

**PRICE AND ACCESS CHARGE DISCRIMINATION IN ELECTRICITY  
DISTRIBUTION: AN APPLICATION TO THE CHILEAN CASE**

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\* We thank anonymous referees for their helpful comments. Financial support from CONICYT, Fondecyt project No. 1010750, is acknowledged. E-mail address [rraineri@ing.puc.cl](mailto:rraineri@ing.puc.cl).

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Keywords: access pricing, price discrimination, electric distribution, utilities.

JEL Classification: L51, L94

Abstract: Under the assumption that the firm has better information than the regulator we analyze a model for electricity distribution pricing where distribution basic cost are independently calculated, but the monopolist is allowed to set discriminatory prices in separate markets subject to constraints intended to induce the convergence of the firm solution to the social optimum. Two classes of constraints are analyzed, a Price Cap as proposed by Laffont and Tirole (1996), and a Physical Cap with prices restricted to be between the marginal cost and the stand-alone cost. The Physical Cap is a specific application for electricity distribution, using biases of the power coincidence factors used as criteria for cost allocation, restricting the firm to balance the power distributed and the peak power sold. The model is calibrated with Chilean data and demonstrates that the proposed model can achieve an increment in social welfare.

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\* We thank anonymous referees for their helpful comments. Financial support from CONICYT, Fondecyt project No. 1010750, is acknowledged. E-mail address [rraineri@ing.puc.cl](mailto:rraineri@ing.puc.cl).

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## I INTRODUCTION

Worldwide the electric sector is experiencing deep structural changes, evolving from integrated state companies, toward disintegrated and private companies with many segments of the industry treated as potentially competitive. Within these process, regulation have evolved to incentive economic efficiency and increase social welfare, promoting competition wherever is possible.

In this paper we analyze alternative regulatory pricing contract schemes for electricity distribution to assign an electricity distribution common cost among the different categories of customers when the distribution company (DISCO) provides capacity access service to competitive energy sellers. The efficiency of the regulatory models is analyzed in terms of social welfare, consumer surplus and DISCO profits. For a quantitative assessment, the model is calibrated to Chilean electricity distribution. The regulatory contracts analyzed are: Ramsey pricing solution or second best social optimum; DISCO is allowed to freely choose final prices and access charge subject to a Physical Cap constrains on peak load sold; and DISCO is allowed to freely choose final prices and access charges subject to a Price Cap constrain on total revenues. All the contract schemes are compared against current situation in Chile where distribution tariffs are set by the regulator assigning the basic cost to the different tariff options.<sup>1</sup> The basic cost is called Distribution Value Added (DVA), and is calculated with a yardstick competition approach for an efficient DISCO.<sup>2</sup> The DVA correspond to the efficient cost of distribution for one unit of peak power coincident with the maximum load of the distribution system. The models analyzed in this paper are based in a distribution basic cost, but allowing for price discrimination when the tariff formulas are set to assign the costs, in which case the demand functions of the different markets are included.

Under a Physical and Price Cap schemes and beneath the assumption that the firm has better information than the regulator, the DISCO is allowed to set his

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<sup>1</sup> The authorities use a full distributed cost concept to assign the common cost to the different categories of customers based on different criteria such as capacity sales, energy sales, distance from distribution grid injection points, etc...

<sup>2</sup> See Rudnick and Raineri (1997).

price policy being subject to the regulatory constraints intended to induce the company to the social optimum solution, where at first the prices are not restricted to lay between the marginal cost and the stand-alone cost. The Physical Cap considered is specifically designed for electricity distribution, and uses a deviation from the coincidence factors of power to set prices, physical cap that restrict the company to balance the power distributed and the peak power sold.

After we analyze the previous three contract schemes we perform some additional experiments to evaluate how some of the obtained results are affected in three other scenarios that frequently come across to policy makers: a case where the regulator doesn't know consumer's demand as needed to set Ramsey Prices, a case where DISCO is allowed to discriminate prices in a range given by the marginal cost floor and stand alone cost ceiling, and a case where access charges should be set at the level of basic or current costs allocation made by the authority.

Ramsey (1927) was the first to analyze the socially optimal price setting for multi-product firm, where lately others recall on Ramsey solution to set prices on regulated industries. For example, Laffont and Tirole (1996) uses Ramsey prices to set access charges in network infrastructure industries, and also suggest the use of a Price Cap constraint on the firm if it is going to be allowed to set prices. Baumol and Willig proposed a ceiling and a floor to the company price policy discretion, where the marginal cost should be used as a floor and the stand-alone cost as a ceiling, expecting with that to prevent a predatory behaviour by the monopolist.

Our results agree that the Ramsey Pricing solution gives higher social welfare for pricing when a common cost should be assigned within the different markets. Also, a global Price Cap on the DISCO reaches the same welfare as Ramsey Pricing if the price weights of the Price Cap are optimally chosen. But, the Physical Cap scenario is the worst from a social perspective, but the preferred by the DISCO where the DISCO covers all the costs through the prices charged in the more inelastic demand, with the more elastic demands being totally subsidized by the first.

However, in a situation where the regulator cannot observe the demand, he can not set the right price weights for the Price Cap. Thus, we set those weights as the quantities of the current situation and find that social welfare increases respect to current situation where the common cost is equally distributed to the different tariffs. Also, if the Physical Cap on the DISCO is complemented with to additional constraints in terms of a price floor, as the marginal cost, and a price ceiling, as a stand alone cost, it improves social welfare becoming closer to Ramsey Pricing solution, but where DISCO profits improve at the expense of consumers welfare.

Finally, we analyze a Price Cap and a Physical Cap complemented by a non-discriminatory access charge constraint and find that it has an almost null or even negative impact on social welfare respect to the situation where the Price and Physical Caps are not complemented with that constraint.

The yardstick competition methodology that at the moment is applied in Chile, to determine the prices of each one of the electricity distribution markets, is effective to incentive production efficiency. But the determination of the prices requires the allocation of a common cost to all the markets what currently is made based on a fully distributed cost criteria that is not necessarily efficient from an economic point of view. Here we propose some mechanisms that complement the current mechanism to reach a better resource allocation. But at the end, the use of any of the mechanisms analyzed will depend on the available information and the degree of discrimination that political authorities are willing to allow.

Section 2 present the tariff models and access charge problem in electricity distribution. The key tariff models considered are Ramsey Pricing, DISCO optimum under a Physical Cap, and DISCO optimum under a Price Cap. Section 3 discusses model calibration, data analysis to pick demand function parameters, consumer surplus and cost functions. Section 4 present the results of the numerical experiments used to evaluate the welfare properties of the alternative contract schemes defined in section 2, and the results of the additional experiments that account for information asymmetries, bounded discrimination, and non discriminatory access charge. Finally, section 5 discusses the main findings of this paper.

