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 lead 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.

Key Words: *Mobile Telephony, Entry, Competition, Efficiency, Empirical Analysis*

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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 firms 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.

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, Lovell and Schmidt, 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, *ICP-ANACOM*, assigned two licenses to operate the digital technology *GSM 900*. 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*.[1] Finally, the legislation of the *EU* imposed the full liberalization of the telecommunications industry at the end of the nineties.

[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 2 *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.

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, analyzed in 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 Figure 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.

[*Figure* 1]

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 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 a non-nested test, 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

[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).

[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 (2002), 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.

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

[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

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:

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

where α is a vector of parameters to be estimated. 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 pre-paid cards.

We also assume that the size of firm i's network in period t, depends on its price p_{it}. Thus, each firm faces a network function of the form:

$$n_{it} = N_{it}(p_{it} \,|\gamma), \tag{2}$$

where γ is a vector of parameters to be estimated. The network function will be useful in Section 5 where we disentangle short-run from long-run pricing decisions. Equations (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.

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. Firms can engage in process research and development,

strategic advantage for a firm of owning a large network.

[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.

managers may spend time and effort in improving the location of inputs within the network, monitoring employees, solving 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:

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

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 equations (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 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 mispecification, and avoid biases in the estimation of the technological

[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.

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 $c_{it}\,(e_{it}, .) + \Psi(e_{it}, .)$:

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

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:

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

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

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

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

$$c^s(e_{it}^s, .), \tag{7}$$

where s denotes the type of competitive regime, that can be either "B" or "A". Note that Equation (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 Roeller (1997) analyzes the impact of regulatory changes on the competitiveness of mobile telecommunications markets. Gagnepain and Ivaldi (2002) shows 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, as well as 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 raw data collected by Autoridade da Concorrência, the Portuguese national competition authority. The data consists of quarterly observations obtained directly 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 ($\omega_{l_{it}}$), 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 ten 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 customers, 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:

$$\ln y_{it} = \alpha_0 + \alpha_{p_i} \ln p_{it} + \sum_{j \neq i} \alpha_{p_{ij}} \ln p_{jt} + \alpha_n \ln n_{it-1} + \alpha_r \ln r_t + \alpha_t t + u_{it}^d \tag{8}$$

where u_{it}^d is an error term. Note that this specification includes cross-price elasticities $\alpha_{p_{ij}}$.

The network growth function corresponding to (2), is specified as follows:

$$\ln n_{it} = \gamma_0 + \gamma_{p_i} \ln p_{it} + \gamma_{n_{it-1}} \ln n_{it-1} + u_{it}^n \tag{9}$$

where u_{it}^n is an error term. Note that the lagged network size term n_{it-1} is included in order to capture short-run dynamics.

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:

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

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 as:[11]

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

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^A can now be written as:

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

[10] In particular, in order to solve for Equation (6), plug it into Equation (3), and estimate Equation (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 $\Psi''(e_{it}) > 0$.

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

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

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, $\frac{\partial^2 C}{\partial \theta_{it} \partial e_{it}} < 0$. 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:

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

and

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

where $\zeta = \frac{\mu}{1+\mu}$, $c_0 = \beta_0 + \frac{1}{1+\mu}(\ln \mu - \beta_0)$, $\beta' = \zeta\beta$, and $u_{it}^{c\prime} = \zeta u_{it}^c$. Note that $\lim_{\mu \to +\infty} \beta_s' = \beta_s$, 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 taken into account, the estimates of the elasticities are biased.

The cost function to be estimated is then:

$$\begin{aligned} \ln c_{it} \;=\; & \xi_{it}^A \left[c_0 + \beta_l' \ln \omega_{l_{it}} + \beta_m' \ln \omega_{m_{it}} + \beta_k' \ln \omega_{k_{it}} + \beta_y' \ln y_{it} + \beta_t' t + \zeta \theta_i + u_{it}^{c\prime}\right] + \\ & \xi_{it}^B \left[\beta_0 + \beta_l \ln \omega_{l_{it}} + \beta_m \ln \omega_{m_{it}} + \beta_k \ln \omega_{k_{it}} + \beta_y \ln y_{it} + \beta_t t + \theta_i + u_{it}^c\right], \end{aligned} \quad (16)$$

