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ORIGINAL ARTICLE

Capacity-based versus time-based access charges in telecommunications

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Abstract The Spanish telecommunications regulator recently introduced a capacity-based access system. Under this regulation, entrants pay a flat charge for the interconnection circuits leased to the incumbent operator and are able to freely use these circuits to provide telecommunications services. This paper determines the optimal capacity-based access charge in the presence of time varying demand and capacity constraints and compares this regulation with the traditional time of use access system. The analysis shows that either type of regulation allows the incumbent to recover its fixed costs and can promote the same pattern of entry. Finally, the optimal capacity-based access charge when the entrant has market power is derived.

Keywords Telecommunications · Capacity-based access charges · Peak-load pricing · Network regulation

JEL Classifications L13 · L51 · H54 · D43

1 Introduction

The liberalization of the electricity, gas and water industries has frequently used vertical disaggregation to promote competition. This policy has not been implemented in the telecommunications industry, except for short periods in countries like the United States, Chile, Bolivia and Brazil. As an alternative, national regulatory agencies have traditionally guaranteed competition by regulating access to the incumbent operators network. In 2001, the Spanish telecommunications regulatory agency introduced a

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capacity-based system to regulate the access to Telefonica's fixed line network. This regulation substitutes a traditional time of use access system with one in which the entrants are charged a flat price for the interconnection circuits they lease. This access system is based on the fact that peak-hour capacity is the principal driver of network costs in telecommunications. Moreover, such pricing allows entrants to commercialize bundles of services and to give discounts that differ from those offered by the incumbent. Thus, for example, entrants can differentiate their services by varying peak and off-peak times and retail prices.

The "one-way" interconnection problem has been extensively analyzed by Baumol (1983), Baumol and Sidak (1994), Laffont and Tirole (1994), Armstrong et al. (1996), Lewis and Sappington (1999) and others.[1] In all these studies the optimal access charges are derived from three assumptions: (a) consumers' demands do not fluctuate with time; (b) operators do not face capacity constraints; and (c) the regulator establishes time of use access charges, i.e., a price for each minute of access. The primary objective of this paper is to relax these assumptions and to determine the optimal access charges when demand fluctuates with time and there are capacity constraints. I explain how the theory of access pricing may be applied to determine the optimal capacity-based access charges and also show that a capacity-based access system may generate the same entry as a time-based one.

The paper considers a market with a regulated incumbent and an unregulated fringe of price-taking entrants. The incumbent operates a network and produces only one type of call. The fringe offers the same service as the incumbent but, in order to initiate and terminate its calls, it leases transmission capacity from the incumbent. I show that the optimal time of use access charges consist of the direct access cost plus the incumbent's opportunity cost of providing access and a Ramsey markup. Interestingly, with continuous and interdependent peak and off-peak demands, the incumbent's opportunity cost of providing one minute of access must reflect the revenues lost by the incumbent in peak and off-peak services during that time period.[2]

The optimal capacity-based access charge consists of the direct costs of the capacity supplied to the fringe, the opportunity costs incurred by the incumbent when it provides a unit of capacity and a positive Ramsey term. In contrast to time of use access charges, however, the incumbent's opportunity costs of access reflect the profits it loses during the entire period (peak and off-peak) where the capacity is leased. This capacity-based access system can be justified because it allows entrants to freely use the contracted circuits to provide any kind of service at any time of the day. In these circumstances, if the objective of the access charge is to defray the incumbent's fixed costs, one has to consider all the profits lost by the incumbent when it supplies one unit of capacity.

This paper also analyzes the case in which there is a unique entrant able to differentiate its service to gain market power. Variations in definition of peak period usage can attract a share of the customers. In this situation, the optimal access charge not

[1] For a complete review of the access pricing problem see Laffont and Tirole (1996 and 2000), Armstrong (2002) and Vogelsang (2003).

[2] Armstrong et al. (1996) show that with time independent demands, product differentiation, bypass and input substitution possibilities reduce the opportunity cost of access.

only allows the incumbent to recover its fixed costs but also reduces the effect of the entrant's market power.

Finally, comparison of capacity-based and time-based access systems shows that either can generate the same level of entry when consumers are forced to buy all their calls from only one operator. With a time-based system there is a positive peak and off-peak time-based access charge that contributes to the incumbent's fixed costs. However, the entrants per minute cost of providing peak calls is higher with a capacity-based system, because there is a unique charge that helps to recover the incumbent's fixed costs during all time periods. In spite of these differences, the entrants provide their service to the same number of consumers and produce the same quantity of peak and off-peak calls with the two systems. The reason is that for any combination of peak and off-peak calls the two systems must allow the incumbent to recover the same amount of revenues.

The idea of this paper is closely related with the literature on peak-load pricing.[3] This research has mostly dealt with the regulation of one utility where demand is constant within pricing periods and independent of demand in other periods. Pressman (1970) considers demand interdependencies under conditions of constant demand within exogenously given pricing periods. Crew and Kleindorfer (1986) consider both time varying and independent demands, but assume a fixed period length. Craven (1971 and 1985) and Dansby (1975 and 1978) allow time varying demand within pricing periods and examine the optimal length of the pricing periods. Burness and Patrick (1991) analyze the regulation of a monopoly under continuous and interdependent demands and determine the optimal pricing period length. Although the authors do not assume capacity constraints, their model has been a useful reference for the purpose of the present paper.

Studies of peak-load pricing have also detailed the optimal determination of capacity and pricing rules under uncertainty. Many authors consider that under uncertainty optimal prices may involve rationing, and as a result several proposals have been submitted that try to mitigate this problem.[4] Lee (1993), for example, proposes the use of maximum demand tariffs, which allow consumers to determine their own maximum instantaneous consumption level, and shows that this type of tariff generates more welfare than other pricing rules. In this paper, however, I try to avoid these problems by assuming that there is perfect information about the demands and the costs of the firms.

Very few papers have considered the peak-load pricing problem in the presence of competition. Crew and Kleindorfer (1991) examine Ramsey optimal peak-load pricing for postal services and some effects of competitive entry. They analyze the appropriate per-letter discount to be allowed for external presorting to prevent excessive discounts that would encourage inefficient entry. Laffont and Tirole (2000) derive optimal Ramsey prices for time of use access charges. This approach is justified because the network operator has different marginal costs in each pricing period. Finally, Poletti (2005) analyzes the optimal regulation of time of use access charges in the telecommunications

[3] For a review of the peak-load pricing literature see Crew et al. (1995).