## **II            TARIFF MODELS AND ACCESS CHARGES IN ELECTRICITY DISTRIBUTION**

The end objective of monopoly regulation is to increase social welfare. For it, the regulator should set down the mechanisms to stimulate an efficient resource allocation and to promote competition whenever is possible, under the assumption that it enlarges social welfare, where always the main difficulty is to design a model with a set of rules and contracts that provides the right balance between the objective of increasing consumers welfare and of promoting an efficient production and investment level in the industry, and too to get the necessary information to feed the model. Some of the models that have been tried for these objectives are *Rate of Return*, *Price Cap*, and *Ramsey Prices* regulation. The *Rate of Return* pricing model has the advantage of being able to determine in an easy and objective form the tariff level, assuring the cost recovery to the firm, where it uses

accounting cost information but has the disadvantage that it provides not efficient investment incentives (Averch and Johnson, 1962). On the other hand, models such as *Price Cap* incentive and efficient resource allocation, but require great quantity and quality of costs information, where it is needed to speculate about future efficiency improvements and demand projections to determine the weights of the Price Cap index. And in the case of *Ramsey Prices* it is required to know cost information and the demand functions or their elasticities.

## 2.1 Model assumptions

We use a homogeneous good model of a natural monopoly in electricity distribution. In electricity distribution some of the conditions needed for a competitive industry are broken, where only one DISCO provides the service of electricity distribution, and where also exist economies of scale, scope and sunk cost that mean entry barriers for new competitors. In an electric network that operates under an open access scheme, and to incentive competition in the selling of electricity through the electricity distribution network, is fundamental to set appropriate access charges, where their determination should be transparent to all the agents in a way that access charges cannot be used as an entry barrier against potential competitors.

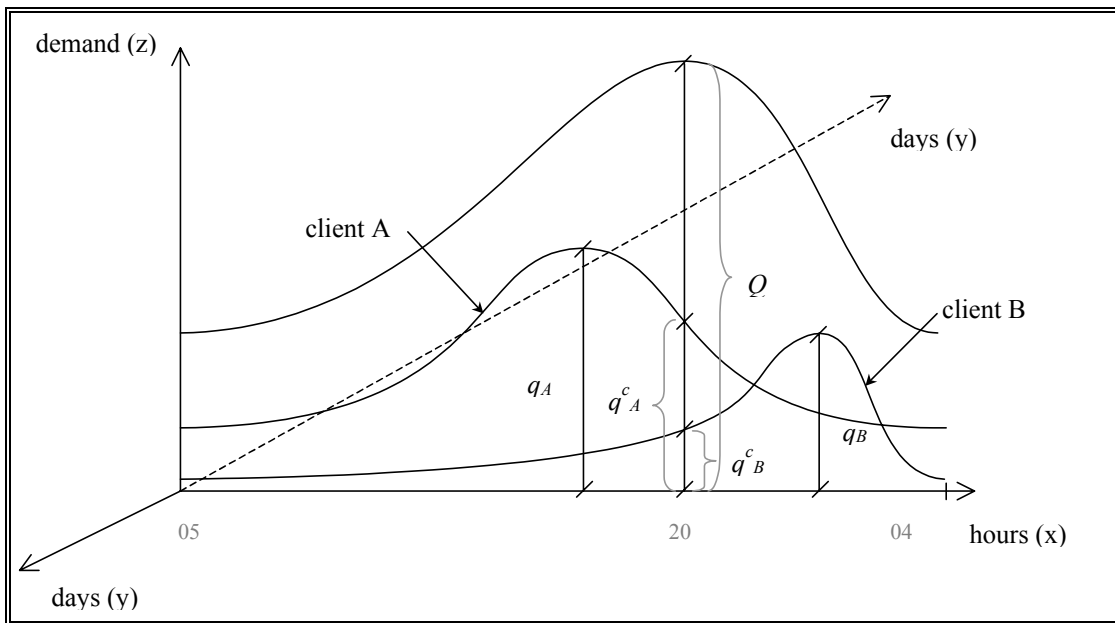
The efficiency of our experiments with alternative tariff structures will be measured against the current pricing scheme used in Chile. However, since our experiments allow for price discrimination, they will benefit some consumers and detriment others, so Pareto optimality conditions are not satisfied.

Without loss of generality, it will be studied the case of a company with just one voltage level and present in one electricity distribution typical area, where the good traded is peak load power. Where we assume that in the purchase and sale of energy distributed there is no margin. The maximum load of the distribution system coincides with the maximum power bought by the distributor.

The costs of the DISCO are peak power purchase costs and peak load power distribution costs. Let  $C_{PM}$  be the purchase cost of peak power incurred by the firm. In general these costs have constant returns to scale without a significant fixed cost, so it will be represented as:

$$C_{PM} = c_{PM} \cdot Q \tag{1}$$

where  $c_{PM}$  is the marginal cost (and the average cost) of buying one unit of peak load power, where  $Q$  corresponds to the peak load power in physical units (KW). This value is obtained carrying out a physical balance of peak load power of the firm subject to regulation.<sup>3</sup> It will be assumed a technological coefficient of power production equal to one, by which to sell one unit of peak load power is required to buy one unit of power (null losses). Let  $C_D$  be peak load power distribution cost of the firm that depends on the distributed peak load power  $Q$ .



Picture 1: Load Profiles

Picture 1 is a load graph, at an individual and aggregate level, where the x axis indicates time of day, the y axis indicate the day of the year (365 days in a year), and the z axis indicates electricity consumption or load. On the graph the day of maximum load of the system is shown, with two hypothetically customers *A* and *B*

<sup>3</sup> It will be understood that the peak load power correspond to the coincident power, the power measured at the date and hour of the annual maximum demand of the distribution system that also, by the assumption previously indicated, coincides with the hour of maximum purchase of power.

whose billed powers,  $q_A$  and  $q_B$ , correspond to each customer respective maximum demand.<sup>4</sup> At the distribution system peak load,  $Q$ , the powers  $q_A^c$  and  $q_B^c$  correspond to the contribution that each of the customers makes to the peak of the distribution system, and we are going to denote it as coincident power. We define the coincidence factor,  $f$ , for each of the consumption as:

$$f_A = \frac{q_A^c}{q_A} \quad (2)$$

$$f_B = \frac{q_B^c}{q_B}$$

The model is one where the DISCO sells power in three markets, power at a tariff 1, power at a tariff 2, and the access services, in quantities  $q_1$ ,  $q_2$  and  $q_3$ , respectively.<sup>5</sup> For simplicity we will assume that each customer consume only one of the three goods. This is consistent with the reality, since customers choose that tariff option that is more appropriate to their load profile, what also makes very difficult for them to change to another tariff option.<sup>6</sup>

Because individual loads have peaks at different periods, the distribution system cope with cost subadditivity, since the distribution system peak load is lower than the sum of the individual maximum loads. Thus, the distribution cost function capacity is related to the quantities of coincident power. The cost function of the DISCO is:

$$C(q_1^c, q_2^c, q_3^c) = C_D(q_1^c + q_2^c + q_3^c) + C_{PM}(q_1^c + q_2^c) \quad (3)$$

where

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<sup>4</sup> For bigger clarity of the illustration, it has been supposed that the individual maximum demands occur the same day of the maximum demand of the system, but it can be in any day.

