile switching centers. They can as well attempt to find cheaper suppliers, bargain better procurement contracts, subcontract non-essential activities, monitor employees, solve potential conflicts, etc. Whatever these cost reducing activities may be, we will refer to them as *effort*. Denote by θ_i and e_{it} firm i 's inefficiency and effort levels, respectively. Note that these two variables are unobservable. We also allow the possibility of technical progress, which is captured by a time trend t . Each firm faces a long-run cost function, conditional on inefficiency and effort, of the form:

$$c_{it} = C(y_{it}, \omega_{l_{it}}, \omega_{m_{it}}, \omega_{k_{it}}, t | \theta_i, e_{it}, \beta), \quad (3)$$

where β is a vector of parameters to be estimated. Note that, while inefficiency θ_i is exogenous, cost reducing effort e_{it} is a choice variable for firm i and will therefore depend on the competitive pressures impinging on the activity of the firm.

In a second step, we need to define the structure of the system of Eqs. (1), (2) and (3). This entails describing the firms' pricing and effort decisions. Before entering into the analysis, it is worth reminding that the pricing structure itself is independent of the nature of the competitive pressures impinging on the activity of the firm.⁷ Thus, although prices and effort are determined simultaneously, the firms' decisions will be presented separately, for ease of exposition.

3. Competitive pressure and cost reduction

This section focuses on the construction of the structural cost function. The entry of *Optimus* in 1998, as well as the 2000 liberalization, may have influenced the cost reducing activities of firms. We propose to account for the competitive pressures potentially unleashed by these two events through the cost function (3) that is conditional on inefficiency θ_i and the effort level e_i . Deriving the equilibrium level of effort and plugging it back into the conditional cost function allows us to derive a structural cost function that can be estimated. The aim of this approach is twofold. First, we can test against each other different scenarios associated with these two events

⁶ There are several ways of thinking about inefficiency. First, it may simply be the result of the irreducible uncertainty that involves the creation of a new production process. This interpretation is in line with Lippman and Rumelt (1982), Hopenhayn (1992), Jovanovic (1982), and Klepper and Graddy (1990). Alternatively, inefficiency may be related to the quality of the firm's production factors.

⁷ The way we incorporate the technical inefficiency and effort parameters allows the incentive-pricing dichotomy principle to hold (Laffont and Tirole, 1993). This means that the same pricing formula applies whether we assume strong or weak competitive pressures.

in order to determine whether the entry of *Optimus* or the 2000 market liberalization had a significant impact on the cost reducing effort of the Portuguese mobile telephony firms. Second, accounting for these changes in incentives through the cost structure enables us to reduce the source of misspecification and avoid biases in the estimation of the technological parameters.⁸

As mentioned before, a firm can exert effort e_{it} to reduce its operating costs c_{it} . The cost reduction activity induces an internal cost $\Psi(e_{it}|\mu)$, where μ is a parameter to be estimated. Taking into consideration the operating cost reduction and the internal cost of effort, the firm sets the optimal effort level e_{it} that maximizes its profit. Firm i 's profit is the difference between revenue $R_{it}=p_{it}D_{it}$ and total cost $c_{it}(e_{it}, \cdot) + \Psi(e_{it}, \cdot)$:

$$\Pi_{it}(p_{it}, e_{it}, n_{it-1}) = p_{it}D(p_{it}, \mathbf{p}_{it}, r_t, n_{it-1}, t) - C(y_{it}, \omega_{it}, \omega_{m_{it}}, \omega_{k_{it}}, t|\theta_i, e_{it}) - \Psi(e_{it}). \quad (4)$$

Assuming an infinite horizon set-up, a firm's effort choice problem, given the output level, is:

$$\max_{e_{it}} \sum_{t=0}^{\infty} \Pi_{it}(p_{it}, e_{it}, n_{it-1}) \quad \text{s.t.} \quad n_{it} = N_{it}(p_{it}).$$

Denote by $V(n_{it})$ the optimal value function for firm i , given the size of the its network n_{it} . The Bellman equation for firm i 's effort choice problem, given the output level, is:

$$V(n_{it-1}) = \max_{e_{it}} \{ \Pi_{it}(p_{it}, e_{it}, n_{it-1}) + \delta V(n_{it}) \}. \quad (5)$$

where δ is the discount factor. The first-order condition for effort is:

$$-\frac{\partial C(y_{it}, \cdot|\theta_i, e_{it})}{\partial e_{it}} = \Psi'(e_{it}), \quad (6)$$

which implies that the optimal effort level equalizes marginal cost reduction and the marginal disutility of effort.

We consider two periods. First, a period "B", which refers either to the phase before the entry of *Optimus* or before the 2000 liberalization. And second, a period "A", which refers either to the phase after the entry of *Optimus* or after the 2000 liberalization. We expect firms to provide effort during both periods, and the effort level in the second period to be higher than the effort level in first period, i.e., $e_i^A > e_i^B$. However, to be able to derive and identify two different closed forms for the cost function (3), we need to normalize $e_i^B=0$ and let e_i^A be determined by condition (6).⁹ Given these two effort levels, we can write the cost function as

$$C^S(e_{it}^s, \cdot), \quad (7)$$

where s denotes the type of competitive regime that can be either be "B" or "A". Note that Eq. (7) entails two different cost structures that are conditional on the period studied.

⁸ Previous studies have attempted to account for cost endogeneity problems after a change in regulation. Among them, Parker and Roller (1997) analyze the impact of regulatory changes on the competitiveness of mobile telecommunications markets. Gagnepain and Ivaldi (2002) show how firms' cost reducing activity is related to the regulatory contracts set by public authorities in the public transit industry.

⁹ This assumption is justifiable, given that what matters in our analysis is the difference $e_i^A - e_i^B$. Note that we do not force e_i^A to be positive when estimating it.

4. Evaluating cost reductions

The next step consists of proposing specific functional forms for the demand, network, and cost functions, as well as for the cost reducing effort, in order to derive the set of structural equations to be estimated. Using data from the Portuguese mobile telephony firms, we are capable of shedding light on the cost structure that fits reality the best, i.e., we are able of figuring out which event, the entry of *Optimus* or the 2000 liberalization, had a significant impact on the firms' behavior. This section describes the data and presents the empirical model and the estimation results.