[4] See Crew and Kleindorfer (1986) and Seeto et al. (1997) for a detailed analysis of the different mechanisms proposed.

sector using a model similar to the one employed in this paper. However, our analysis is different in two major elements: (1) it assumes continuous and interdependent demands and therefore some aspects such as the optimal length of the pricing periods and the substitution effects between peak and off-peak demands are considered; and (2) it includes an analysis of the optimal regulation of access charges when operators face capacity constraints. Since operators contract a fixed transmission capacity, they can supply only a limited number of call-minutes. Finally, an interesting point of Poletti's paper is that entrants may have market power. This enables him to identify a tension between the need to regulate access charges to offset the inefficiencies resulting from the entrant's market power and the need to recover fixed costs. A similar tension appears in the present paper, although here it is assumed that market power is generated endogenously by the entrant's decision to differentiate its service by modifying the length of the pricing periods. The entrant can differentiate its services with a capacity access system, but not with time of use access charges.

The next section explains the main motivation for capacity-based access systems and describes some recent applications of this regulation. Section 3 presents the main features of the model, defines the optimal time-based and capacity-based access charges and compares the two regulatory systems. An analysis of capacity-based access charges when there is one entrant with market power is the subject of Sect. 4, and Sect. 5 concludes.

2 Interconnection in the telecommunications industry

In the telecommunications industry demand fluctuates with time.[5] If price is uniform over time, the amount demanded will rise and fall periodically. Meeting the demand at the peak requires the installation of capacity that will be under-utilized over the remainder of the cycle. The theory of peak-load pricing developed in the 1940s and 1950s proposed the utilization of time of use prices to solve this problem. Subsequently, national regulators have imposed peak-load pricing to discourage consumption during the peak periods and encourage off-peak consumption. In the telecommunications industry, since voice and Internet traffic use the same telephone circuits, it is necessary to jointly determine the prices of these services in order to efficiently manage the aggregate load curve. For example, in order to reduce capacity requirements, operators move Internet consumption to off-peak periods.

Since the liberalization of the telecommunications industry, national regulatory agencies have also implemented time of use access charges to optimize the use of the incumbent's local network.[6] In spite of this, the principal driver of network costs is the peak-hour capacity cost, which is fixed and does not directly depend on the number of minutes the incumbent provides to the entrants. An access system based on time of use access charges may generate several distortions in the market:

[5] Koschat et al. (1995) provide a detailed quantitative study of the optimal peak-load pricing of local telephone calls. Their model incorporates intraperiod variation and uncertainty of demand.

[6] See Mitchell et al. (1995).

(1) The incumbent does not have reliable information on the entrant's needs for capacity. As a result, it may install more or less capacity than the necessary.
(2) Entrants are forced to set their retail prices in accord with the time of use access charges defined by the regulator. They cannot differentiate their services from that of the incumbent's by offering different pricing periods.
(3) Entrants do not take advantage of the scale economies generated with their interconnection traffic. Although the capacity cost decreases with the number of interconnection circuits used, access charges generally remain constant.
(4) Entrants do not have incentives to use the excess capacity present in the off-peak period.

The recognition of these problems has led the regulatory authorities of some countries to look for an alternative interconnection system. In the UK, in 2000 OFTEL compelled BT to set a flat rate for access to the Internet, called Digital Local Exchange Flat Rate Internet Access Call Origination (FRIACO). This mechanism allows the Internet service providers to emulate the flat rate of BT. With the same aim, in February 2001 the German Regulatory Authority introduced a wholesale flat rate in addition to its linear pricing scheme.[7]

Finally, in 2001, the Spanish National Regulatory Agency (CMT) implemented a capacity-based access system to regulate the use of Telefonica's network.[8] Since then, access charges have consisted of a flat price per access-circuit and are independent of the interconnection traffic effectively offered through the circuits.[9] Spanish operators can buy elementary units of 64 Kbit/s of capacity (or multiples of it) of a predetermined quality. In contrast to other capacity-based access systems, in Spain the capacity contracted can be used in all pricing periods, for both voice and Internet traffic. Entrants can use the capacity of the circuits unoccupied during the off-peak periods to provide new services. Moreover, once their needs are covered, they can resell the remaining capacity.

Four years after the creation of the capacity-based access system, most Spanish operators use this mechanism to contract all or most of their interconnection traffic. The result has been a great variety of pricing structures, which increases consumer choices.

3 The model

Consider an incumbent telecommunications operator ($i = 1$) and a fringe of price-taking entrants ($i = 2$) that provide telephone calls in the period $[0, T]$. Entrants use the incumbent's local network to originate and terminate their calls and, for that, they pay the incumbent an access charge. Our objective is to analyze the regulation of the access charge when regulators implement time-based or a capacity-based access systems.

[7] OFTEL (2001) and Reutter (2001).

[8] Cave and Crowther (1999) and CMT (2000) describe some advantages of capacity-based access systems.

[9] In France and Belgium there is a mixed system that consist of a fixed price per circuit and a variable price that depends on the number of minutes that are used.

Consumers have continuous and intertemporally dependent quasi-linear preferences; the utility from consuming q^i at t depends on all values taken by $q^i(t)$ for $t \in [0, T]$. Let us assume that firms only establish two pricing periods, peak ($j = p$) and off-peak ($j = o$).[10] The peak price P_p^i is applied in the time interval $L_p^i = [\tau_l^i, \tau_u^i]$, where τ_s^i, $s = \{l, u\}$, are the time bounds that separate the peak and off-peak periods. The off-peak price P_o^i is applied in the interval $L_o^i = [0, \tau_l^i) \bigcup (\tau_u^i, T]$.