<sup>5</sup> The supply of energy is assumed to be potentially competitive, open to third party sellers who contract the access services or network use with the DISCO.

<sup>6</sup> For example in Chile the typically residential tariff BT-1 is for a maximum load of 10 kW, where the typically industrial tariff BT-4.3 is not cost effective for residential customers given the high cost of the metering devices.

$$q_i^c = f_i q_i \quad i = 1, 2, 3. \quad (4)$$

$$Q = q_1^c + q_2^c + q_3^c = f_1 q_1 + f_2 q_2 + f_3 q_3 \quad (5)$$

$$Q_M = q_1^c + q_2^c = f_1 q_1 + f_2 q_2 \quad (6)$$

$Q$  represents the peak load of the distribution system, and  $Q_M$  peak load sold by the DISCO. The DISCO prices in the three markets (power tariff 1, power tariff 2 and access services) are  $p_1$ ,  $p_2$  and  $a$ , respectively. For these prices we set pricing formulas:

$$p_1 = \alpha_1 f_1 p_D + f_1 p_P$$

$$p_2 = \alpha_2 f_2 p_D + f_2 p_P \quad (7)$$

$$a = \alpha_3 f_3 p_D$$

where

$$p = p_D + p_P \quad (8)$$

$p_D$  and  $p_P$  are previously determined distribution and peak power prices, and  $\alpha_1$ ,  $\alpha_2$ , and  $\alpha_3$  are free variables that at the end allow us to change DISCO final prices. Our interest is to analyze price discrimination in distribution, it is for that reason that we use the factors  $\alpha_i$  with the corresponding price component  $p_D$ .<sup>7</sup>

In this way DISCO profits are:

$$\begin{aligned} \Pi_1 = & p_1 q_1(p_1) + p_2 q_2(p_2) + a q_3(p_3) \\ & - C_D(f_1 q_1(p_1) + f_2 q_2(p_2) + f_3 q_3(p_3)) \\ & - C_{PM}(f_1 q_1(p_1) + f_2 q_2(p_2)) \end{aligned} \quad (9)$$

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<sup>7</sup> Also is feasible to apply discriminatory factors to  $P_P$ , but in our particular case it can be demonstrated that it is of no value, and that in the case of the Physical Cap it implies a different set of factors (see Physical Cap).

On other side, the behavior of the competitive fringe that contract access service will be summarized in a broker company that sells peak load, who produces peak load  $q_3$  at a tariff 3, where for each unit sold the company should pay an access charge  $a$  to the DISCO. The peak load seller company has a peak load purchase cost  $C_{PE}$  defined as:

$$C_{PE}(f_3 q_3) = c_{PE} f_3 q_3 \quad (10)$$

Since the broker company offers his good in a competitive market, its price is equal to the marginal cost:

$$p_3 = a + c_{PE} f_3 \quad (11)$$

Thus the peak load seller company profits are:

$$\Pi_2 = p_3 q_3(p_3) - a q_3(p_3) - c_{PE} f_3 q_3(p_3) \quad (12)$$

It is supposed that the demand for each good only depends on its own price, thus the cross price elasticities are zero.

Let  $V(q_1, q_2, q_3)$  be the aggregated gross consumer welfare, then consumer's surplus is:

$$\Pi_C = V(q_1(p_1), q_2(p_2), q_3(p_3)) - p_1 q_1(p_1) - p_2 q_2(p_2) - p_3 q_3(p_3) \quad (13)$$

For a Utilitarian Social Planner the social welfare is given by the sum of consumers' plus producers' surplus:

$$\begin{aligned} \Pi_S = & V(q_1(p_1), q_2(p_2), q_3(p_3)) \\ & - C_D(f_1 q_1(p_1) + f_2 q_2(p_2) + f_3 q_3(p_3)) \\ & - C_{PM}(f_1 q_1(p_1) + f_2 q_2(p_2)) - C_{PE}(f_3 q_3(p_3)) \end{aligned} \quad (14)$$

The maximization of Utilitarian Social Planner objective function is subject to companies nonnegative profits constrains, where choice variables are power tariff 1, power tariff 2, and access charge, and where basic distribution price

$p_D$  and basic peak load power price  $p_P$  have been previously determined by some other mechanism.<sup>8</sup>

The regulator, in possession of global prices, basic distribution price  $p_D$  and basic peak load power price  $p_P$ , looks to maximize the social welfare through the differentiation of capacity prices for the different segments of the market. With these objectives, the prices and charges can be deviated from the costs allocation made when determining  $p_D$  and their effective coincidence factors ( $f_i$ ) through the application of factors  $\alpha_i \neq 1$ .

## 2.2 Alternative contract structure

The three alternative contract structures of resource allocation considered are: Ramsey solution or Second Best Social Optimum; DISCO freely chooses  $p_1, p_2$ , and  $a$  subject to a Physical Cap constrain on capacity sold; and DISCO freely chooses  $p_1, p_2$ , and  $a$  subject to a Price Cap constrain on total revenues.

### 2.2.1 Self-financing of the Firm: Social Optimum

Because there is a fixed cost to be recovered the Benevolent Social Planner chooses  $\alpha_i \geq 0 \quad i = 1, 2, 3$  to determine power tariff 1, power tariff 2, and access charge to maximize social welfare (14) subject to the constraint that DISCO profits are (9) larger or equal to zero, where in the optimization problem Lagrangean function  $\lambda$  is the shadow price of the DISCO budget constraint.

$$\begin{aligned}
 L = & V(q_1(p_1), q_2(p_2), q_3(p_3)) \\
 & - C_D(f_1q_1(p_1) + f_2q_2(p_2) + f_3q_3(p_3)) \\
 & - C_{PM}(f_1q_1(p_1) + f_2q_2(p_2)) - C_{PE}(f_3q_3(p_3)) \\
 & + \lambda(p_1q_1(p_1) + p_2q_2(p_2) + aq_3(p_3) \\
 & \quad - C_D(f_1q_1(p_1) + f_2q_2(p_2) + f_3q_3(p_3)) \\
 & \quad - C_{PM}(f_1q_1(p_1) + f_2q_2(p_2)))
 \end{aligned} \tag{15}$$

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<sup>8</sup> In the case of Chile,  $p_D$  is calculated through Yardstick Competition, while  $p_P$  is based on a projected marginal cost.