4.1. Data

In this study, we use data at the firm level. For the cost and the network equations, this is the type of data that is usually considered. However, on the demand side, this could constitute a potential drawback. It is useful to have disaggregated demand data at the consumers level to estimate the own price elasticity of demand. The advantage of this is that it takes into account consumers' characteristics that may affect firms' behavior, and it allows describing with greater precision consumers' decisions. However, we do not have data at the consumer level. This obliges us to evaluate an average demand elasticity for all the firms of the sample. Note that this is a minor concern in our study, since our main objective on the demand side is to shed light on whether firms produce on the elastic or inelastic part of the industry demand curve. The data we have is perfectly valid for our aim.

The dataset has been constructed for the period 1992–2003 from data collected by Autoridade da Concorrência, the Portuguese national competition authority. The data consists of quarterly observations obtained from the three firms under consideration in our study, namely *Tmn*, *Vodafone*, and *Optimus*.

The variables were constructed as follows. In the cost function, total costs (c_{it}), production (y_{it}), wages (ω_{it}), prices of materials ($\omega_{m_{it}}$), and price of capital ($\omega_{k_{it}}$) correspond to total operating expenses, telecommunications traffic in thousands minutes supplied, total labor costs over number of employees, costs of supplies, and national interest rates on 10 years treasury bonds, respectively.

With respect to demand and network growth, firm i 's price (p_{it}) for year t is measured as total revenues over traffic supplied. Moreover, the size of i 's network (n_{it}) is measured by the number of i 's subscribers, and the income per capita (r_t) is measured by the Portuguese gross national product per capita in 1995 prices.

In all three equations, t the time trend is equal to one in the last quarter of 1992 and incremented by one each quarter.

4.2. Empirical implementation

The demand function corresponding to (1) is specified in a log-linear form as follows:

$$\ln y_{it} = \alpha_0 + \alpha_{p_i} \ln p_{it} + \sum_{s=B,A} \sum_{j \neq i} \alpha_{p_{ij}}^s \ln p_{jt} + \alpha_{n-1} \ln n_{it-1} + \alpha_r \ln r_t + \alpha_t t + \alpha_{y-1} \ln y_{it-1} + u_{it}^d \quad (8)$$

where u_{it}^d is an error term. This specification entails constant own and cross-price elasticities. Note that the cross-price elasticities $\alpha_{p_{ij}}^s$ are allowed to vary from one period to another, i.e., we

consider a switching regime methodology that permits estimating different cross-price elasticities, depending on whether two firms, during period “B”, or three firms, during period “A”, were competing in the industry.

Following the same specification, the network growth function corresponding to (2) is specified as follows:

$$\ln n_{it} = \gamma_0 + \gamma_{p_i} \ln p_{it} + \sum_{s=B,A} \sum_{j \neq i} \gamma_{p_{ij}}^s \ln p_{jt} + \alpha_r \ln r_t + \gamma_t t + \gamma_{n-1} \ln n_{it-1} + u_{it}^n, \quad (9)$$

where u_{it}^n is an error term.

We assume a Cobb-Douglas specification for the cost function presented in (3). This specification retains the main properties desirable for a cost function, while remaining tractable. Alternative more flexible specifications, such as the translog function, lead to cumbersome computations of the first-order conditions when effort is unobservable.¹⁰ The cost function is then specified as:

$$\ln c_{it} = \beta_0 + \beta_l \ln \omega_{l_{it}} + \beta_m \ln \omega_{m_{it}} + \beta_k \ln \omega_{k_{it}} + \beta_y \ln y_{it} + \beta_t t + \theta_i - e_{it} + u_{it}^c, \quad (10)$$

where u_{it}^c is an error term. We impose homogeneity of degree one in input prices, i.e., $\beta_l + \beta_m + \beta_k = 1$.

The reader should remember that θ_i and e_{it} are both unobservable. First, the inefficiency θ_i is characterized by a density function $f(\theta_i)$, defined over an interval $[\theta_L, \infty[$, where θ_L denotes the most efficient firm. Second, the effort e_{it} is defined as follows. Define the cost of effort as¹¹:

$$\Psi_{it}(e_{it}) = \exp(\mu e_{it}) - 1, \quad \mu > 0. \quad (11)$$

Then, using the functional forms of operating costs (10), the cost of effort (11), and the first-order condition for effort (6), we can express the effort level for period “A”. The first-order condition that determines the effort level e_{it}^A can now be written as:

$$c_{it} = \mu \exp(\mu e_{it}). \quad (12)$$

Substituting (10) in (12), we can solve for e_{it}^A it as:

$$e_{it}^A = \frac{1}{\mu + 1} (\beta_0 + \beta_y \ln y_{it} + \beta_l \ln \omega_{l_{it}} + \beta_m \ln \omega_{m_{it}} + \beta_k \ln \omega_{k_{it}} + \beta_t t + \theta_i - \ln \mu + u_{it}^c), \quad (13)$$

while $e_{it}^B = 0$.

As suggested by the new theory of regulation, the effort level of a firm increases with θ_i , i.e., a more inefficient firm optimally exerts more effort than a less inefficient firm, $\frac{\partial^2 c}{\partial \theta_i \partial e_{it}} < 0$. Moreover, firms are willing to provide less effort when effort is more costly, i.e., when the cost reducing technology parameter μ is larger. Substituting back e_{it}^A and e_{it}^B into (10) allows us to obtain the final forms to be estimated $c^A(\cdot)$ and $c^B(\cdot)$. We therefore obtain:

$$\ln c_{it}^A = c_0 + \beta_l' \ln \omega_{l_{it}} + \beta_m' \ln \omega_{m_{it}} + \beta_k' \ln \omega_{k_{it}} + \beta_y' \ln y_{it} + \beta_t' t + \zeta \theta_i + u_{it}^{c'}, \quad (14)$$

¹⁰ In particular, in order to solve for Eq. (6), plug it into Eq. (3) and estimate Eq. (7) applying parametric techniques, we need a Cobb-Douglas specification.