Consumers have different preferences for making telephone calls during the period $[0, T]$, which we denote by $\theta \in [0, 1]$. The number of consumers of type θ is given by the distribution function $F(\theta)$, which has a continuous density $f(\theta)$. We assume that each consumer is obliged to buy all calls from only one firm. Let $S(\psi^i, \theta)$ denote the net surplus obtained by consumers θ during the peak and off-peak periods, where $\psi^i = (P_p^i, P_o^i, \tau_l^i, \tau_u^i)$. Clearly, one consumer will buy from one of the entrants if he obtains a greater surplus than when buying from the incumbent, i.e., when

$$\gamma(\psi^1, \psi^2, \theta) = S(\psi^2, \theta) - S(\psi^1, \theta) > 0. \tag{1}$$

In order to simplify the problem we impose the single crossing property on consumers' preferences. This implies that a "higher type" consumer places a greater value on any combination of peak and off-peak prices than do "lower type" consumers. In addition, given ψ^1 and ψ^2, there is a greater difference in the valuation of the firms' offers for higher type consumers; that is $\frac{\partial \gamma(\psi^1, \psi^2, t)}{\partial \theta} > 0$.[11] When these conditions are satisfied, there exists a unique cut-off point $\theta^* \in [0, 1]$ that separates the consumers of the incumbent and those buying from the entrants. Define $\theta^*(\psi^1, \psi^2) \in [0, 1]$ as the higher type consumer that buys from the incumbent. The demands in time t for the incumbent and the entrants can now be expressed as[12]

$$\begin{aligned} q_j^1(\psi^1, \psi^2, t) &= \int_0^{\theta^*} q(\psi^1, t; \theta) dF(\theta); \\ q_j^2(\psi^2, \psi^1, t) &= \int_{\theta^*}^1 q(\psi^2, t; \theta) dF(\theta). \end{aligned} \tag{2}$$

[10] Joskow (1976) and Craven (1971 and 1985) analyze the optimal number of pricing periods.

[11] More formally, take ψ^1 and ψ^2 as given and let consumers be indexed by $\overline{\theta}$ and $\underline{\theta}$, where $\overline{\theta} > \underline{\theta}$. The single crossing property holds if there exists an ordering of consumers such that:

$$S(\psi^i, \overline{\theta}) > S(\psi^i, \underline{\theta});$$

$$S(\psi^2, \overline{\theta}) - S(\psi^1, \overline{\theta}) > S(\psi^2, \underline{\theta}) - S(\psi^1, \underline{\theta}).$$

[12] Burness and Patrick (1991) solve the consumer's problem considering that the individual demand is $q_j^i(t) = q(\mathbf{P_j^i}, \mathbf{P_{-j}^i}, t, \theta)$ where $\mathbf{P_p^i} = \{P_p^i(t) : t \in L_p^i\}$ and $\mathbf{P_o^i} = \{P_o^i(t) : t \in L_o^i\}$. For tractability, we simplify this demand as $q_j^i(t) = q(\psi^i, t, \theta)$.

We assume that these demands vary with time. Usually, in peak load theory intraperiod time invariant demand is assumed. Here, however, we assume that demand varies within the price periods and, therefore, the number of calls sold varies with time. Finally, we write the aggregated consumers' surplus as follows

$$CS(\psi^1, \psi^2) = \int_0^{\theta^*} S(\psi^1, \theta) dF(\theta) + \int_{\theta^*}^1 S(\psi^2, \theta) dF(\theta). \quad (3)$$

The firms' cost of operating q_j^i call minutes is $C_i(q_j^i)$, where $\partial C_i(q_j^i)/\partial q_j^i = c_i(q_j^i)$. This cost depends exclusively on the firms' traffic and is generated by activities such as backbone switching, information services and billing.

In addition to this cost, the provision of calls requires the use of transmission circuits. We assume that firms need to install as many units of capacity as the maximum number of call-minutes sold during the peak period. In our model, the incumbent is the only firm that can install and manage the capacity units. The number of capacity units that each firm can potentially use is K_i and β the incumbent's "stand alone" cost per each capacity unit. In addition, we assume that the marginal cost of providing capacity is zero as long as it is not exhausted.

The timing of the game is as follows. Firstly, the regulator establishes the incumbent's retail prices, peak period, capacity, and access charges. The access charges can be regulated with a time-based or a capacity-based system. Secondly, the incumbent supplies telephone calls at the prices established by the regulator. Simultaneously, the fringe of entrants, taking into account the access charges, decides the quantity of peak and off-peak calls it will supply.

Next, we define the optimal access charges for a time-based and a capacity-based access system and we compare them. In order to ease the exposition, we present only the expressions for access charges, while placing the equations for retail prices in the appendix.

3.1 Time of use access charges

A time-based access system establishes different access charges for the peak and off-peak time periods, which are denoted by a_j. Let us assume that the fringe behaves as if it were a single price-taking entrant. Taking this into account, the entrant considers ψ^2 as given and produces a combination of peak and off-peak calls $\{q_p^2, q_o^2\}$ that maximizes its profits.

$$\pi^2(\psi^2, a_p, a_o) \equiv \max_{\{q_p^2, q_o^2\}} : \sum_j \int_{t \in L_j^2} [(P_j^2 - a_j) q_j^2 - C_2(q_j^2)] dt. \quad (4)$$

In this model the incumbent is totally non-strategic, since all prices are established by the regulator. The incumbent observes the prices and supplies the calls that, at these prices, exhaust its demands. When the regulator implements a time-based access system the incumbent considers the profit function

$$\pi^1(\psi^1, K_1, a_p, a_o) \equiv \sum_j \int_{t\in L_j^1} [P_j^1 q_j^1 - C_1(q_j^1)]dt + \sum_j \int_{t\in L_j^2} a_j q_j^2 dt - \beta K_1 - \beta q_p^{2M} - F, \quad (5)$$

subject to the incumbent's capacity constraint $K_1 \geq q_p^{1M}$, where $q_p^{iM} = \max_{t\in L_j^i} q_j^i(\psi^1, \psi^2, t)$ is the maximum level of demand of firm i in period j.

The regulator determines the incumbent's retail prices, the access charges, the capacity installed and the times at which the peak period begins and ends. In particular, the objective of the regulator is to maximize the following social welfare function:

$$W(\psi^1, \psi^2, K_1, a_p, a_o) \equiv CS(\psi^1, \psi^2, a_p, a_o) + \pi^1(\psi^1, K_1, a_p, a_o) + \pi^2(\psi^2, a_p, a_o), \quad (6)$$

where the entrant's and incumbent's profits are given by Eqs. (4) and (5). On the other hand, the regulator may take into account the incumbent's break-even constraint, $\pi^1 \geq 0$. We denote by $\lambda \geq 0$ the Lagrange multiplier of this constraint.