where ξ_{it}^A takes value 1 during period "A", and 0 otherwise, while ξ_{it}^B 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 simultaneously. Accordingly, and in order to avoid endogeneity problems, these equations are estimated by the Instrumental Variables Estimation Method. In particular, we use the prediction $\hat{n}_{it}$ from the network function (9) to express n_{it} in the demand function (8). Likewise, we use a prediction $\hat{y}_{it}$ from the demand function (8) to express y_{it} in the cost function (16). Moreover, to account for the endogeneity of p_{it} in the demand and network equations (8) and (9), we use p_{it-1} as an instrument for p_{it}. The cost function (16) includes a non-observable parameter, θ_i, characterized by a Half-Normal density function $f(\theta)$. When estimating this cost-function, one needs to compute the integral of the joint density function of θ_i and u_{it}^c over $[0, \infty[$.[12] Note that the

[12] For more details, the reader should refer to Kumbhakar and Lovell (2000).

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

4.3 Estimation Results

Tables 1 to 3 in Appendix 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 non-nested test helps 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 demand are presented in Table 1, where different types of estimation procedures are considered. In all cases the goodness of fit measured by the $\overline{R}^2$ is close to 1. Model 1 is a simple *OLS* procedure. To account for the presence of autocorrelation,[13] we estimated Models 2 and 3 using the *Cochrane-Orcutt* method for a fourth-order autoregressive model. Note that Model 3 adds to Model 2 firms' fixed effects and a time trend. A Wald Test whose statistic is $F = 9.11$, suggests that firms' fixed effects and the trend are jointly significant, and thus favors Model 3. Finally, in order to account for short run dynamics, we estimated Model 4, which adds to Model 3 lagged output, y_{it-1}, as an explanatory variable.

Table 2 presents the estimates of the network growth equation obtained by the *Cochrane-Orcutt* method for a fourth-order autoregressive model.[14]

Taken together, the demand and network equations allow us to evaluate short-run and long-run price as well as income elasticities, using a procedure described in Appendix 1. The demand and network functions exhibit a pattern of short-run dynamics. In Table 1, the estimate of the lagged output, $\alpha_{y_{-1}}$, is significant at a 1% level and positive, which implies that a shock to one of the demand function variables will fully translate into demand only over time. Similarly, in

[13] Several tests were performed in order to test for the presence of heteroscedasticity and autocorrelation. The White's statisitc is 23.039, which discards the presence of heteroscedasticity. On the other hand, the Lagrange statistic is 80.492, indicating that the null hypothesis that there is no autocorrelation is rejected.

[14] An initial simple *OLS* estimation showed evidence of autocorrelation with a Lagrange multiplier statistic equal to 49.596. The White's statistic, equal to 5.395, failed to reject the null hypothesis that the residuals are homoescedastic.

Table 2, the estimate for the coefficient of the lagged network size, n_{t-1}, is significant at a 1% level.

The results obtained for Model 4 of Table 1, and those of Table 2, suggest the following three observations:

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

From Model 4 of Table 1, the short-run demand network elasticity is $\alpha_n = 0.35$, and the long-run demand network elasticity is $\eta_{yn} = \frac{\alpha_n}{1-\alpha_{y_{-1}}} = 0.48$. This implies that a 1% increase in the size of the network causes demand to increase by 0.351% (0.48% resp.) in the following quarter (in the long-run resp.). This result is in line with both economic theory and empirical studies (see Doganoglu and Grzybowski (2003), Madden et al. (2004), and Pereira and Pernias (2004)). With respect to the network function, it can be seen from Table 2 that the short-run network price elasticity is $\gamma_{p-1} = -0.139$, while the long-run network price elasticity is $\eta_{np} = \frac{\gamma_{p_{-1}}}{1-\gamma_{n_{-1}}} = -1.112$. This implies that a 1% increase in the price causes the size of the network to decrease by 0.13% in the same quarter, and to decrease by 1.11% in the long-run. 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.* ■

Model 4 of Table 1 shows that the estimate of the direct short-run price elasticity is $\eta_{dsr} = -0.384$, while the estimate of the direct long-run price elasticity is $\eta_{dlr} = -0.53$.[15] This suggests that a 1% increase in price causes demand to decrease by 0.384% in the same quarter, and to decrease by 0.53% 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.[16] Note that, however, the total long-run price elasticity is $\eta_{tlr} = -1.11$. This interesting result shows that accounting for the long-run impact of a price change is important to evaluate the

[15] These are average values across firms. We also estimated elasticities for each firm, which are: -0.107 for *Vodafone*, -0.404 for *Tmn*, and -0.797 for *Optimus*. The elasticity of *Vodafone* is not significant.