¹¹ The function $\Psi(\cdot)$ is a convex, with $\Psi(0)=0$, $\Psi'(e_{it})>0$, and $\Psi''(e_{it})>0$.

and

$$\ln c_{it}^B = \beta_0 + \beta_l \ln \omega_{li} + \beta_m \ln \omega_{mi} + \beta_k \ln \omega_{ki} + \beta_y \ln y_{it} + \beta_t t + \theta_i + u_{it}^c, \quad (15)$$

where $\zeta = \frac{\mu}{1+\mu}$, $c_0 = \beta_0 + \frac{1}{1+\mu}(\ln \mu - \beta_0)$, $\beta' = \zeta \beta$, and $u_{it}^{c'} = \zeta u_{it}^c$. Note that $\lim_{\mu \rightarrow +\infty} \beta'_s = \beta_s$, i.e., as the cost of effort grows, the effort level falls, and expression (14) converges to (15). This implies that, if effort is not properly identified, the estimates of the cost elasticities are biased.¹²

The cost function to be estimated is then:

$$\begin{aligned} \ln c_{it} = & \xi_{it}^A [c_0 + \beta'_l \ln \omega_{li} + \beta'_m \ln \omega_{mi} + \beta'_k \ln \omega_{ki} + \beta'_y \ln y_{it} + \beta'_t t + \zeta \theta_i + u_{it}^{c'}] \\ & + \xi_{it}^B [\beta_0 + \beta_l \ln \omega_{li} + \beta_m \ln \omega_{mi} + \beta_k \ln \omega_{ki} + \beta_y \ln y_{it} + \beta_t t + \theta_i + u_{it}^c], \end{aligned} \quad (16)$$

where ξ_{it}^A takes value 1 during period “A” and 0 otherwise, while ξ_{it}^B it takes value 1 during period “B” and 0 otherwise. In the course of the estimation, several vectors ξ_{it}^A and ξ_{it}^B will be assumed, depending on which scenario is considered, and their results will be tested against each other, to unravel their effects on competition.

The system of equations formed by (8), (9), and (16) is determined sequentially. Since prices p_{it} in the demand and network Eqs. (8) and (9) are certainly endogenous, the equations are estimated with instrumental variables techniques. We use as instruments for p_{it} firms’ average costs and Portugal gross national product per capita. Note that, in the network equation, the OLS estimate of the own-price elasticity is not significant, while the instrumental variables estimate is highly significant. In the demand equation, the OLS and instrument variable estimates of own-price elasticity are both significant, although the former is lower in absolute value.

With respect to the cost function (16), note that it includes a non-observable parameter, θ_i , which is, from the viewpoint of the econometrician, an unobservable random variable in the same sense as u_{it}^c . Parameter θ_i plays a central role in the analysis since it is at the same time the parameter measuring firms’ inefficiency and the source of heterogeneity across them. There has been a long debate on how to estimate cost frontiers with parametric and nonparametric techniques, each one having specific advantages and disadvantages. We choose here a parametric technique, i.e., θ_i is characterized by a Half-Normal density function $f(\theta)$ which needs to be estimated. The main advantage of such framework is its ease of exposition, which is important for us, since we are more concerned in this article with the discussion around the cost reducing activity of the firms than with exogenous inefficiency. Note that, when estimating this cost-function, one needs to compute the integral of the joint density function of θ_i and u_{it}^c over $[0, \infty]$.¹³

We also expect unobserved shocks to be autocorrelated in the demand and the network equations. Since we are dealing with time series with periods not too far apart in time, error terms, which capture omitted variables, measurements errors, or purely unpredictable effects, might be correlated. A Lagrange test for autocorrelation is computed for each equation and presented in the next section. It confirms the presence of autocorrelation in the demand and network equations.

¹² We could measure the cost reduction after the entry of *OPTIMUS* estimating two costs functions, one pre- and one post-entry, and comparing the predicted costs. Our methodology, however, improves upon this alternative approach for two reasons. First, we estimate the coefficients describing the underlying technology with a larger sample. Note that, for instance, in order to estimate β_y , the alternative methodology would use information only for the period 1992–1997, while with our methodology, we use information from the period 1992–2003, at the cost of adding one more parameter. And second, in Section 5, we need to estimate marginal costs to evaluate competition. A biased measure of marginal costs would lead to wrong conclusions about the evolution of price–cost margins after the entry of *OPTIMUS*.

¹³ For more details on these issues, the reader should refer to Kumbhakar and Lovell (2000).

Interestingly, accounting for autocorrelation in the network equation reduces the lagged network parameter γ_{n-1} , suggesting that switching costs are a less important explanatory variable for the size of the network than what one would expect if autocorrelation was not accounted for.

Finally, note that the system is identified and all parameters can be recovered, given the homogeneity of degree 1 in input prices.

4.3. Estimation results

Tables 1 and 2 provide the results for the econometric model. We emphasize in this section the two main arguments discussed in this paper. First, depending on how incentives and cost reduction activities are interpreted, different cost structures can be estimated. Then, a test enables us to choose the best cost structure in the sense that it is the one that fits the data the best. Once this is done, a precise evaluation of the nature of competition in the industry can be obtained in a second step. This latter procedure also requires important ingredients on the demand and network growth sides, which are discussed below.

4.3.1. Demand and network

The results for network and demand are presented in Table 1, where three types of estimation procedures are considered. In all cases, the goodness of fit measured by the adjusted R^2 is close to 1. Model 1 is a simple OLS procedure, where no instruments for price and no procedure for autocorrelation are considered. Model 2 uses instruments for price. Model 3 uses instruments for prices and accounts for autocorrelation using the *Cochrane-Orcutt* method for a first-order autoregressive model.¹⁴ Note that the variable revenue (r_i) has been dropped from the regressions since it is used as an instrument for price, and keeping it in the equations causes issues of multicollinearity.

Taken together, the demand and network equations allow us to evaluate short-run and longrun price elasticities, using a procedure described in the Appendix. The network and demand functions exhibit a pattern of short-run dynamics. In Table 1, the estimate for the coefficient of the lagged network size, γ_{n-1} , is significant at a 1% level, which implies that a shock to one of the variables of the network function will fully translate into the network only over time. Similarly, the estimate for the coefficient of the lagged network size, α_{y-1} , is significant at a 1% level.

The results obtained from model 3 of the network and demand functions in Table 1 are the ones we use to discuss the economic issues related to the industry. They suggest the following three observations:

Observation 1. *The industry is characterized by significant network economies.*

The short-run demand network elasticity is $\alpha_{n-1}=0.82$, and the long-run demand network elasticity is $\eta_{yn} = \frac{\alpha_{n-1}}{1-\alpha_{y-1}} = 0.90$. This implies that a 1% increase in the size of the network causes demand to increase by 0.82% (0.90% respectively) in the following quarter (in the long-run respectively). This result is in line with both economic theory and empirical studies (see Doganoglu and Grzybowski, 2003; Madden et al., 2004; Pereira and Pernias, 2004). With respect to the network function, it can be seen from Table 1 that the short-run network price elasticity is $\gamma_p = -0.78$, while the long-run network price elasticity is $\eta_{np} = \frac{\gamma_p}{1-\gamma_{n-1}} = -2.12$. This implies that a 1% increase in the price

¹⁴ Several tests are performed in order to test for the presence of heteroscedasticity and autocorrelation. In the demand equation, the White's statistic is 23, which discards the presence of heteroscedasticity. The Lagrange statistic is 53.4, indicating that the null hypothesis that there is no autocorrelation is rejected. In the network equation, the Lagrange statistic is 72.2, suggesting autocorrelation. The White's statistic, equal to 5.4, discards the presence of heteroscedasticity.