The next proposition defines the optimal access policy when the shifting-peak possibility is excluded (see the proof in the Appendix).

Proposition 1 *Assume that $\lambda > 0$ and P_p^1 and P_o^1 are higher than the first best prices. The optimal time of use access charges satisfy:*

$$a_p = \frac{\beta \frac{\partial q_p^{2M}}{\partial a_p}}{\int_{t\in L_p^2} \frac{\partial q_p^2}{\partial a_p} dt} + \frac{\sum_j \int_{t\in L_j^1} (P_j^1 - c_1) \frac{\partial q_j^1}{\partial a_p} dt - \beta \frac{\partial q_p^{1M}}{\partial a_p}}{\int_{t\in L_p^2} \frac{\partial q_p^2}{\partial a_p} dt} - \frac{\lambda}{1+\lambda} \frac{\int_{t\in L_p^1} q_p^2 dt}{\int_{t\in L_p^2} \frac{\partial q_p^2}{\partial a_p} dt}; \quad (7)$$

$$a_o = \frac{\sum_j \int_{t\in L_j^1} (P_j^1 - c_1) \frac{\partial q_j^1}{\partial a_o} dt}{\int_{t\in L_o^2} \frac{\partial q_o^2}{\partial a_o} dt} - \frac{\lambda}{1+\lambda} \frac{\int_{t\in L_o^1} q_o^2 dt}{\int_{t\in L_o^2} \frac{\partial q_o^2}{\partial a_o} dt}. \quad (8)$$

where L_j^i is the optimal length of period j.

The derived expressions show that, as is usual in peak-load pricing, the direct access cost is charged only during the peak period.[13] The proportion of the capacity

[13] Optimal access charges are different when the entrant only supplies services in the off-peak period or in the switching peak case. On the other hand, Dansby (1978) shows that with diverse technology this result may also be modified.

cost included in the peak access charge depends on the length of the entrant's peak period. An increase in the duration of the peak period reduces the contribution of each minute of peak access charge toward the incumbent's capacity cost.

When $\lambda > 0$ both retail prices and access charges are higher than marginal costs. As a result, all services contribute to financing the incumbent's fixed costs, although they do it in different proportions. If the regulator establishes higher access charges, retail prices contribute less to financing fixed costs.

The access charges set for each period also contribute differently toward the incumbent's fixed costs. Each access charge is increased by the incumbent's opportunity cost of providing access in that period and by a Ramsey term. Due to the presence of demand interdependencies between time periods, the incumbent's opportunity cost of giving one minute of access in a particular time period reflects the incumbent's lost profits in both peak and off-peak services during this minute. Thus, for example, an increase in the peak access charge allows the incumbent to sell more calls during the peak period, but if there are demand interdependencies this also modifies the number of off-peak calls it supplies.

In each access charge equation the incumbent's opportunity costs can be separated into the product of two factors: the incumbent's marginal profit per minute of call and a displacement ratio that is defined as follows:

$$\sigma_{kj} = \frac{\int_{t \in L_j^1} \frac{\partial q_j^1}{\partial a_k} dt}{\int_{t \in L_k^2} \frac{\partial q_k^2}{\partial a_k} dt}. \tag{9}$$

The displacement ratio of service j in period k reflects the change in the incumbent's sales of service j generated by a change in the entrant's sales of product k due to a change in the access charge of period k. Taking this into account, when the products of the incumbent and the entrant are homogeneous and there are not demand interdependencies we have $\sigma_{jj} = 1$ and $\sigma_{kj} = 0$, where $k \neq j$.

The Ramsey term included at the end of each access charge equation is higher for time periods with low elasticity. This happens because when an entrant's supply elasticity is lower a price increase causes a smaller production decrease and, as a result, the incumbent can recover more revenues at a lower social cost.

The access charges of Proposition 1 can be simplified when the services offered by the incumbent and the entrant are homogeneous and intraperiod demands are time invariant. In this case we obtain:

$$a_p = \frac{\beta}{L_p} + \left(P_p^1 - c_1 - \frac{\beta}{L_p}\right) - \frac{\lambda}{1+\lambda} \frac{q_p^2}{\frac{\partial q_p^2}{\partial a_p}}; \tag{10}$$

$$a_o = (P_o^1 - c_1) - \frac{\lambda}{1+\lambda} \frac{q_o^2}{\frac{\partial q_o^2}{\partial a_o}}, \tag{11}$$

where L_p is the optimal length of the peak period. The regulator determines the peak period, L_p, by choosing the switch times τ_s^1 and τ_u^1 which allow "net social welfare" from peak and off-peak prices to be equal. In this way, the optimal value of the welfare function is continuous at the times when the prices change.

Note that after this simplification, the access charges are still higher than the direct capacity cost. In the last decade, a number of papers has proposed the utilization of the Efficient Component Pricing Rule (ECPR) for regulating the time of use access charges.[14] The ECPR states that the access charge should be equal to the access direct cost plus the incumbent's opportunity cost of providing access to the fringe. If this condition is satisfied, the incumbent's viability is guaranteed and only those operators that are more efficient than the incumbent find entering the market profitable. In spite of these properties, Laffont and Tirole (1994), Economides and White (1995) and Armstrong et al. (1996) have questioned the efficiency of this rule. They show that optimal time-based access charges are equal to the ECPR only under restrictive circumstances. The same result is obtained in our model. Only when the products of both the incumbent and the entrant are homogeneous, intraperiod demands are time invariant, there is no bypass and the incumbent's budget constraint is not binding, are optimal time of use access charges equal to the ECPR.