Solving first order conditions for  $\alpha_1$ ,  $\alpha_2$  and  $\alpha_3$ , that in turn define  $p_1(\alpha_1)$ ,  $p_2(\alpha_2)$  and  $p_3(\alpha_3)$ , according to the equations (7) and (11), it is obtained that:

$$p_1 - (C_D^Q + c_{PM})f_1 = \frac{\lambda}{1 + \lambda} \frac{p_1}{\eta_1} \quad (16)$$

$$p_2 - (C_D^Q + c_{PM})f_2 = \frac{\lambda}{1 + \lambda} \frac{p_2}{\eta_2} \quad (17)$$

$$p_3 - (C_D^Q + c_{PE})f_3 = \frac{\lambda}{1 + \lambda} \frac{p_3}{\eta_3} \quad (18)$$

where  $C_D^Q = \frac{\partial C_D}{\partial Q}$  and  $c_{PM} = \frac{\partial C_{PM}}{\partial Q_M}$ . From (18) and (11) we obtain the optimal access charge:

$$a = C_D^Q f_3 + \frac{\lambda}{1 + \lambda} \frac{p_3}{\eta_3} \quad (19)$$

As in Laffont and Tirole (1996), the obtained prices are Ramsey prices that exceed the marginal cost since exists fixed costs to be recovered, where the additional margin that is charge over the marginal cost of each good is inversely related to the price elasticity of each good as it is shown next:

$$\frac{[p_1 - (C_D^Q + c_{PM})f_1]/p_1}{[p_2 - (C_D^Q + c_{PM})f_2]/p_2} = \frac{\eta_2}{\eta_1} \quad (20)$$

$$\frac{[p_2 - (C_D^Q + c_{PM})f_2]/p_2}{[p_3 - (C_D^Q + c_{PE})f_3]/p_3} = \frac{\eta_3}{\eta_2} \quad (21)$$

$$\frac{[p_3 - (C_D^Q + c_{PE})f_3]/p_3}{[p_1 - (C_D^Q + c_{PM})f_1]/p_1} = \frac{\eta_1}{\eta_3} \quad (22)$$

### 2.2.2 Physical Cap: Firm Optimum

As was defined in (7), prices  $p_i$  and access charges can be biased from distribution price  $p_D$  and the effective coincidence factors ( $f_i$ ) through the application of factors  $\alpha_i \neq 1$ . DISCO revenues are  $p_1q_1 + p_2q_2 + aq_3$ , using (7) we obtain  $(\alpha_1f_1q_1 + \alpha_2f_2q_2 + \alpha_3f_3q_3)p_D + (f_1q_1 + f_2q_2)p_P$ , where  $\alpha_1f_1q_1 + \alpha_2f_2q_2 + \alpha_3f_3q_3 = Q$ . This last constraint is what we name as the DISCO Physical Cap:

$$\alpha_1f_1q_1 + \alpha_2f_2q_2 + \alpha_3f_3q_3 = f_1q_1 + f_2q_2 + f_3q_3 = Q \quad (23)$$

$$\alpha_i \geq 0 \quad i = 1, 2, 3$$

Subject to the Physical Cap (23), the DISCO will maximize profits (9) choosing  $\alpha_1$ ,  $\alpha_2$ , and  $\alpha_3$ , and with them  $p_1$ ,  $p_2$ , and  $a$ , according to equations (7) and (11).

The Lagrangean of the DISCO optimization problem is:

$$\begin{aligned} L = & p_1q_1(p_1) + p_2q_2(p_2) + aq_3(p_3) \\ & - C_D(f_1q_1(p_1) + f_2q_2(p_2) + f_3q_3(p_3)) \\ & - C_{PM}(f_1q_1(p_1) + f_2q_2(p_2)) \\ & + \lambda(\alpha_1f_1q_1(p_1) + \alpha_2f_2q_2(p_2) + \alpha_3f_3q_3(p_3) \\ & - f_1q_1(p_1) - f_2q_2(p_2) - f_3q_3(p_3)) \end{aligned} \quad (24)$$

where  $\lambda$  is the DISCO shadow price of the Physical Cap constraint. Solving first order conditions for  $\alpha_1$ ,  $\alpha_2$  and  $\alpha_3$  that in turn define  $p_1(\alpha_1)$ ,  $p_2(\alpha_2)$  and  $p_3(\alpha_3)$ , is obtained:

$$p_1 - (C_D^O + c_{PM})f_1 = \frac{p_1}{\eta_1} + \frac{\lambda}{1 + \lambda}(p - C_D^O - c_{PM})f_1 \quad (25)$$

$$p_2 - (C_D^O + c_{PM})f_2 = \frac{p_2}{\eta_2} + \frac{\lambda}{1 + \lambda}(p - C_D^O - c_{PM})f_2 \quad (26)$$

$$p_3 - (C_D^O + c_{PE})f_3 = \frac{p_3}{\eta_3} + \frac{\lambda}{1 + \lambda}(p_D - C_D^O)f_3 \quad (27)$$

With equation (11) we obtain the optimal access charge:

$$a = C_D^Q f_3 + \frac{p_3}{\eta_3} + \frac{\lambda}{1+\lambda} (p_D - C_D^Q) f_3 \quad (28)$$

Then to obtain the prices, is enough to solve the previous equations with the demand equations and restriction (23).

### 2.2.3 Price Cap: Firm Optimum

The regulator in the determination of the tariffs wants to incentive cost efficiency on the DISCO and to maximize social welfare. Thus, the regulator should maximize (14) to determine the DISCO Price Cap that will restrict his pricing policy. Laffont and Tirole (1996) proposed this mechanism, demonstrating that if the weights of the basket of prices considered to set the Price Cap are in proportion with the exactly carried out quantities, then Ramsey prices are induced.