Table 1
Demand and network equations

Variable	Eq. (9): Network			Eq. (8): Demand		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Constant	4.357*** (0.5272)	5.373*** (0.578)	6.272*** (0.368)	3.758*** (0.416)	4.180*** (0.497)	4.307*** (0.365)
Own price	-0.023 (0.117)	-0.704*** (0.240)	-0.782*** (0.135)	-0.451*** (0.091)	-0.693*** (0.185)	-0.633*** (0.135)
Cross prices						
TMN-VOD 1	-0.359 (0.280)	-0.009 (0.458)	0.225 (0.180)	-0.264 (0.221)	-0.054 (0.246)	0.139 (0.182)
TMN-VOD 2	0.327* (0.183)	0.328* (0.179)	0.138 (0.110)	0.126 (0.147)	0.125 (0.153)	0.127 (0.112)
TMN-OPT	-0.244** (0.118)	-0.045 (0.138)	-0.034 (0.080)	-0.150 (0.093)	-0.022 (0.110)	-0.009 (0.077)
VOD-TMN 1	-0.215* (0.120)	-0.230** (0.091)	-0.150*** (0.058)	-0.051 (0.096)	0.209*** (0.079)	0.271*** (0.059)
VOD-TMN 2	0.890*** (0.245)	0.837*** (0.240)	0.438*** (0.150)	0.731*** (0.203)	0.653*** (0.212)	0.607*** (0.156)
VOD-OPT	-0.970*** (0.215)	-0.900*** (0.205)	-0.565*** (0.131)	-0.652*** (0.174)	-0.507*** (0.181)	-0.392*** (0.134)
OPT-TMN	0.578*** (0.194)	0.542*** (0.183)	0.438*** (0.113)	0.502*** (0.171)	0.334*** (0.172)	0.483*** (0.127)
OPT-VOD	-0.076 (0.234)	-0.045 (0.220)	-0.049 (0.138)	-0.016 (0.194)	0.162 (0.194)	0.078 (0.143)
Lag network	1.191*** (0.157)	0.892*** (0.167)	0.632*** (0.105)	0.715*** (0.143)	0.717*** (0.156)	0.824*** (0.115)
Trend	0.399*** (0.156)	0.558*** (0.147)	0.790*** (0.092)	0.438*** (0.124)	0.331*** (0.124)	0.377*** (0.091)
Lag demand				0.179*** (0.032)	0.159*** (0.034)	0.086*** (0.026)
Error standard deviation	0.207*** (0.014)	0.198*** (0.013)	0.124*** (0.008)	0.163*** (0.011)	0.170*** (0.011)	0.125*** (0.008)
Adjusted R^2	0.977	0.979	0.991	0.985	0.984	0.991
T	109	109	109	109	109	109

Standard deviations are in parenthesis. ***Significant at 1%; **significant at 5%; *significant at 10%.

Model 1: No instruments for prices; model 2: instrumental variables for prices; model 3: instrumental variables for prices and treatment for autocorrelation.

causes the size of the network to decrease by 0.78% in the same quarter and to decrease by 2.12% in the long-run. As expected, since most of our data refers to the period of diffusion of the industry, the network increases over time. This can be seen from the fact that the coefficient of the time trend in the network equation is significant and positive. This set of results has two main implications. First, it suggests that the size of the network responds to price variations. Second, it shows that there is considerable inertia in the way the size of the network responds to price. This can be taken as indirect evidence of the presence of consumer switching costs in the industry.

Observation 2. *The market demand is inelastic with respect to price if indirect effects on the size of the network are not accounted for.*

Table 1 shows that the estimate of the direct short-run price elasticity is $\eta_{dsr} = -0.63$, while the estimate of the direct long-run price elasticity is $\eta_{dlr} = -0.69$. This suggests that a 1% increase in

Table 2
Cost equation

Variable	Scenarios				
	(1)	(2)	(3)	(4)	(1')
β_0	-2.640*** (0.468)	-2.825*** (0.417)	-3.329*** (0.422)	-2.718*** (0.437)	1.364*** (0.360)
β_l	0.736*** (0.046)	0.736*** (0.045)	0.759*** (0.042)	0.723*** (0.048)	0.514*** (0.057)
β_m	0.176*** (0.031)	0.141*** (0.038)	0.177*** (0.034)	0.139*** (0.038)	0.062 (0.041)
β_y	1.004*** (0.035)	1.028*** (0.038)	1.029*** (0.034)	1.022*** (0.039)	0.786*** (0.039)
β_Γ	-0.047*** (0.004)	-0.045*** (0.005)	-0.033*** (0.005)	-0.042*** (0.006)	-
μ	-	-	2.856*** (0.219)	4.738*** (0.964)	-
θ standard deviation	-	0.366*** (0.047)	0.234* (0.142)	0.361*** (0.050)	-
Error standard deviation	0.251*** (0.017)	0.123*** (0.029)	0.159** (0.070)	0.126*** (0.032)	0.349*** (0.023)
Adjusted R^2	0.971				0.943
Vuong Test: (3) against alternative models	38 ^(a)	31.3 ^(a)	-	2.679 ^(b)	
T			112		

Standard errors are in parenthesis. Vuong Test: (a) nested test, (b) non-nested test. In all models, ***significant at 1%; **significant at 5%; *significant at 10%.

Models: (1) Model with no inefficiency and no effort. (2) Model with inefficiency but no effort. (3) Model with inefficiency and effort. Firms exert effort after the entry of Optimus. (4) Model with inefficiency and effort. Firms exert effort from full liberalization in 2000. (1') Same as (1), with no trend.

price causes demand to decrease by 0.63% in the same quarter, and to decrease by 0.69% in the long-run. These estimates are small but highly significant. Besides, they are in line with the results reported in previous studies of the mobile telephony industry.¹⁵ Note that, however, the total long-run price elasticity is $\eta_{lir} = -2.61$. This interesting result shows that accounting for the long-run impact of a price change is important to evaluate the overall impact of price on demand.