3.2 Capacity-based access charges

Imagine now that the regulator implements a capacity-based access system. This consists of establishing a flat price for available capacity, which the entrant can freely use to provide calls in the peak and off-peak periods. In particular, consider that given the capacity-based charge one entrant establishes the pair of quantities $\{q_p^2, q_o^2\}$ to maximize the following profit:

$$\pi^2(\psi^2, a) \equiv \max_{\{q_p^2, q_o^2\}} : \sum_j \int_{t \in L_j^2} [P_j^2 q_j^2 - C_2(q_j^2)]dt - aK_2, \tag{12}$$

subject to the capacity constraint $K_2 \geq q_p^{2M}$, where $q_p^{2M} = \max_{t \in L_j^2} q_p^2$ is the maximum number of minutes the entrant supplies during the peak period and K_2 is the total amount of capacity it contracts. We assume that, in equilibrium, the entrant's capacity constraint is binding.

In a capacity-based access system the incumbent's profit over the demand cycle is represented as

$$\pi^1(\psi^1, K_1, a) \equiv \sum_j \int_{t \in L_j^1} [P_j^1 q_j^1 - C_1(q_j^1)]dt - \beta K_1 + (a - \beta) q_p^{2M} - F, \tag{13}$$

subject to the capacity constraint $K_1 \geq q_p^{1M}$.

[14] This rule was originally formulated by Willig (1979) and afterwards developed by Baumol and Sidak (1994). See Laffont and Tirole (2000) or Armstrong (2002) for an analysis of its properties.

In order to determine the optimal access charge, the regulator now considers the welfare function in Eq. (6) when both the entrant's and the incumbent's profits are defined as in (12) and (13). As before, we assume that the regulator establishes the incumbent's retail prices, the switch times that determine the peak period, the access charge and the capacity installed. The next proposition shows the optimal access policy.

Proposition 2 *Assume that* $\lambda > 0$ *and* P_p^1 *and* P_o^1 *are higher than the first best prices. The optimal capacity-based access charge satisfies:*

$$a = \beta + \frac{\sum_j \int_{t \in L_j^1} (P_j^1 - c_1) \frac{\partial q_j^1}{\partial a} dt - \beta \frac{\partial q_p^{1M}}{\partial a}}{\frac{\partial q_p^{2M}}{\partial a}} - \frac{\lambda}{1+\lambda} \frac{q_p^{2M}}{\frac{\partial q_p^{2M}}{\partial a}}. \tag{14}$$

where L_j^1 *is the optimal length of period* j.

The structure of this access charge is similar to the one obtained for the time-based access system in Proposition 1; the optimal access charge for one capacity unit is equal to the direct capacity cost plus the incumbent's opportunity cost of providing access to the entrant and a positive Ramsey term. In this case, however, the incumbent's opportunity cost includes the profits lost by the incumbent over both peak and off-peak periods.

Underlying this result is the realization that in a capacity-based access system the entrant may use that contracted capacity at any time of the day. Therefore, for the incumbent to recover its fixed costs, it must be compensated for the profits lost during all the time that the capacity can be used. Bearing this in mind, it is straightforward to determine the access charge when the incumbent establishes more than two pricing periods.

The access charge of Eq. (14) can be further simplified when we assume that both the incumbent and the entrant offer homogeneous services and that the intraperiod demands are time invariant.

$$a = \beta + \sum_j L_j (P_j^1 - c_1) - \beta - \frac{\lambda}{1+\lambda} \frac{q_p^{2M}}{\frac{\partial q_p^{2M}}{\partial a}}. \tag{15}$$

Note that if the incumbent's break-even constraint is not binding, we obtain an expression for the access charge that can be considered an adaptation of the ECPR for the capacity-based access systems.

The characterization of the optimal access rules facilitates the comparison of time-based and capacity-based access systems. Consider that firms' retail prices and pricing periods are fixed and that the incumbent's break-even constraint is binding ($\lambda > 0$). In this situation, regardless of the access system implemented, for each pair of quantities $\{q_p^2, q_o^2\}$ provided by the entrant, the incumbent must receive the same compensation in order to finance its fixed costs. As a result, the following condition should be satisfied

$$L_p a_o q_p^2 < a; \quad since\ a_o > 0\ and\ L_p a_p q_p^2 + L_o a_o q_o^2 = a, \tag{16}$$

where $\{a_p, a_o\}$ are the optimal time of use access charges and a is the optimal capacity-based access charge.

As we have seen, in a time-based access system the regulator establishes separate charges for peak and off-peak periods. For the entrant, access charges are variable costs that are added to its marginal production cost. Therefore, if the entrant faces increasing marginal costs, the access charges reduce the amount of peak and off-peak calls that it can profitably provide. By contrast, a capacity-based access system establishes a unique charge for each capacity unit contracted. As a consequence, if the entrant has increasing marginal production costs an increase of the access charge reduces the number of peak calls that it can profitable provide, because the cost of those calls are driven by the cost of the capacity contracted. Moreover, from (16) we observe that the reduction of peak calls is greater than it would be with a time-based access system. However, the capacity-based access charge does not affect the production cost of off-peak calls.

Although the two access systems have different effects on the entrant's production costs, they may offer equivalent results when consumers are forced to buy from only one firm.

Proposition 3 *Assume that consumers buy all their peak and off-peak calls from only one firm. Under either time-based or a capacity-based access system the entrant will be able to provide service to the same number of consumers and offer the same number of peak and off peak calls.*

Underlying this result is the understanding that the choice of access system does not affect the combination of peak and off-peak calls that the entrant provides in equilibrium. For each pair of quantities $\{q_p^2, q_o^2\}$, the entrant pays the same price regardless of the access system implemented. Although the capacity-based system does not distinguish between peak and off-peak access charges, it permits the incumbent to recover its fixed costs as efficiently as a time-based system. Bearing this in mind, if the entrant chooses a profit-maximizing combination of peak and off-peak calls when the regulator implements a time-based system, it will choose the same combination when it is regulated with a capacity-based system.

4 Capacity-based access charges when the entrant has market power

Entrants in the telecommunications market try to attract specific groups of consumers by commercializing bundles of services and tariff discounts that differ from those of the incumbent. Thus, they may offer different pricing periods to those offered by the incumbent, beginning and/or ending the peak period at different times. To account for this situation, this section examines a capacity-based access system when one entrant differentiates its products in order to maximize profits. Laffont and Tirole (1994) and Poletti (2005) have analyzed the optimal time of use access charges when unregulated entrants have market power. However, while they consider that the level of product differentiation is determined exogenously, this paper assumes that the capacity-based access system allows the entrant to determine the characteristics of its products and, as a result, to obtain market power.