The Price Cap can be expressed in a similar way to the Physical Cap multiplying each term by the preset price  $p_D$  and balancing it with the evaluation of peak power distribution. Contrary to the Physical Cap, under a Price Cap the quantities  $q_i$  are predetermined as  $\bar{q}_i$  for the DISCO. In this way, the Price Cap restriction can be expressed as a particular case of the Physical Cap, thus DISCO profits under a Price Cap should be at most as big as the ones obtained under the Physical Cap.

$$\alpha_1 p_D f_1 \bar{q}_1 + \alpha_2 p_D f_2 \bar{q}_2 + \alpha_3 p_D f_3 \bar{q}_3 = \bar{Q} p_D \quad (29)$$

It is possible to express this constraint in terms of final prices, adding to both sides of the equation the constant terms (independent of  $\alpha_i$ ) and then the valuation of peak power,  $\bar{Q}_M p_P$ :

$$\begin{aligned} \alpha_1 p_D f_1 \bar{q}_1 + p_P f_1 \bar{q}_1 + \alpha_2 p_D f_2 \bar{q}_2 + p_P f_2 \bar{q}_2 + \alpha_3 p_D f_3 \bar{q}_3 \\ = \bar{Q} p_D + p_P f_1 \bar{q}_1 + p_P f_2 \bar{q}_2 \\ p_1 \bar{q}_1 + p_2 \bar{q}_2 + p_3 \bar{q}_3 = \bar{Q} p_D + \bar{Q}_M p_P = \bar{P}C \end{aligned} \quad (30)$$

Subject to the Price Cap (30), the DISCO maximize profits (9) choosing final prices through the parameters  $\alpha_i \geq 0$ ,  $i = 1,2,3$ .

The Lagrangean of the DISCO optimization problem is:

$$\begin{aligned}
L = & p_1 q_1(p_1) + p_2 q_2(p_2) + a q_3(p_3) \\
& - C_D(f_1 q_1(p_1) + f_2 q_2(p_2) + f_3 q_3(p_3)) \\
& - C_{PM}(f_1 q_1(p_1) + f_2 q_2(p_2)) \\
& + \lambda(p_1 \bar{q}_1 + p_2 \bar{q}_2 + a \bar{q}_3 - \overline{PC})
\end{aligned} \tag{31}$$

where  $\lambda$  is the shadow price of the Price Cap constrain. Solving first order conditions for  $\alpha_1$ ,  $\alpha_2$  and  $\alpha_3$ , that in turn define  $p_1(\alpha_1)$ ,  $p_2(\alpha_2)$  and  $p_3(\alpha_3)$ , according to equations (7) and (11), we obtain:

$$p_1 - (C_D^0 + c_{PM})f_1 = (1 + \lambda) \frac{p_1}{\eta_1} \tag{32}$$

$$p_2 - (C_D^0 + c_{PM})f_2 = (1 + \lambda) \frac{p_2}{\eta_2} \tag{33}$$

$$p_3 - (C_D^0 + c_{PE})f_3 = (1 + \lambda) \frac{p_3}{\eta_3} \tag{34}$$

With (34) and equation (11) the optimal access charge is:

$$a = C_D^0 f_3 + (1 + \lambda) \frac{p_3}{\eta_3} \tag{35}$$

The solution has the same structure as the one obtained in the social optimum with Ramsey prices, what gives the same inverse relationship of margins and elasticities settled down in the equations (20), (21) and (22). To obtain final prices is enough to solve the previous equations with the demand equations and the constraint (30). In this way, a social optimum with Ramsey Prices and a firm optimum with a Price Cap set under the right weights give the same solution.

### III MODEL CALIBRATION

The model is calibrated based on a Chilean distribution company cost and demand data implicit in the tariff decree in force<sup>9</sup>. Basic data required is an estimate of the costs structure, a point of peak load demand and an estimate of the price elasticity of the respective demand for capacity.

For each of the three markets served by the DISCO we use a linear demand function

$$q_i(p_i) = a_i - b_i p_i \quad i = 1, 2, 3 \quad (36)$$

for which we need to pick  $a_i$  and  $b_i$  parameters,  $i = 1, 2, 3$ , from the point of the demand curve and using the following equation

$$\eta_{i,j,T} = -\frac{\partial q_i}{\partial p_i} \frac{p_{i,j,T}}{q_{i,j,T}} = -b_i \frac{p_{i,j,T}}{q_{i,j,T}} \quad (37)$$

#### 3.1 Data analysis to pick demand function parameters

For power at tariff 1 we are going to consider BT-1 tariff, for power at tariff 2 we are going to consider BT-3 PPP tariff, and since representative data for access demand do not exist, we will assimilate tariff BT-3 PP as if it is supplied by a third party.<sup>10</sup>

The DISCO informed that in the year 1999 2.500 GWh were billed in BT-1 tariff, typically residential, that considered 420 hours of use, they imply 862 MW of power (not peak), at an average price of \$ 11.25 per kW-month; in BT-3 PPP tariff were billed 100 MW of power at an average price of \$ 9.78 per kW-month; and

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<sup>9</sup> Decree N°300 of 1997 of the Economy Ministry.

<sup>10</sup> Tariff BT-1 is a residential tariff that only measures energy and is for consumers with a connected capacity below 10 kW or whose peak load is constrained to be below 10 kW. In the BT-3 tariff energy and peak load are measure, the PP option is for customers whose peak load is coincident with the peak load of the system, and the PPP option is for customers whose peak load is partially coincident with the peak load of the system.

in tariff BT-3 PP were billed 300 MW of power (not peak), at an average price of \$ 14.68 per kW-month.

To obtain demand elasticities for the three goods we use the following econometric model of demand:

$$q_{i,j,T} = bp_{i,j,T} + \beta I_{j,T} + \sum_{m=1}^{12} \gamma_m e_m + \sum_{n=1}^5 \delta_n r_n + E_{i,j,T} \quad (38)$$

where  $q_{i,j,T}$  is the quantity of units of the good in market  $i$  in the month  $j$  in the year  $T$ ;  $p_{i,j,T}$  the price for unit of the good in market  $i$  in the month  $j$  in the year  $T$ ;  $I_{j,T}$  is a monthly index of economic activity, IMACEC<sup>11</sup>, of the month  $j$  in the year  $T$ ;  $e_m$  a seasonal variable,  $e_m = 1$  if  $m = j$ ,  $e_m = 0$  if  $m \neq j$ ;  $r_n$  a dummy variable for electricity rationing,  $r_n = 1$  in the months that in 1999 Chilean economy suffer an energy shortage as a result of an extreme draw that affect most of the hydroelectric power plants, and  $r_n = 0$  for the rest of the months;  $E_{i,j,T}$  an error of the regression for the good in market  $i$  in the month  $j$  in the year  $T$ ; and  $b$ ,  $\beta$ ,  $\gamma_m$ ,  $\delta_n$  be the regression coefficients of the previously suitable variables.

Since there is no historical record on power bills, we will assume the same price elasticity for energy and power, assumption that is not far from the reality for the BT-1 tariff that is measured and billed on a linear energy-power charge (monomic price). For the case of the non-linear tariffs, BT-3 PPP and BT-3 PP, the monomic price is an approximation. It is reasonable to assume that the price elasticity obtained in this way is an approximation for peak load price elasticity.

For the good  $q_1$  in market 1 historical data from the main Chilean DISCO on physical billing of residential energy consumption was used, as also for the other markets goods  $q_2$  and  $q_3$  was used main Chilean DISCO historical data on commercial energy consumption corresponding to PPP and PP, respectively. The final tariffs were used, upgraded by CPI, where in the case of the tariffs BT-3 PPP and BT-3 PP, a load factor of 0,65 was used to determine a monomic price.