With respect to cross-price elasticities in both equations, note that changes in the prices of *Vodafone* and *Optimus* are shown to have a non-significant effect on the demand of *Tmn*. On the other hand, changes in the price of *Tmn* have a significant positive impact on the demand of *Vodafone* and *Optimus*. A surprising result is that some of the cross-price elasticities are negative and significant. For instance, a price decrease of *Vodafone* may increase the demand of *Optimus*. We justify this result in the following way. A decrease in the price of a firm may have three effects. First, it causes consumers of the rival firms to switch to the firm. Second, it causes consumers that were outside the market to join the firm. Since most of our data refers to the diffusion period of the industry this second effect is likely to be strong. Third, if network economies are strong, the increase in the number of consumers in the market caused by the second effect increases the marginal benefit of consuming the service, which causes consumers that were outside the market to join any of the firms in the industry. Hence, a decrease in the price of a firm may increase the demand of its rivals. This may explain why we obtain significant negative cross-price effects between some firms.

¹⁵ See Hausman (1997), Madden et al. (2004), and Ofel (2002).

Finally, demand increases over time. The coefficient of the time trend is significant and positive. This highlights again the importance of accounting for dynamics in the industry. Note that the time trend captures the growth in demand that occurs for reasons unrelated to short-run dynamics or network economies, which also exert their impact on demand over time.

4.3.2. Costs

Table 2 presents the estimates for the cost function. This equation is estimated under alternative scenarios related to the entry of *Optimus* in 1998 and the 2000 liberalization. In all cases but model 1, we include the term θ_i to measure inefficiency. Additionally, the following distinctions are made: (i) scenario 1, with no effort and no inefficiency term; (ii) scenario 2, where firms do not make any additional effort to reduce inefficiency after the entry of *Optimus* and the 2000 liberalization, i.e., the effect of either of these two shocks to the industry is not accounted for; (iii) scenario 3, where only the entry of *Optimus* in 1998 affects firms' cost reducing behavior; and (iv) scenario 4, where only the 2000 liberalization affects the firms' cost reducing behavior. Additionally, we considered scenario 1', which is similar to scenario 1 without a time trend. The latter model will be useful to discuss returns to scale.

Note that the variables are significant and have the expected sign.¹⁶ In particular, costs increase with input prices and production. Moreover, we propose the following two observations:

Observation 3. *The entry of Optimus caused firms to increase their effort level and reduce costs.*

Fig. 2 suggests that the average costs of *Tmn* and *Vodafone* decreased from 1997. We can test that the entry of *Optimus* had a significant impact on the cost reducing activity of these firms.

The alternative scenarios are tested against each other, applying the tests for model selection proposed in Vuong (1989).¹⁷ The test shows that scenario 4 is rejected against scenario 3. This suggests that the 2000 liberalization had limited effect on the firms' cost reduction effort, compared to the entry of *Optimus* in 1998. Scenarios 1 and 2 are rejected against scenario 3, which includes an inefficiency measure, and assumes that firms exert cost reducing effort after the entry of *Optimus* in 1998. Given that scenario 1 represents the standard approach proposed by the literature on oligopolistic competition, its rejection advocates the construction of models including these components and indicates that one has to be cautious when interpreting the results derived from other models. Moreover, the rejection of scenario 2 shows the importance of accounting for the effects of cost reducing effort on firms' technology and inefficiency.

There are alternative explanations that could possibly justify the increase in cost reduction after the entry of *Optimus*. A first possibility is preemptive behavior by the incumbents, which could have taken the form of capital or capacity expansion with delayed effects on costs. Preemption in the sense of market foreclosure should be discarded because the decision to allow the entry of additional firms was taken at the *EU* level. Preemption in the sense of preparation for future competition was tested. We estimated alternative scenarios where cost reduction occurred before

¹⁶ The Lagrange statistic is 3.14. Thus, the test fails to reject the null hypothesis that there is no autocorrelation. The value of White's heteroscedasticity test is 18.033. Hence, the test fails to reject the null hypothesis that the residuals are homoscedastic.

¹⁷ Note that models (1) and (2) are nested in (3). However, models (3) and (4) are non-nested since they are conditional on a pair of vectors ξ_{it}^A and ξ_{it}^B that varies from one model to another, since, in these two models, deregulation occurs at a different point in time. Hence, to test (3) against (1) and (2), we use a likelihood ratio test for nested models. To test (3) against (4), we use a likelihood ratio test for non-nested models.

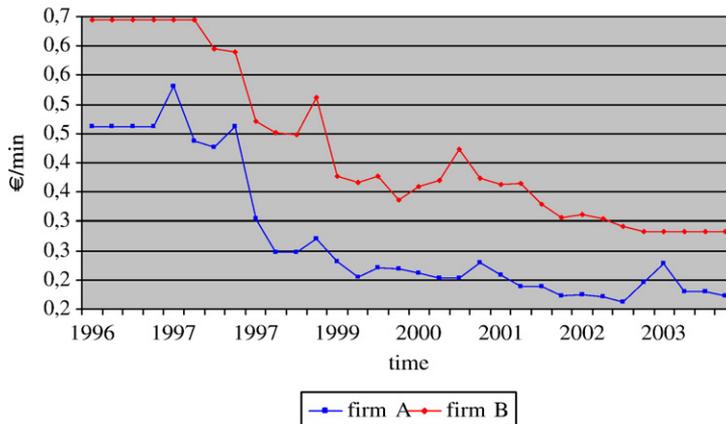


Fig. 2. Average costs.

the entry of *Optimus*, namely in 1997 and 1996. Both scenarios were rejected by our test. Another possible explanation for the cost reduction after the entry of *Optimus* could be spillover effects. *Optimus* could have been a lower cost firm from whom the incumbents learned. However, the estimation of the inefficiency scores θ_{it} for each firm suggests that *Optimus* is the most inefficient firm. In addition, a lower cost firm would have optimally charged lower prices. But over our period of observation, *Optimus* did not offer the lowest prices.¹⁸ Taken together, these two remarks suggest that there is no clear evidence that *Optimus* enjoyed any technological advantage that benefited the two incumbents.

Observation 4. *The industry is characterized by constant returns to scale.*

Scenarios 1 to 4 suggest that the production parameter β_y ranges from 1.004 to 1.029. These parameters are not statistically different from 1, indicating that the industry is characterized by constant returns to scale with respect to traffic. This result is consistent with the few previous studies on mobile telecommunications: McKenzie and Small (1997) shed light on constant or slightly decreasing returns to scale, while Foreman and Beauvais (1999) find mild scale economies. We expect costs to increase proportionally to output, since the mobile telephony is less lumpy, or more modular, than the fixed telephony technology which is characterized by increasing returns to scale. Mobile telephony firms can meet demand increases by splitting the cells where their capacity is binding.¹⁹ Note that scenario 1' contains a production parameter β_y that is significantly lower than 1. This clearly shows the importance of accounting for technological progress at the moment of identifying returns to scale. The equipment required to meet the increasing levels of demand is acquired at different points in time, representing different technology vintages. Technological progress during our period of observation was very robust.