[16] See Hausman (1997), Madden et al. (2004), and OFTEL (2002).

overall impact of price on demand.

The only cross-price demand elasticity that is statistically significant is the one that describes the interaction between *Vodafone* and *Optimus*. It suggests that the products of these two firms may be substitutes. The estimates of the cross-price elasticities of *Tmn* and *Vodafone*, and of *Tmn* and *Optimus*, are small and not significant. However, they seem to indicate that the products of *Vodafone* and *Optimus* may be complements of the product of *Tmn*.

Observation 3: *Mobile telephony is a luxury good and demand increases over time.* ■

Demand increases with the gross national product per capita. This result is in line with other studies such as Gruber and Verboven (2001). Note that the income elasticity of demand is $\alpha_r = 1.94$, suggesting that mobile telephony is a luxury good.

Finally, demand increases over time. The coefficient of the time trend although small 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 3 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.[17] In particular, costs increase with input prices and production. Moreover, we propose the following two observations:

[17] The value of the Breusch-Godfrey Lagrange multiplier 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 homoescedastic.

Observation 4: *The entry of* Optimus *caused firms to increase their effort level and reduce costs.* ■

The alternative scenarios are tested against each other, applying the non-nested hypothesis test proposed in Vuong (1989).[18] 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 the entry of *Optimus*, namely in 1997 and 1996. Both scenarios were rejected by our non-nested 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_i for each firm suggest 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.[19] Taken together, these two remarks suggest that there is no clear evidence that *Optimus* enjoyed any technological advantage that benefited the two incumbents.

Observation 5: *The industry is characterized by constant returns to scale.* ■

From Scenarios 1 to 4, it appears that the production parameter β_y ranges form 1.004 to

[18] Values for the Vuong test below –2 favor the alternative model against Model 4, and values above 2 favor Model 4 against the alternative model.

[19] These values are not presented in the paper, but are available upon request.

1.029. These parameters are not statistically different from 1, indicating that the industry is characterized by constant returns to scale. 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.[20] 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. 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.

[*Figure* 2]

Taken together, the two periods before and after the entry of *Optimus* allow us to identify the cost reducing activity since we considered different cost structure for each period.[21] Accordingly, one can compute a direct measure of the effect of entry of *Optimus*. From Equation (13), a cost reduction ratio is given by $\varphi = \frac{c^A(.) - C^B(.)}{C^B(.)} = \exp(-e) - 1$. The cost reduction ratio for the average firm for the period after the entry of *Optimus* is $\varphi = -0.266$. This implies that, on average, the entry of *Optimus* in 1997 led to a 26.6% cost decrease at the industry level. Figure 2 illustrates the evolution of the average costs of *Tmn* and *Vodafone*.

[20] A cell is an 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.

[21] 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 the next section 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*.

In a second step, one can obtain a precise evaluation of the nature of competition in the industry after the entry of *Optimus*. We turn in the following section to the competitive aspect of our study.

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 Figure 2, 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.[22] Note that these price reductions are in line with our previous results that firms reduced costs following the entry of *Optimus*.

[*Figure* 3]

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.[23] 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:

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

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

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

The associated first-order condition for firm i is:

$$y_{it} + p_{it}\frac{\partial y_{it}}{\partial p_{it}} - MC_{it}\frac{\partial y_{it}}{\partial p_{it}} + \delta \left[p_{it+1}\frac{\partial y_{it+1}}{\partial n_{it}}\frac{\partial n_{it}}{\partial p_{it}} - MC_{it+1}\frac{\partial y_{it+1}}{\partial n_{it}}\frac{\partial n_{it}}{\partial p_{it}} \right] = 0, \tag{18}$$

[22] 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.