The coefficients  $\delta_n$  should take a negative value to represent the energy rationing suffered by the Chilean economy in November of 1998 and the period from March to June of 1999. For each of the variables we use data for the period January

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<sup>11</sup> IMACEC: Monthly Index of Economic Activity, calculated by the Central Bank of Chile.

of 1992 to December of 1999. In each point of the historical time series we assume that the demand curve intercepts a completely elastic supply curve, assumption that is consistent with the service obligation that the law imposes on DISCO, who are forced to supply all the demand at the corresponding regulated price. The fact of being able to identify the precise months when exist energy rationing together with large quantity of monthly data, allow as to use monthly regression, from where we will extrapolate annual parameters. The following Table gives as the regression results.

Table 1: Demand Regression Results

Variable		Coefficient			
Quantity			$q_1$	$q_2$	$q_3$
Price	$p$	$B$	-726	-789	-520
IMACEC	$I$	$\beta$	820	270	181
Season factor 1	$e_1$	$\lambda_1$	17.297	37.823	24.698
Season factor 2	$e_2$	$\lambda_2$	6.636	35.390	23.092
Season factor 3	$e_3$	$\lambda_3$	8.755	35.562	23.179
Season factor 4	$e_4$	$\lambda_4$	24.786	35.880	23.390
Season factor 5	$e_5$	$\lambda_5$	35.205	36.285	23.669
Season factor 6	$e_6$	$\lambda_6$	43.409	36.241	23.647
Season factor 7	$e_7$	$\lambda_7$	61.185	42.321	27.708
Season factor 8	$e_8$	$\lambda_8$	54.451	42.460	27.802
Season factor 9	$e_9$	$\lambda_9$	45.629	39.893	26.099
Season factor 10	$e_{10}$	$\lambda_{10}$	32.251	36.518	23.834
Season factor 11	$e_{11}$	$\lambda_{11}$	22.783	37.509	24.505
Season factor 12	$e_{12}$	$\lambda_{12}$	26.364	40.464	26.473
Rationing 1	$r_1$	$\delta_1$	-4.322	0	0
Rationing 2	$r_2$	$\delta_2$	0	0	0
Rationing 3	$r_3$	$\delta_3$	-5.160	-163	0
Rationing 4	$r_4$	$\delta_4$	-1.949	-519	-357
Rationing 5	$r_5$	$\delta_5$	-2.480	-3.208	-2.219
Mean Error	EM		5	2	1
Correlation	$R^2$		0,979	0,977	0,977

Variables of season factor were chosen fixed in the time, since it was observed that the difference among the consumption in the months of winter and in those of summer doesn't significantly change during the period of analysis. It was obtained that the models represent in a reasonable form the evolution of the demand, with  $R^2$  near to 0,98 and a Fisher test with a probability close to zero (less than 0,0005) that all the defined parameters are null. The t-student test is useful to determine the probability that each parameter is null, and therefore not explanatory in the regression, obtaining in most of the cases that each parameter is significant with 95% of trust, if the certainty probability is smaller at 0,05. In particular, the prices parameters, our focus of interest to determine price elasticities, satisfy the t test with a confidence interval larger than 95%. Also IMACEC parameters for the three markets and the seasonal parameters for markets 2 and 3, satisfy the t test with a confidence interval larger than 95%. In the case of the seasonal parameter for market 1, it fails to satisfy the t test with a confidence interval larger than 95%. In spite of this condition, we kept the seasonal parameters to maintain the integrity of the group and the homogeneity of the models.

With regard to the rationing parameters, none demonstrated to be explanatory of the series. This is founded in the fact that each one of these coefficients affects only one value of the regression, for the specific month where the variable is one, but we kept these parameters since their presence doesn't degrade the value of the other parameters, in particular those of the prices, to be consistent with the fact that the country was affected by a severe draw and a mandatory energy rationing that finally appear to have no effect on energy consumption.

Also we tested some alternative model specifications with other explanatory variables such as a tendency variable and temperature. We find that IMACEC captured the growth in consumption as well as in the number of consumers, thus the trend variable is redundant. The temperature variable, positively and highly correlated with the brightness of the day, was proven in substitution for the seasonal variables. In the case of the market 2 and 3, it was proven through the t test that it was not an explanatory variable; and in case of the market 1, where the seasonal parameters were not sufficiently explanatory, the temperature variable demonstrated bigger degree of significance, however, the significance of the price parameter diminished below 95% of trust, deteriorating the coefficient of interest.

Some rationing parameters were null, what indicates that rationing effect on those consumption months was not significant. Indeed, for the first two periods of rationing, November of 1998 and March of 1999, the effect of the rationing was smaller, since rationing measures were only taken during the last two weeks in

November and only the last days of March. Also the observed differences between different types of consumers has to do with the way how rationing took place, either for programmed disconnection, voltage decrease, or as agreements within DISCOs and big clients. The way how rationing measures was carried out and the capacity that the customers have to displace their consumptions over the day, finally determine their decrease in consumption. Even though some coefficients of the rationing variables were null or not significant, they stayed as group in the model regression to have a common framework for the regression of the three tariff types.

### 3.2 Consumer Surplus

From the consumer point of view, in the optimum he equates the price of a good with the marginal benefit that it reports to him, where the consumer solves:

$$\text{Max}_{\{q_1, q_2, q_3\}} V(q_1, q_2, q_3) - p_1 q_1 - p_2 q_2 - p_3 q_3 \quad (39)$$

where the first order condition is:

$$\frac{\partial V(q_1, q_2, q_3)}{\partial q_i} = p_i \quad i = 1, 2, 3 \quad (40)$$

If we assume that  $V(q_1, q_2, q_3)$  is linear in  $q_i$ , we have that this is another representation for the demand function of market  $i$ , and therefore it should be consistent with the demand function (36) previously defined. In this way, the consumer's utility function is similar to the sum of the integrated inverse demands functions for each market.

$$V(q_1, q_2, q_3) = \int_0^{q_1} p_1(q_1) dq_1 + \int_0^{q_2} p_2(q_2) dq_2 + \int_0^{q_3} p_3(q_3) dq_3 \quad (41)$$

replacing the inverse demand functions from (36) and integrating, it is obtained:

$$V(q_1, q_2, q_3) = \sum_{i=1}^3 \left( \frac{a_i}{b_i} q_i(p_i) - \frac{1}{b_i} q_i^2(p_i) \right) \quad (42)$$

Thus to measure consumer surplus we use (42) and subtract expenditures.