¹⁸ These values are not presented in the paper, but are available upon request.

¹⁹ A cell is a hexagonal geographic region. See Hausman (2002) for a description of the mobile telephone technology. A cell has a limited number of channels. However, this limit can be overcome. Cells can be split into smaller cells in order to increase capacity. This implies an increase in underlying infrastructure, such as the number of base transceiver stations, antennas, supporting towers, backhaul links, base station controllers, and possibly an upgrade of the mobile switching centers.

This makes it hard to disentangle whatever scale economies that might exist from technological progress if a time trend is not accounted for in the course of the estimation.

5. Evaluating competition

We focus now on the competitive aspect of our study. Before turning to the evaluation of firms' price–marginal cost margins, note that the analysis of the time series of the average prices of *Tmn* and *Vodafone*, presented in Fig. 3, shows that the average prices of *Tmn* and *Vodafone* are co-integrated, and have a downward break in 1997. This suggests that the entry of *Optimus* in 1998 caused the rivals to reduce prices.²⁰ Note that these price reductions are in line with our previous results that firms reduced costs following the entry of *Optimus*.

Having now the most adequate cost estimates in hand, we are capable of characterizing the degree of competition in the industry from the evaluation of firms' price–marginal cost discrepancies.²¹ We will also compare our results with those obtained if cost endogeneity is not accounted for.

In an infinite horizon set-up, a firm's price choice problem, given the effort level, is:

$$\max_{p_{it}} \sum_{t=0}^{\infty} \Pi_{it}(p_{it}, e_{it}, n_{it-1}) \quad \text{s.t.} \quad n_{it} = N(p_{it}), \quad (17)$$

where the profit $\Pi_{it}(\cdot)$ is defined in (4). The Bellman equation for firm i 's pricing problem, given the effort level, is:

$$V(n_{it-1}) = \max_{p_{it}} \{ \Pi_{it}(p_{it}, e_{it}, n_{it-1}) + \delta V(n_{it}) \}.$$

The associated first-order condition for firm i is:

$$y_{it} + (p_{it} - MC_{it}) \frac{\partial y_{it}}{\partial p_{it}} + \delta (p_{it-1} - MC_{it+1}) \frac{\partial y_{it+1}}{\partial n_{it}} \frac{\partial n_{it}}{\partial p_{it}} = 0, \quad (18)$$

where MC_{it} denotes marginal cost of firm i , suggesting that a firm's optimal price at t should account for two effects. The first effect is the direct impact of the current price on the current demand, $\frac{\partial y_{it}}{\partial p_{it}}$. The second effect is the impact of the current price on the current size of the firm's network, and thereby on the next period firm's demand, $\frac{\partial n_{it}}{\partial p_{it}} \frac{\partial y_{it+1}}{\partial n_{it}}$. Eq. (18) can be rewritten as:

$$M_{it} = \frac{p_{it} - MC_{it}}{p_{it}} = - \frac{1}{\eta_{dir} + \delta \Delta_{y_i} \Delta_{\mu_i} \Delta_{p_i} \eta_{yn} \eta_{np}}, \quad (19)$$

where η_{dir} is the direct long-run price elasticity, η_{yn} is the long-run demand network elasticity, and η_{np} is the long-run network price elasticity. Additionally, we denote the *demand growth* of

²⁰ Note that economic theory is not always conclusive regarding the relation between the number of competitors in a specific industry and firms' prices. Garcia et al. (2005), Rosenthal (1980), and Seade (1980) develop models where prices increase with the number of firms in the market.

²¹ By estimating cost and demand functions, we are able to generate direct measures of the price–cost margins. This approach follows the spirit of Genesove and Mullin's (1998) paper that shows that direct estimations of the conduct parameter through the pricing rule may lead to significant underestimation of market power. Similarly, imposing a specific conduct and estimating costs may lead to over or underestimation of costs when perfect competition or monopoly are assumed respectively. On the contrary, estimates are quite insensitive to the assumed demand functional form.

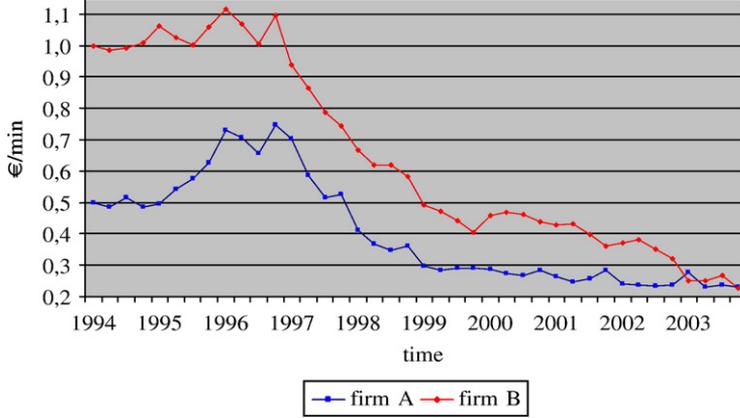


Fig. 3. Average prices.

firm i as $\Delta_{y_i} := \frac{y_{it+1}}{y_{it}}$, the *margin growth* of firm i as $\Delta_{\mu_i} := \frac{M_{it+1}}{M_{it}}$, and the *price growth* for firm i as $\Delta_{p_i} := \frac{p_{it+1}}{p_{it}}$.²²

Hence, using our estimates of the cost, network, and demand equations, we evaluate in a first step the price-cost margins expressed in the left-hand side of Eq. (19) under the various scenarios under consideration. Thus, we determine whether different conclusions can be reached regarding firms' competitive behavior, depending on which scenario is accounted for. In a second step, we test these margins against those obtained if firms followed a Nash behavior, as expressed in the right-hand side of Eq. (19).

From the expressions of costs (16), demand (8), and network growth (9), the first-order condition (19) can be rewritten as:

$$M_{it} = \frac{p_{it} - MC_{it}}{p_{it}} = \left\{ \left(\frac{\alpha_{p_i}}{1 - \alpha_{y-1}} \right) + \delta \Delta_y \Delta_{\mu_i} \Delta_{p_i} \left(\frac{\alpha_n}{1 - \alpha_{y-1}} \right) \left(\frac{\gamma_p}{1 - \gamma_{y-1}} \right) \right\}^{-1}. \quad (20)$$

Through the estimation of the cost function, marginal costs MC_{it} can be easily recovered. Putting them together with the observed values of prices, we are able to evaluate the price-marginal cost margin M_{it} set by each firm, defined as the left-hand side of Eq. (20). Table 3 presents the values obtained under scenario 1 and scenario 3.