The timing of the model is the same as before and it is also assumed that the regulator establishes the incumbent's prices and the pricing periods, as well as the access charge paid by the entrant. The only difference with respect to the previous framework is that in this case the entrant maximizes its profit by optimally choosing the prices and switch times, τ_l^2 and τ_u^2, that determine the peak period. In other words, now the incumbent's peak period may differ from the entrant's peak period. The entrant maximizes the following profit function

$$\pi^2(\psi^2, a) \equiv \sum_j \int_{t \in L_j^2} [P_j^2 q_j^2 - C_2(q_j^2)]dt - aK_2, \tag{17}$$

subject to the capacity constraint $K_2 \geq q_j^{2M}$.

The next Lemma describes the entrant's profit-maximizing prices and its profit function. For simplicity, we present the results assuming that intraperiod demands are time invariant.

Lemma 1 *Given the incumbent's prices and the access charge, the profit-maximizing retail prices and the profit function of one entrant with market power satisfy:*

$$P_p^2 = \frac{1}{1+\hat{\eta}_p}\left(c_2 + \frac{a}{L_p^2}\right); \quad P_o^2 = \frac{c_2}{1+\hat{\eta}_o}; \tag{18}$$

$$\pi^2(a) = \sum_j \int_{t \in L_j^2} \left[\frac{\alpha_j}{(1+\hat{\eta}_j)L_j^2} - \frac{\hat{\eta}_j c_2}{1+\hat{\eta}_j}\right] q_j^2 dt - a q_p^{2M} - F; \tag{19}$$

where $\hat{\eta}_k(\psi^1, \psi^2) = \frac{(\eta_{jj} - \frac{R_j}{R_k}\eta_{kj})}{L_k^2(\eta_{kk}\eta_{jj} - \eta_{kj}\eta_{jk})}$*, for* $k \neq j$*, and* L_j^2 *is the entrant's profit-maximizing length of pricing period* j*.*

The term $\hat{\eta}_j \leq 0$ reflects the entrant's market power and increases the peak and off-peak prices with respect to the socially optimal levels. On the other hand, it can be observed that the access charge is only included in the peak price. Indeed, due to the capacity constraint, an increase in demand must be met with an increase in capacity.

The entrant can differentiate its product from that of the incumbent's by offering different prices in different peak and off-peak time periods. Moreover, the retail prices in Eq. (18) show that there is a relationship between the prices and the lengths of the pricing periods. If the entrant increases the length of the peak period, more calls will contribute to financing the access costs and the peak price can be reduced. The entrant's decision about the length of the time periods depends on consumer preferences. On the other hand, when a group of consumers buys from the entrant, the incumbent's load curve is modified and the regulator will establish different time periods for the incumbent than would have been the case had there been no entry.

The access charge can help the regulator to monitor the entrant's retail prices and the level of product differentiation. Consider that the regulator determines the incumbent's retail prices and time periods, the capacity installed and the access charge that maximizes social welfare:

$$W(\psi^1, \psi^2, a) = CS(\psi^1, \psi^2, a) + \pi^1(\psi^1, a) + \pi^2(\psi^2, a), \tag{20}$$

where $CS(\psi^1, \psi^2, a)$ and $\pi^1(\psi^1, a)$ are defined as in Sect. 3.2 and $\pi^2(\psi^2, a)$ is defined as in Eq. (18). The next proposition characterizes the optimal capacity-based access charge when the incumbent's break-even and capacity constraints are binding, and the entrant has market power.

Proposition 4 *Assume that $\lambda > 0$ and P_p^1 and P_o^1 are higher than the first best prices. The optimal capacity-based access charge when the entrant has market power satisfies:*

$$a = \beta + \frac{\sum_j \int_{t \in L_j^1} (P_j^1 - c_1) \frac{\partial q_j^1}{\partial a} dt - \beta \frac{\partial q_j^{1M}}{\partial a}}{\frac{\partial q_p^{2M}}{\partial a}} - \frac{\lambda}{1+\lambda} \frac{q_p^{2M}}{\frac{\partial q_p^{2M}}{\partial a}} - \frac{1}{1+\lambda} \frac{\sum_j \int_{t \in L_j^2} (P_j^2 - c_1 - \alpha_j) \frac{\partial q_j^2}{\partial a} dt}{\frac{\partial q_p^{2M}}{\partial a}} \tag{21}$$

where α_j is the Lagrangian multipliers of the entrant's capacity constraint in period j and L_j^i is the optimal length of pricing period j for firm i.

This access charge can be seen as an extension of the capacity charge of Proposition 2 for the case in which the entrant has market power. Indeed, we obtain the same expression minus a term that reflects the entrant's market power. When the incumbent's services are different from those of the entrant, the entrant establishes a markup over its costs. In this situation, the regulator reduces the access charge to compensate for the increase of the entrant's retail prices and to increase the consumer's surplus.

The regulator's objective is to mitigate the effect of market power. In order to do so the regulator reduces the incumbent's prices.[15] In addition, in order to rebalance the consumers' choice between the two firms the entrant's retail prices must be reduced, and this is accomplished by reducing the access charge.

As Poletti (2005) explains, the access charge reflects a tension between the need for the regulator to reduce the inefficiencies of market power and the need to recover fixed costs in an efficient way. The incentive of reducing the consequences of market power by setting a lower access charge is balanced with an increase of the access charge when it is necessary to help the incumbent to recover its fixed costs. Following this idea, it would even be possible to set the access charge below the capacity cost. This happens, for example, when the incumbent has zero fixed cost or when its break-even constraint is not binding.