[23] 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.

suggesting that a firm's optimal price at t should account for two effects. The first one is the direct impact of the current price on the current demand, $\frac{\partial y_{it}}{\partial p_{it}}$. The second one 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, $\frac{\partial n_{it}}{\partial p_{it}} \frac{\partial y_{it+1}}{\partial n_{it}}$. Equation (18) can be rewritten as:

$$M_{it} = \frac{p_{it} - MC_{it}}{p_{it}} = -\frac{1}{\eta_{dlr} + \delta \Delta_{y_i} \Delta_{\mu_i} \eta_{yn} \eta_{np}}, \tag{19}$$

where MC_{it} denotes marginal cost, η_{dlr} 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* for firm i by $\Delta_{y_i} = \frac{y_{it+1}}{y_{it}}$, and the *margin growth* for firm i by $\Delta_{\mu_i} = \frac{M_{it+1}}{M_{it}}$.[24]

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 Equation (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 Equation (19).

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

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

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 Equation (20). Table 4 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 : $M^3_{it} - M^1_{it} = 0$), whose statistic is equal to 1.718.

In a second step, we simulate the Nash margin M^N_{it}, as defined by the right-hand side of Equation (20). Our aim is to test whether firms follow a Nash behavior, i.e., we test whether

[24] 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.

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

If firms have a myopic behavior, i.e., if $\delta = 0$, Equation (20) becomes $M_{it} = -\frac{1}{\eta_{dlr}}$. The latter corresponds to the standard static Nash behavior index, whose value is 1.887. This theoretical 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 Equation (20). To do so, we set $M_{it} = M_{it}^N = 0.088$, and solve for the corresponding values of δ, Δ_{y_i}, and Δ_{μ_i}. Table 5 presents these values. Note for instance that, if firms expect their margins to grow by 33%, ($\Delta_\mu = 1.33$), and demand to grow by 58% ($\Delta_y = 1.49$), they should have a discount factor δ equal to 0.9, i.e., a discount rate $\epsilon = \frac{1}{\delta} - 1 = 0.11$. These figures make sense only if firms have a high discount factor δ, i.e., a discount rate ϵ close to zero, 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 ten 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 Conclusions

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 suguests 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 1: Short-run and long-run price elasticity

Using a lagged output variable y_{it-1}, Equation (8) can be rewritten as follows:

$$\ln y_{it} = \alpha_0 + \alpha_{p_i} \ln p_{it} + \sum_{j \neq i} \alpha_{p_{ij}} \ln p_{jt} + \alpha_n \ln n_{it-1} + \alpha_r \ln r_t + \alpha_t t + \alpha_{y-1} \ln y_{it-1} + u_{it}^d.$$

Or,

$$\ln y_{it} = \frac{1}{1 - \alpha_{y_{-1}} L} \left[\alpha_0 + \alpha_{p_i} \ln p_{it} + \sum_{j \neq i} \alpha_{p_{ij}} \ln p_{jt} + \alpha_n \ln n_{it-1} + \alpha_r \ln r_t + \alpha_t t + u_{it}^d \right], \quad (21)$$

where L is a lag operator. Similarly, equation (9) can be rewritten as:

$$\ln n_{it} = \frac{1}{1 - \alpha_{n_{it-1}} L} \left[\gamma_0 + \gamma_{p_i} \ln p_{it} + u_{it}^n \right]. \quad (22)$$

Replacing Equation (22) in (21) yields:

$$\ln y_{it} = \frac{1}{1 - \alpha_{y_{-1}} L} \left[\alpha_0 + \frac{\gamma_0}{1 - \alpha_{n_{it-1}} L} + \left(\alpha_{p_i} + \frac{\alpha_n \gamma_{p_i} L}{1 - \alpha_{n_{it-1}} L} \right) \ln p_{it} + \right.$$
$$\left. + \sum_{j \neq i} \alpha_{p_{ij}} \ln p_{jt} + \alpha_n \ln n_{it} + \alpha_r \ln r_t + \alpha_t t + u_{it}^d + \frac{u_{it}^n}{1 - \alpha_{n_{it-1}} L} \right],$$