One first interesting result is worth emphasizing. The traditional approach with no inefficiency and no effort, namely scenario 1, underestimates the average marginal costs MC_{it} , and overestimates the average margin M_{it} of the industry. Hence, the traditional approach underestimates the competition faced by the Portuguese mobile firms. The margins obtained under scenarios 1 and 3 are significantly different at the 10% level as shown by a t -test ($H_0: M_{it}^3 - M_{it}^1 = 0$), whose statistic is equal to 1.718.

In a second step, we simulate the Nash margin M_{it}^N , as defined by the right-hand side of Eq. (20). Our aim is to test whether firms follow a Nash behavior, i.e., we test whether the Nash margins M_{it}^N are close to the real margins M_{it} . Note that values of the elasticities η_{dlr} , η_{yn} , and η_{np}

²² We are implicitly assuming a perfect information setting; otherwise, we would have to incorporate the firms' expectations about the future values of the relevant variables.

Table 3
Estimated margins

	P_{it}	MC_{it}	M_{it}
Scenario (1)	0.514	0.334	0.128
Scenario (3)	0.514	0.350	0.088

Average values at the industry level.

are obtained from the estimation of the network and demand equations, while we need to simulate values for δ , Δ_{y_i} , Δ_{μ_i} , and Δ_{p_i} since these latter parameters are unobservable.

If firms have a myopic behavior, i.e., if $\delta=0$, Eq. (20) becomes $M_{it} = -\frac{1}{\eta_{dir}}$. The latter corresponds to the standard static Nash behavior index, whose value is 1.44. This value is unrealistic and suggests that the behavior of firms producing on the inelastic part of the demand curve is not compatible with a static approach. This therefore calls for the dynamic approach that we advocate in this section.

In the case where firms care about the future, i.e., if $\delta \neq 0$, we adopt the following approach. We test the hypothesis that estimated margins M_{it} are equal to the dynamic Nash margins M_{it}^N expressed in Eq. (20). To do so, we set $M_{it} = M_{it}^N = 0.230$,²³ and solve for the corresponding values of δ , Δ_{y_i} , Δ_{μ_i} , and Δ_{p_i} . Table 4 presents the values of Δ_{y_i} and Δ_{μ_i} that satisfy this condition under the conservative assumption that prices are expected to remain constant $\Delta_{p_i} = 1$.²⁴ Note for instance that, if firms expect their margins to grow by 25% ($\Delta_{\mu_i} = 1.25$) and demand to grow by 68% ($\Delta_{y_i} = 1.68$), they should have a discount factor δ equal to 0.91, i.e., a discount rate, $\epsilon = \frac{1}{\delta} - 1 = 0.10$. These figures make sense only if firms have a high discount factor δ , i.e., a small discount rate ϵ and expect a large industry growth. Thus, in order to reconcile firms' actual margins and the dynamic Nash margins, one has to assume that firms: (i) are patient and (ii) have optimistic beliefs about the industry growth. These two latter assumptions seem to be relevant in the case of the Portuguese mobile telephony industry, as illustrated by the following observations: First, note that this is an industry where it took firms from 3 to 6 years to reach profitability and where network effects and switching costs play an important role. Our data set refers to a period where the industry had not yet reached the maturity phase. During this period, firms were conceivably more concerned with building their customer base than extracting abnormal profits. Second, we could compare the discount rate ϵ to any relevant discount rate that is currently practiced. Note for instance that the average interest rate of Portuguese 10 years treasury bonds is 6.8% over the period we study. Likewise, OfTel (2002) presents estimates of the weighted average cost of capital for the UK mobile firms in the range of 13% to 17%. These values are in line with our results and seem to validate our test.

6. Impact on consumer welfare

We finally propose an evaluation of the effect of the operating cost reducing activity on welfare. Note that we are only able to provide an incomplete measure of welfare changes. Although social welfare is defined as the sum of the consumer surplus and the firms' profits, we

²³ Note that we set $M_{it} = M_{it}^N = 0.230$ and not 0.088, as suggested by Table 3. The reason is that *Optimus*, which appears to have negative margins most of the time, is excluded from the sample for this particular exercise. We therefore obtain 0.230 as the average of *Tmn* and *Vodafone's* margins over the period of observation.

²⁴ Note that Δ_{p_i} is the only variable that is fully under the control of operator *i*, since Δ_{y_i} and Δ_{μ_i} also depend on factors that are beyond its control. Setting $\Delta_{p_i} = 1$ allows simplifying our presentation. We could as well let Δ_{p_i} vary. Allowing additional sources of variation only increases our scope to rationalize the estimated margins.

Table 4
Industry growth levels and impatience

Δ_{μ}	Δ_y	δ
0.01	1907.14	0.10
	229.78	0.83
	219.21	0.87
	209.58	0.91
	200.75	0.95
1.00	19.07	0.10
	2.30	0.83
	2.19	0.87
	2.10	0.91
	2.01	0.95
1.25	15.20	0.10
	1.84	0.83
	1.75	0.87
	1.68	0.91
	1.61	0.95
1.50	12.71	0.10
	1.53	0.83
	0.46	0.87
	0.40	0.91
	0.34	0.95
2.00	9.54	0.10
	1.15	0.83
	1.10	0.87
	1.05	0.91
	1.00	0.95

restrict our analysis to consumer surplus and operating costs. The reason is that our dataset does not allow us to identify the internal cost of effort, defined in Eq. (11), and therefore characterize fully the change in the firms' welfare.

Consider the period "A" that starts after the entry of *Optimus*. We can evaluate the actual consumer surplus associated to current prices and demand levels, and report the observed operating costs. We can as well simulate the hypothetical consumer surplus and operating costs that would have emerged if the firms had not increased their effort level, i.e., if the increase in cost reducing activity defined in Eq. (13) was nil. To compute the hypothetical price and demand level obtained in a situation where no additional effort is provided, we proceed as follows.