### 3.3 Costs Functions

Because the cost studies used to set distribution tariffs are not made public, to obtain cost parameters we use reverse engineering. For that we use tariff decree prices and economies of scale factors used to set tariffs to recover the parameters of the cost function. We will assume that DISCO has a cost function as:

$$C_D(Q) = F + c_D Q \quad (43)$$

This function is used by the National Energy Commission (CNE). The Distribution Value Added calculated in the tariff studies determines the average cost per unit of coincident power with the peak of the distribution system. However, when tariffs are set it is expected that electricity demand will grow, and to avoid DISCO excess profits over the four years that the tariff decree last, economies of scale factors are calculated to adjust tariffs on incoming years.

In the 1996 tariff setting process, the CNE determined for a typical low voltage distribution area served by an aerial network the following economies of scale factors:

Table 2: Economies of Scale Factors

Date	Factor
1 Jan 1997	0,9881
1 Jan 1998	0,9763
1 Jan 1999	0,9647
1 Jan 2000	0,9532

At the beginning of each period these factors multiply the original power price. Reproducing the CNE equation, the price per unit of power for the initial period 1996 can be obtained from (43) as:

$$\frac{C_D(Q_0)}{Q_0} = \frac{F}{Q_0} + c_D \quad (44)$$

where  $C_D(Q_0)$  is total distribution cost of producing a quantity  $Q_0$  in first year. In an equivalent manner we can define the cost per unit of power for the following period, where  $Q_1$  is a function of  $Q_0$  and the growth rate  $g_1$ :

$$\frac{C_D(Q_0(1+g_1))}{Q_0(1+g_1)} = \frac{F}{Q_0(1+g_1)} + c_D \quad (45)$$

The economy of scale factor between period 0 and 1 is obtained as the quotient between the average costs of each of the periods. Let  $f$  the fixed cost defined unitarily as  $f = \frac{F}{Q_0}$ , in this way, the economy of scale factor for the period 1  $FEE_1$  is given by:

$$FEE_1 = \frac{\frac{C_D(Q_0(1+g_1))}{Q_0(1+g_1)}}{\frac{C_D(Q_0)}{Q_0}} = \frac{\frac{f}{1+g_1} + c_D}{f + c_D}, \quad (46)$$

and let  $\xi = \frac{f}{f + c_D}$ . Then, with this normalization, the economy of scale factor equation for period 1 can rewrite as:

$$FEE_1 = \frac{\xi}{1+g_1} + (1-\xi) \quad (47)$$

By symmetry, economy of scale factor equations can be obtained for the rest of the periods with respect to the initial period:

$$\begin{aligned} FEE_2 &= \frac{\xi}{1+g_2} + (1-\xi) \\ FEE_3 &= \frac{\xi}{1+g_3} + (1-\xi) \\ FEE_4 &= \frac{\xi}{1+g_4} + (1-\xi) \end{aligned} \quad (48)$$

$FEE_i$  are known and they originate four equations in five variables  $g_1, g_2, g_3, g_4$  and  $\xi$ , so we need a fifth equation to find a solution set. The fifth equation will be given by what was the electricity demand growth expected by the CNE for the whole period, who expected a 7.5% average growth rate for the whole period in the Central Interconnected System, the largest electrical system in the country. From these we obtained growth rates and the fix component of the cost function  $\xi = 18\%$ . Upgrading this last figure, through the growths, to the 1999 cost structure, is obtained  $\xi_{1999} = 15\%$ . Finally, applying the effective rate to December of 1999, we calibrate cost function parameters  $F = 948$  [M\$/month] and  $c_D = 9.10$  [\$/kW-month].

To calibrate the DISCO purchase power costs we use peak power nodal price in Santiago. To determine this price, the power nodal prices of Alto Jahuel and Cerro Navia were used, determined by the October 1999 nodal prices decree, giving weights of 0.661 and 0.339 to each other and applying the corresponding sub transmission charges as is established in the same CNE decree. With these we obtained that  $c_{PM} = 5.22$  [\$/kW-month] in December of 1999.

To calibrate a competitive power purchase price we took the regulated effective nodal price of December 1999, minus 10% under the assumption that this free price has a similar pattern as the one observed between the regulated energy nodal price and the marginal cost of energy. In this way  $c_{PE} = 4.70$  [\$/kW-month]

The  $p_P$  value is the same as  $c_{PM}$ . For the preset price  $p_D$  it was considered the low voltage distribution cost (CDBT) effective in the tariff decree. Since many simplifications have been made as excluding value added taxes and electricity losses, is necessary to equilibrate supply and demand, balancing regulated revenues and costs, where the effective CDBT was adjusted to December of 1999 in +0,9%, so that DISCO profits are null. Thus  $p_D = 10.80$  [\$/kW-month] and  $p_P = 16.02$  [\$/kW-month]. For the current regulatory scheme used in Chile a parameter  $\alpha_i = 0.85$   $i = 1, 2, 3$ , gives the cost allocation of the variable part of the distribution cost (marginal cost), while  $\alpha_i = 1.00$ ,  $i = 1, 2, 3$ , equally assigns the variable and the common costs of distribution within the markets.

For the coincidence factors and/or hours of use we used the ones settled down in the tariff decree, where  $f_1 = 0,58$ ,  $f_2 = 0,50$  and  $f_3 = 0,75$ .

## IV EXPERIMENT RESULTS

In 4.1 we look at simulation results for Ramsey Prices, Physical Cap and Price Cap using as benchmark basic CNE cost allocation,  $\alpha_i = 1, i=1,2,3$ . Next in 4.2 we look at three additional experiments: when the regulator doesn't know consumer's demand; when the DISCO is not allowed cross subsidy between the markets,  $\alpha_i \geq 0.85, i=1,2,3$ ; and when access charges are restricted to be set at the level of CNE current cost allocation,  $\alpha_3 = 1$ .

### 4.1 Base Cost Allocation, Ramsey Prices, Physical Cap and Price Cap

With the last section parameters we carry three experiments to see the effects on resource allocation having as benchmark today situation where tariff charges are set by the distribution of the costs within the different tariffs. The experiments are respect to:

- Ramsey Prices, where  $\alpha_i (i=1,2,3)$  is chosen to distribute the fix cost.
- DISCO profit maximization subject to a Physical Cap.
- DISCO profit maximization subject to a Price Cap, where Price Cap price weights are set equal to the social optimum weights obtained in the Ramsey solution.

Table 3 present experiment results. In the first column we have the base case where the prices are determined by a cost allocation according to CNE pricing policy. When CNE determines the Distribution Value Added it determines an average respect to peak power. In this way, from the cost function (43) can be obtained:

$$p_d = \frac{C_d(Q)}{Q} = \frac{F}{Q} + c_d \quad (49)$$

In this case  $\alpha_i = 1 (i=1,2,3)$  on equations (7).