15 The calculation of the incumbent's prices shows that prices are reduced if the entrant has market power.

5 Conclusions and policy implications

In 2001, the Spanish agency regulating telecommunications (CMT) introduced a capacity-based access system that replaced the traditional time-based access system. Under this mechanism entrants pay a flat charge for the incumbent's interconnection circuits and can freely use the capacity of these circuits to provide any kind of telecommunication services. The CMT justifies this regulation because the principal driver of the incumbent's network's cost is the peak-hour capacity cost. Moreover, in order to allow entrants to compete on a level field with the incumbent, they must be able to freely establish their time of use retail prices.[16]

This paper has derived the optimal access charges in a capacity-based and in a time-based access system and has compared the performance of these two systems in the presence of time varying demands and capacity constraints. I show that the theory on access charges can be applied to determine the optimal capacity-based access charges. As in the case of the optimal time of use access charges analyzed by Laffont and Tirole (1994) and Armstrong et al. (1996), the optimal capacity-based access charge consists of the direct capacity cost plus the incumbent's opportunity cost of giving access to its competitors and a Ramsey term. With a capacity-based access system, however, if the incumbent establishes time of use retail prices, its opportunity cost takes into account the profits lost during the entire peak and off-peak periods. More generally, if the incumbent establishes several time of use retail prices the access charge has to be modified to reflect the profits lost in each period.

A second contribution of the present paper is to show that under some general conditions time-based and capacity-based access systems can allow an entrant to serve the same number of consumers and are equally efficient in allowing the incumbent to recover its fixed costs. When consumers buy from only one firm, both regulatory instruments allow the entrant to offer the same amount of peak and off-peak calls at the same costs.

The analysis presented here has considered a simplified model of the telecommunications sector. In spite of this, the determination of the optimal capacity-based access charge for a multiproduct industry could be obtained in a straightforward way.[17] In telecommunications, networks are used to provide several services, such as, local and long distance telephone calls, or dial-up connection to Internet. In this context, operators establish the prices and pricing periods for all services in order to optimize the joint use of the network. Bearing this in mind, the optimal capacity-based access charge that an incumbent multiproduct firm should receive must be determined while taking into account that the pricing periods chosen by the incumbent and the entrants differ if they offer different bundles of services.

In future research, it would also be interesting to analyze the determination of the access charges in the presence of demand uncertainty. With uncertainty about the

[16] As stated by CMT (2001), "*activities such as the management of the load curve, the efficient use of the interconnection traffic, the opening of new businesses such as the commercialization of the excess capacity, will determine the optimization of the interconnection capacity and the way to secure lower interconnection costs*".

[17] Calzada (2003) analyzes this problem.

demand the entrants may generate different entry patterns under capacity-based and time-based access systems. In the first case, the entrants have to determine how many interconnection circuits they require, while with a time-based system the incumbent is responsible for determining the number of circuits that will be needed for the future. Another relevant question that should be addressed in future research is how the capacity-based access system would perform in the presence of network competition.

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Appendix

Proof of Proposition 1 Consider the welfare function in (6) and write $\mu \geq 0$ as the Lagrangian multiplier associated to the incumbent's capacity restriction and $\lambda \geq 0$ as the multiplier associated to the incumbent's break-even constraint. Next, notice that:

$$\frac{\partial(CS+\pi^2)}{\partial P_j^1} = -\int_{t\in L_j^1} q_j^1(\psi^1,\psi^2,t)dt; \qquad \frac{\partial(CS+\pi^2)}{\partial a_j} = -\int_{t\in L_j^2} q_j^2(\psi^2,\psi^1,t)dt. \tag{22}$$

In addition, from (3) we have:

$$[S(\psi^1,\theta^*)-S(\psi^2,\theta^*)]f(\theta^*)\frac{\partial\theta}{\partial P_j^*} = 0 \tag{23}$$

Taking this into account, the Kuhn-Tucker theorem for P_k^i and $a_k, k=\{p,o\}$, gives the following conditions:

$$\sum_j \int_{t\in L_j^1} (P_j^1-c_1)\frac{\partial q_j^1}{\partial P_k^1}dt + \sum_j \int_{t\in L_j^2} a_j\frac{\partial q_j^2}{\partial P_k^1}dt - \beta\frac{\partial q_p^{2M}}{\partial P_k^1} - \sum_j \mu_j\frac{\partial q_j^{1M}}{\partial P_k^1}$$
$$= -\frac{\lambda}{1+\lambda}\int_{t\in L_k^1} q_k^1 dt, \tag{24}$$

$$\sum_j \int_{t\in L_j^1} [(P_j^1 - c_1)\frac{\partial q_j^1}{\partial a_k}]dt + a_j \int_{t\in L_j^2} \frac{\partial q_k^2}{\partial a_k}dt - \beta\frac{\partial q_j^{2M}}{\partial a_k} - \sum_j \mu_j \frac{\partial q_j^{1M}}{\partial a_k}$$
$$= -\frac{\lambda}{1+\lambda}\int_{t\in L_k^1} q_k^2 dt, \tag{25}$$

$$\mu_j \geq 0; \quad \mu_j(K_1 - q_j^{1M}) = 0, \tag{26}$$

$$\sum_j \mu_j \leq \beta; \quad K_1\left(\sum_j \mu_j - \beta\right) = 0. \tag{27}$$

Since the shifting-peak case is excluded, from (26) and (27) we obtain that $\mu_p = \beta$ and $\mu_o = 0$. Taking this into account and rearranging (25) we obtain the result of the Proposition.

In order to characterize the peak period, we differentiate the social welfare function with respect to τ_s^i, for $s = l, u$. Before doing so consider the following results:

$$\int_{t\in L_j^i} \frac{\partial q_j^i(\psi^1, \psi^2, t)}{\partial \tau_s^i}dt = 0; \quad \frac{\partial S(\psi^i, \theta)}{\partial \tau_s^i} = ics_p(\psi^i, \tau_s^i, \theta) - ics_o(\psi^i, \tau_s^i, \theta), \tag{28}$$

where $ics_j = ics_j(\psi^i, \tau_s^i, \theta)$ is the instantaneous consumer's surplus of type θ in time τ_s^i, when he is charged with the price P_j^i. In order to simplify the proof, we assume that intraperiod demand is time invariant. Substituting the optimal access charges in the welfare function and differentiating it with respect to τ_s^i yields[18]

$$\begin{aligned} &ics_p + (1+\lambda)\left[P_p^1\hat{q}_p^1 - C_1\left(q_p^1\right) + \left(P_p^1 - C_1\left(q_p^1\right)\right)q_p^2\right] \\ &\quad + \left[P_p^2 - \left(P_p^1 - C_1\left(q_p^1\right)\right)\right]q_p^2 - C_2\left(q_p^2\right) \\ &= ics_o + (1+\lambda)\left[P_o^1 q_o^1 - C_1\left(q_o^1\right) + \left(P_o^1 - C_1\left(q_o^1\right)\right)s_o^2\right] \\ &\quad + \left[P_o^2 - \left(P_o^1 - C_1\left(q_o^1\right)\right)\right]q_o^2 - C_2\left(q_o^2\right), \end{aligned} \tag{29}$$

where $q_j^1 = q_j^1(\psi^1, \psi^2, \tau_s^{i*})$, $q_j^2 = q_j^2(\psi^2, \psi^1, \tau_s^{i*})$. In order to simplify, this expression can be written as follows:

$$V_p(\psi^1, \psi^2, a_p, a_o, \tau_s^{i*}) = V_o(\psi^1, \psi^2, a_p, a_o, \tau_s^{i*}), \tag{30}$$

[18] The principle that characterizes the value of the welfare function when prices are charged is derived and proved in more detail by Dansby (1975) and Burness and Patrick (1991).