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 (they may have large switching costs) demand less of i's product:

$$\frac{\partial y_{it}}{\partial p_{it}} = \frac{\alpha_{p_i}}{1 - \alpha_{y_{-1}}}. \quad (23)$$

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:

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

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:

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

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:

$$\eta_{tlr} := \frac{1}{1 - \alpha_{y_{-1}}} \left(\alpha_{p_i} + \frac{\alpha_n \gamma_{p_i}}{1 - \alpha_{n_{it-1}}} \right). \quad (27)$$

Appendix 2: Estimation Results

Table 1: Demand Function

Variable	Model 1	Model 2	Model 3	Model 4
α_0	1.334$^{(a)}$ (0.530)	0.822 (0.107)	0.963 (0.118)	0.679 (0.139)
α_{p_m}	-0.402 (0.084)	-0.541 (0.094)	-0.373 (0.091)	-0.384 (0.086)
$\alpha_{p_{12}}$	-0.016$^{(c)}$ (0.066)	-0.262 (0.083)	-0.068$^{(c)}$ (0.100)	-0.053$^{(c)}$ (0.094)
$\alpha_{p_{13}}$	0.353 (0.073)	-0.059$^{(c)}$ (0.089)	-0.007$^{(c)}$ (0.123)	0.012$^{(c)}$ (0.109)
$\alpha_{p_{23}}$	0.599 (0.065)	0.257 (0.089)	0.234$^{(b)}$ (0.121)	0.210$^{(b)}$ (0.113)
α_n	1.041 (0.042)	0.598 (0.078)	0.415 (0.076)	0.351 (0.074)
α_r	5.028 (0.920)	3.718 (0.822)	2.783 (0.779)	1.940$^{(a)}$ (0.773)
$\alpha_{y_{-1}}$				0.277 (0.081)
α_t	-	-	0.007 (0.001)	0.004$^{(a)}$ (0.001)
α_{VO}	-	-	0.065$^{(c)}$ (0.045)	0.042$^{(c)}$ (0.042)
α_{TM}	-	-	0.096$^{(a)}$ (0.041)	0.054$^{(c)}$ (0.040)
Error Standard Dev.	0.267 (0.018)	0.078 (0.006)	0.068 (0.005)	0.064 (0.005)
Adjusted R^2	0.971	0.853	0.886	0.897
T	112	92	92	92

Note Standard deviations are in parenthesis.
In all models, all parameters (but (*a*): Significant at the 5% level, (*b*): Significant at the 10% level, and (*c*) not significant) are significant at the 1% level.

Table 2: Network growth

Variable	Parameter
γ_0	0.242 (0.063)
γ_{p_t}	-0.139 (0.043)
$\gamma_{n_{-1}}$	0.875 (0.103)
Error Standard Dev.	0.050 (0.004)
Adjusted R^2	0.911
T	88

Note: Standard deviations are in parenthesis.
All parameters are significant at the 1% level.

Table 3: 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[(c)] (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_t	-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 Dev.	-	0.366 (0.047)	0.234[(b)] (0.142)	0.361 (0.050)	-
Error Standard Dev.	0.251 (0.017)	0.123 (0.029)	0.159[(a)] (0.070)	0.126 (0.032)	0.349 (0.023)
Adjusted R^2	0.971				0.943
Vuong Test. (3) against alternative models	3.401	2.708	-	2.679	
T			112		

Note: Standard errors are in parenthesis.
Values for the Vuong test below –2 favor the alternative model against model (3), and above 2 favor model (3) against the alternative model.
In all models, all parameters (but (*a*): Significant at the 5% level, (*b*): Significant at the 10% level, and (*c*) not significant) are significant at the 1% level.

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.