Taken together, the two periods before and after the entry of *Optimus* allow identifying the cost reducing activity since we considered different cost structure for each period. Accordingly, one can compute a direct measure of the effort activity e . Denote as c^A the operating costs after the entry of *Optimus*, if no additional effort is provided. From Eq. (13), a cost reduction ratio is therefore $\varphi = \frac{c^A(\cdot) - c^A(\cdot)}{c^A(\cdot)} = \exp(-e) - 1$. From our estimates, the ratio for the average firm is $\varphi = -0.266$. This implies that, on average, the increase in cost reducing activity of all firms after the entry of *Optimus* led to a 26.6% cost decrease at the industry level.

Now, from (19), we can compute the hypothetical prices that firms would set if their costs were 26.6% higher during period "A". Assuming that the environment was otherwise expected to remain stationary, i.e., $\Delta_{\mu_i} = \Delta_{p_i} = \Delta_{y_i} = 1$, a 26.6% cost increase would lead to a 26.6% price increase. We therefore set the hypothetical prices, under a situation where the firms provide no additional effort, to be 26.6% higher than the ones under a situation where firms optimally provide

Table 5
Welfare evaluation after entry

Variable	Net change if “effort” instead of “no effort”
Δ Operating costs	-23.6
Δ Cons. net surplus	+24.8

Average values per subscriber, for one quarter, in euros.

additional effort. Table 5 presents the changes in operating costs and consumer surplus per subscriber after the entry of *Optimus*. Our results take into account not only the effect of a price change, but also the variation in the quantity of minutes of traffic consumed. They suggest a quarterly increase in consumer net surplus of 24.8 euros per subscriber, if operators provide additional effort level, compared to a situation where no additional effort is provided.

Thus, competition led to a significant increase in consumer surplus. Unfortunately, our analysis cannot be extended to the operators’ profit. Although competition induced a large decrease in operating costs, we are not able to evaluate the associated increase in firms’ internal costs. This drawback may be solved in the future, if more disaggregated data are available.

7. Conclusion

The results obtained in this paper have proved fruitful on both the methodological and the institutional side. First, we showed that a cost-network growth-demand structure that accounts for the firms’ technical inefficiency and cost reducing activities fits the data better than the usual model of the oligopolistic competition literature. Our application of this methodology to the Portuguese mobile telephony industry shows that the estimates obtained from a standard oligopoly model are potentially biased and can lead to wrong conclusions about cost reduction and competition in the industry.

Second, it is suggested that the entry of a third firm in 1998 introduced a significant change in the behavior of firms regarding costs reduction. We show that the full liberalization of the telecommunications sector in 2000 had very limited effects. We also showed that the standard oligopoly model underestimates the toughness of competition. This result is consistent with previous contributions that account for cost endogeneity.

The results of this paper illustrate nicely the two channels through which competition can increase welfare. Competition may lead to a reduction of both prices and costs. Such reductions occurred in the Portuguese mobile industry, while firms were producing on the inelastic part of the demand function. This suggests that firms were more concerned with increasing their customer base than with receiving high profits, as has been tested and validated in this article. Whether such concerns will vanish in the near future remains to be seen.

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Appendix A. Short-run and long-run price elasticity

Eq. (9) can be rewritten as:

$$\ln n_{it} = \frac{1}{1-\alpha_{n_{it-1}}L} \left[\gamma_0 + \gamma_{p_i} \ln p_{it} + \sum_{s=A,B} \sum_{j \neq i} \gamma_{p_{ij}}^s \ln p_{jt} + \gamma_t t + u_{it}^n \right], \quad (21)$$

where L is a lag operator. Replacing t by $t-1$ gives:

$$\ln n_{it-1} = \frac{1}{1-\alpha_{n_{it-1}}L} \left[(\gamma_0 - \gamma_t) + \gamma_{p_i} \ln p_{it-1} + \sum_{s=A,B} \sum_{j \neq i} \gamma_{p_{ij}}^s \ln p_{jt-1} + \gamma_t t + u_{it-1}^n \right]. \quad (22)$$

After replacing Eq. (22), Eq. (8) can be written as:

$$\begin{aligned} \ln y_{it} = \frac{1}{1-\alpha_{y-1}L} & \left\{ \left[\alpha_0 + \frac{\alpha_{n-1}(\gamma_0 - \gamma_t)}{1-\alpha_{n_{it-1}}L} \right] + \left[\alpha_t + \frac{\alpha_{n-1}\gamma_t}{1-\alpha_{n_{it-1}}L} \right] t + \left[\alpha_{p_i} + \frac{\alpha_{n-1}\gamma_{p_i}L}{1-\alpha_{n_{it-1}}L} \right] \ln p_{it} \right. \\ & \left. + \sum_{s=A,B} \sum_{j \neq i} \left[\alpha_{p_{ij}} + \frac{\alpha_{n-1}\gamma_{p_{ij}}L}{1-\alpha_{n_{it-1}}L} \right] \ln p_{jt} + \left[u_{it}^d + \frac{\alpha_{n-1}u_{it-1}^n}{1-\alpha_{n_{it-1}}L} \right] \right\}, \end{aligned}$$

which suggests that an increase in i 's price can be decomposed into two effects. First, we define a direct effect which states that the consumers that choose to stay with firm i , perhaps because they have large switching costs, demand less of i 's product:

$$\frac{\partial \ln y_{it}}{\partial \ln p_{it}} = \alpha_{p_i}. \quad (23)$$

Second, we define an indirect effect which states that some consumers choose to leave firm i for a different firm, reducing thus the size of i 's network:

$$\frac{\partial \ln y_{it}}{\partial \ln n_{it-1}} \frac{\partial \ln n_{it-1}}{\partial \ln p_{it-1}} = \left(\frac{1}{1-\alpha_{y-1}} \right) \left(\frac{\alpha_{n-1}\gamma_{p_i}}{1-\alpha_{n_{it-1}}} \right). \quad (24)$$

Hence, we refer to the *direct short-run price elasticity* as the immediate partial impact of a change in p_{it} on the demand of firm i measured by:

$$\eta_{dsr} := \alpha_{p_i}. \quad (25)$$

As such partial impact fully translates into the demand of firm i only over time, we construct in a second step the *direct long-run price elasticity* measured by:

$$\eta_{dlr} := \left(\frac{1}{1-\alpha_{y-1}} \right) \alpha_{p_i}. \quad (26)$$

Finally, we define the *total long-run price elasticity* which accounts for both direct and indirect effects, and is defined as the sum of the two elasticities in (24) and (25). It is therefore equal to:

$$\eta_{llr} := \left(\frac{1}{1-\alpha_{y-1}} \right) \left(\alpha_{p_i} + \frac{\alpha_{n-1}\gamma_{p_i}}{1-\alpha_{n_{it-1}}} \right). \quad (27)$$

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