Here V_j represents the net social welfare in time τ_s^{i*}. This condition implies that τ_s^{i*} is chosen so that the optimal value of V_j is continuous at the time when the prices are changed. Bearing this in mind, condition (30) together with (24)–(27) characterizes the optimal length of the pricing periods. □

Proof of Proposition 2 Define $\mu \geq 0$ as the Lagrangian multiplier associated to the incumbent's capacity restriction and $\lambda \geq 0$ as the multiplier associated to the incumbent's break-even constraint. The first order condition of the welfare function with respect to the access charge is

$$\sum_j \int_{t \in L_j^1} (P_j^1 - c_1)\frac{\partial q_j^1}{\partial a} dt + (a - \beta)\frac{\partial q_p^{2M}}{\partial a} - \sum_j \mu_j \frac{\partial q_j^{1M}}{\partial a} = -\frac{\lambda}{1+\lambda} q_p^{2M}. \quad (31)$$

When the shifting-peak case is excluded we obtain that $\mu_p = \beta$ and $\mu_o = 0$. Finally, we can rearrange this expression to obtain the result of the proposition.

In order to characterize the peak period, we substitute the optimal access charge in the welfare function and differentiate it with respect to τ_s^i. By doing so we obtain the same condition as in the case of the time-based access system. □

Proof of Lemma 1 Defining α_j the multiplier associated to the entrant's capacity constraint and differentiating the profit with respect to the prices, the capacity and the switch times τ_s^2, we obtain:

$$\int_{t \in L_k^2} q_k^2 dt + \sum_j \int_{t \in L_j^2} (P_j^2 - c_2)\frac{\partial q_j^2}{\partial P_k^2} dt - \sum_j \alpha_j \frac{\partial q_j^{2M}}{\partial P_k^2} = 0, \quad \text{for } k = p, o \quad (32)$$

$$\sum_j \alpha_j \leq a; \quad K_2 \left(\sum_j \alpha_j - a \right) = 0, \quad (33)$$

$$P_p^2 q_p^2 - C_2(q_p^2) = P_o^2 q_o^2 - C_2(q_o^2), \quad \text{for } s = l, u \quad (34)$$

$$\alpha_j \geq 0; \quad \alpha_j (K_2 - q_j^{2M}) = 0. \quad (35)$$

Following Crew et al. (1995) and assuming an interior solution, we rearrange Eq. (32) to obtain:

$$\frac{\sum_j \int_{t \in L_j^2} (P_j^2 - c_2)\frac{\partial q_j^2}{\partial P_k^2} dt - \sum_j \alpha_j \frac{\partial q_j^{2M}}{\partial P_k^2}}{\int_{t \in L_k^2} q_k^2 dt} = -1, \quad \text{for } k = p, o. \quad (36)$$

When intraperiod demand is time invariant we can rewrite this expression in the form:

$$\sum_j \frac{R_j}{R_k}\left[\int\limits_{t^2\in L_j^2} \frac{(P_j^2-c_2)\eta_{kj}dt}{P_j^2} - \alpha_j\frac{\eta_{kj}}{P_j^2}\right] = -1, \quad \text{for } k=p,o. \tag{37}$$

where $\eta_{jk} = (\partial q_j^2/\partial P_k^2)(P_k^2/q_j^2)$ and $R_j = \int\limits_{t^2\in L_j^2} q_j^2 dt P_j^2$. If $\partial q_j^2/\partial P_k^2 = \partial q_k^2/\partial P_j^2$ we also obtain:

$$\sum_j \left[\int\limits_{t^2\in L_j^2} \frac{(P_j^2-c_2)\eta_{kj}dt}{P_j^2} - \alpha_j\frac{\eta_{kj}}{P_j^2}\right] = -1, \quad \text{for } k=p,o. \tag{38}$$

Finally, by using Cramer's rule we further solve this expression to obtain:

$$\frac{(P_k^2-c_2-\frac{\alpha_k}{L_k^2})}{P_k^2} = -\frac{(\eta_{jj}-\frac{R_j}{R_k}\eta_{kj})}{L_k^2(\eta_{kk}\eta_{jj}-\eta_{kj}\eta_{jk})} = -\hat{\eta}_k, \tag{39}$$

where L_k^2 is the optimal length of the pricing period derived from Eq. (34). Finally, if we exclude the shifting-peak case we have that $\alpha_p = a$ and $\alpha_o = 0$. □

Proof of Proposition 4 Differentiate the welfare function in Eq. (20) with respect to the capacity charge. Writing $\mu \geq 0$ for the multiplier of the incumbent's capacity constraint and $\lambda \geq 0$ for the multiplier associated to the incumbent's break-even constraint yields:

$$\lambda q_p^2 + \sum_j \int\limits_{t\in L_j^2} [P_j^2 - c_2 - \alpha_j]\frac{\partial q_j^2}{\partial a}dt + (1+\lambda)[a\frac{\partial q_p^{2M}}{\partial a})$$
$$+\sum_j \int\limits_{t\in L_j^1} (P_j^1 - c_1)\frac{\partial q_j^1}{\partial a}dt - \sum_j \mu_j\frac{\partial q_j^{1M}}{\partial a} - \beta\frac{\partial q_p^{2M}}{\partial a}] = 0. \tag{40}$$

Finally, rearranging we obtain the result of the proposition. □

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