Table 4: Estimated Margins

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

Table 5: Industry Growth levels and impatience

Δ_{μ}	Δ_{y}	δ
0,01	1786,12	0,10
	223,27	0,80
	210,13	0,85
	198,46	0,90
	188,01	0,95
1	17,86	0,10
	2,23	0,80
	2,10	0,85
	1,98	0,90
	1,88	0,95
1,33	13,43	0,10
	1,68	0,80
	1,58	0,85
	1,49	0,90
	1,41	0,95
1,66	10,76	0,10
	1,34	0,80
	1,27	0,85
	1,20	0,90
	1,13	0,95
2	8,93	0,10
	1,12	0,80
	1,05	0,85
	0,99	0,90
	0,94	0,95

Appendix 3: Figures

Figure 1: Revenue Market Shares

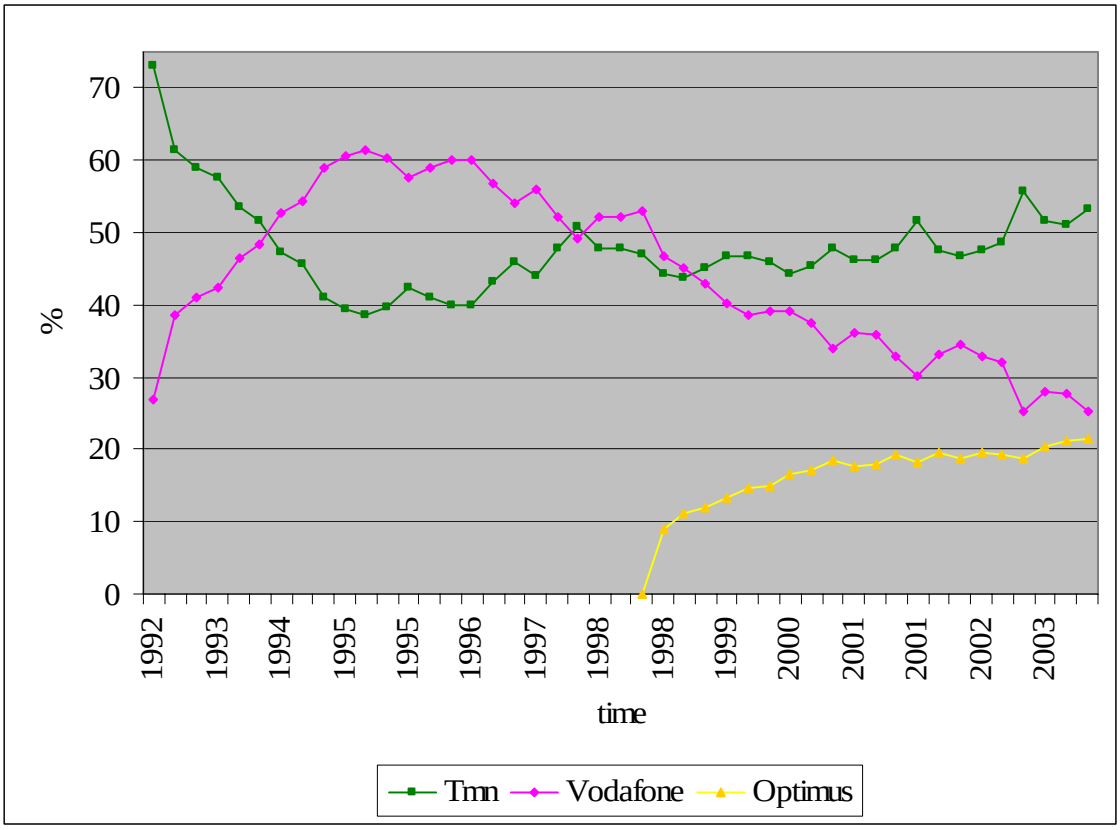

Figure 2: Average Costs

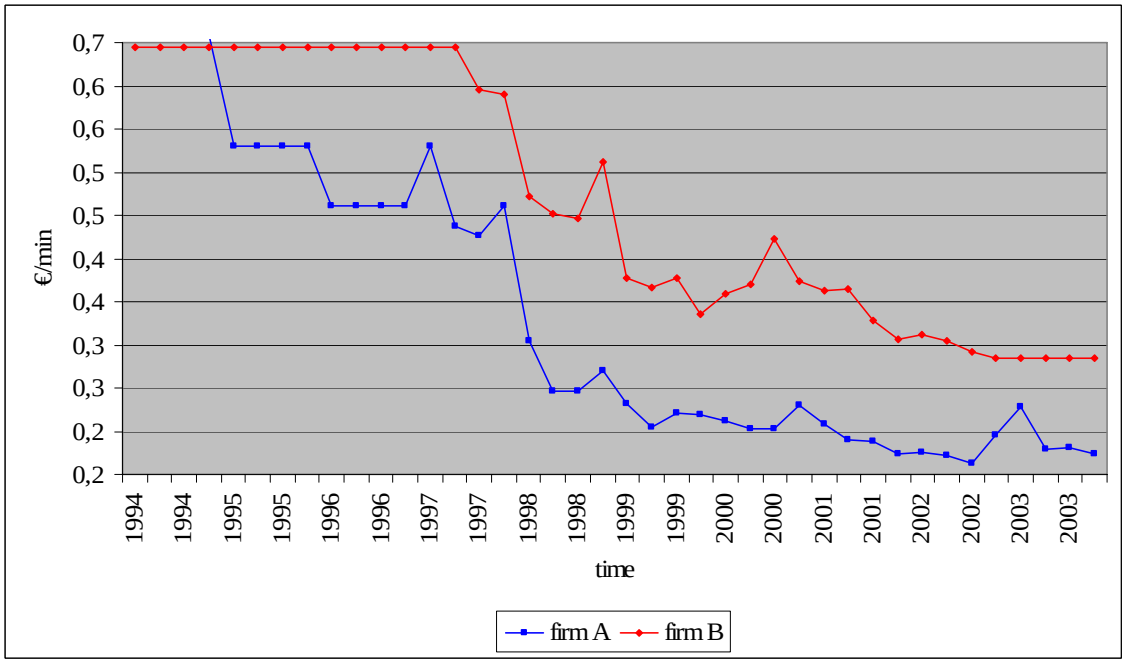
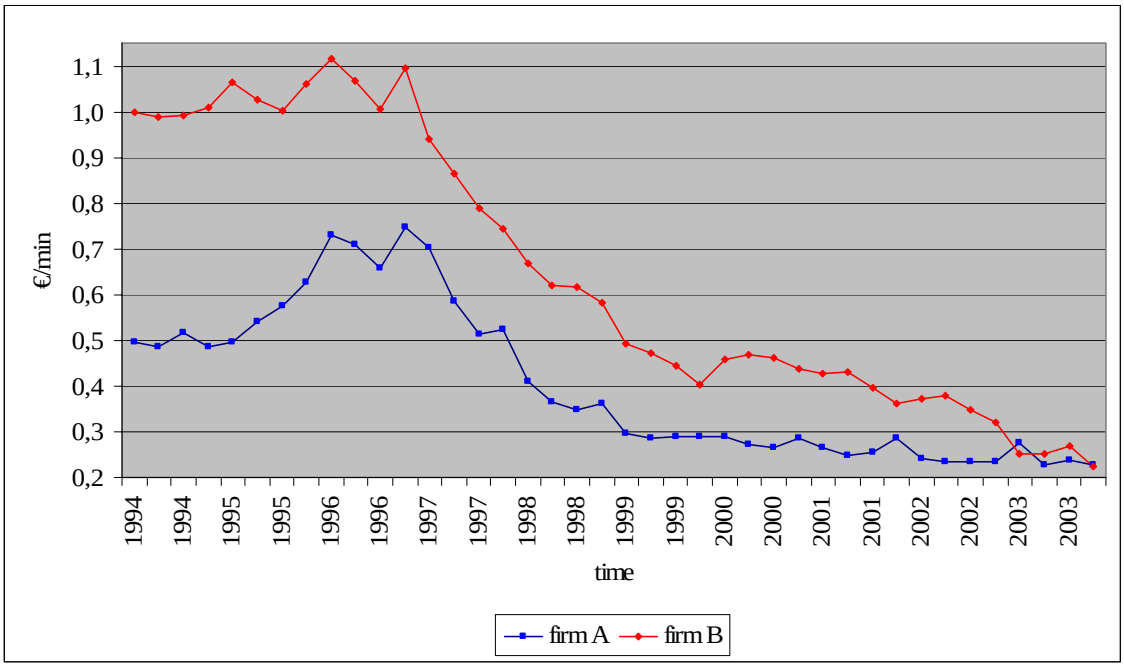
Figure 3: Average Prices