In the second column of the table 3, the Ramsey solution is presented, where  $\alpha_i$  takes values different to one, being  $\alpha_i$  values inversely related to the price elasticity of the market in question.

Under the Ramsey Pricing the social surplus (consumers' plus producers' surplus) increases respect to CNE pricing policy, although not significantly.

<b>Var.</b>	<b>Cost Allocation st: <math>\Pi_1=0</math></b>	<b>Ramsey st: <math>\Pi_1=0</math></b>	<b>Max <math>\Pi_1</math> st: Physical Cap</b>	<b>Max <math>\Pi_1</math> st: Price Cap</b>
$\alpha_1$	1.000	1.028	1.453	1.028
$\alpha_2$	1.000	0.968	0.000	0.968
$\alpha_3$	1.000	0.877	0.000	0.877
$p_1$ \$/kWmonth	9.2	9.4	12.0	9.4
$p_2$ \$/kWmonth	8.0	7.8	2.6	7.8
$p_3$ \$/kWmonth	11.6	10.6	3.5	10.6
$a$ \$/kWmonth	8.1	7.1	0.0	7.1
$q_1$ kW	861,989	861,989	861,988	861,989
$q_2$ kW	299,952	299,953	299,967	299,953
$q_3$ kW	99,688	99,700	99,784	99,700
$Q$ kW	720,681	720,690	720,759	720,690
$Q_M$ kW	645,915	645,915	645,921	645,915
$\eta_1$	0.0000057	0.0000058	0.0000075	0.0000058
$\eta_2$	0.0000715	0.0000699	0.0000233	0.0000699
$\eta_3$	0.0013854	0.0012663	0.0004194	0.0012663
$\Delta \Pi_1$ \$/month	0.0	0.0	103.3	0.0
$\Delta \Pi_2$ \$/month	0.0	0.0	0.0	0.0
$\Delta$ Consumer Surplus \$/month	0.0	6.0	-431.1	6.0
$\Delta$ Social Surplus \$/month	0.0	6.0	-327.9	6.0

In the third column of table 3 is the solution of the firm optimum subject to a Physical Cap. Under this restriction the firm can affect the coincidence factors through  $\alpha_i$ , but is restricted to maintain a global balance of peak power. In the optimum of this model  $\alpha_1$  that set prices for the most inelastic demand exceeds one, while  $\alpha_2$  and  $\alpha_3$  are made zero. Under a Physical Cap in global terms the DISCO has incentives to increase the number of peak power units sold that pass through the system. Under these conditions, the DISCO polarizes its prices, moving up the price of the most inelastic market and lowering the price of the rest down to what is

feasible. In this case DISCO profits increase by \$ 103.3 with regard to the base case, but social welfare diminishes in \$ 327.9 also respect to the base case in \$ 333.9 respect to Ramsey solution. Physical Cap solution implies that consumers in markets 2 and 3 are cross subsidized by consumers in market 1.

Finally, in the fourth column of table 3, gives the result for the firm optimum subject to a Price Cap constraint. The parameters of the Price Cap are calibrated knowing the social optimum Ramsey result, where the weights of the Price Cap are set with the Ramsey solution. Also, the polynomial obtained in this case was evaluated, with the resulting prices in the social optimum, to determine the Price Cap. Under the conditions before described, the solution of the firm equals the Ramsey solution.

#### **4.2 Asymmetric information, Bounded Discrimination, and Constrained Access Charge**

In what follow we consider a case where the regulator doesn't know consumer's demand, a case when DISCO is not allowed to discriminate prices as much as it wants, and a case where access charges should be set at the level of basic cost allocations.

##### **Asymmetric Information**

If the regulator doesn't know consumers' demand, he cannot know ahead of time the quantities and the prices of the Ramsey Price solution, in the way of determining the weights of prices and the Price Cap. Conversely, if the regulator knew consumers' demand and cost functions, then it would not be necessary to establish a Price Cap regulation mechanism, since from the beginning the regulator can set directly optimal prices. The application of the Price Cap methodology is justified in light of information asymmetries between the firm and the regulator, where the objective is to have the firm to use his better knowledge to determine the prices in a socially optimal way.

The regulator, without knowledge respect to the quantities and the prices that leads to the social optimum, should determine price weights and the Price Cap for the regulated company. A slanted regulator could be tended to determine the weighting favoring some type of customers and making worst others. Confronting a lack of information, a simple solution could be to use the current quantities to set the weights that in turn determine the Price Cap as long as the price of peak power was already appropriately set in a previous stage by the regulator.

While here we assume information asymmetries respect to demand, information asymmetries can also be respect to the cost function or its parameters, as the peak load coincidence factors. Under this situation the base case has the power of being a case where the prices indeed reflect the costs involved, so if costs are deviated from social optimum setting, cross subsidies arise from the more elastic to the more inelastic markets, and social welfare decrease. An example with these two cases is presented in Table 4. Where the first column present a Price Cap situation where price weights have been set according to the original quantities, and the second column represents a case where costs are assigned with a bias toward the consumers with a more elastic demand.

<b>Var.</b>	<b>Max <math>\Pi_1</math> st: Price Cap (weights based on original quantities)</b>	<b>Cost Allocation Deviation (favoring less elastic demand)</b>
$\alpha_1$	1.025	0.955
$\alpha_2$	0.946	1.100
$\alpha_3$	0.939	1.100
$p_1$ \$/kWmonth	9.4	8.9
$p_2$ \$/kWmonth	7.7	8.6
$p_3$ \$/kWmonth	11.1	12.4
$a$ \$/kWmonth	7.6	8.9
$q_1$ kW	861,989	861,989
$q_2$ kW	299,953	299,951
$q_3$ kW	99,694	99,678
$Q$ kW	720,686	720,673
$Q_M$ kW	645,915	645,914
$\eta_1$	0.0000058	0.0000055
$\eta_2$	0.0000689	0.0000763
$\eta_3$	0.0013269	0.0014821
$\Delta \Pi_1$ \$/month	3.1	-10.3
$\Delta \Pi_2$ \$/month	0.0	0.0
$\Delta$ Consumer Surplus \$/month	1.5	-4.3
$\Delta$ Social Surplus \$/month	4.6	-14.6

The results of the simulation show that when price weights in the Price Cap are defined as the quantities of the base case or current situation, social welfare is lower with regard to the Ramsey case or Price Cap with the ideal weights, but in anyway it represents an improvement of \$ 4.6 with regard to the base case situation with current cost allocation. Next, when cost allocation is biased in the wrong direction social welfare decreases in \$ 14.6 with regard to the base case situation.

### **Bounded Discrimination**

As was observed in the case with a Physical Cap, the DISCO uses price discrimination up to the extreme where it covers all its costs through the price charged in the more inelastic market, being totally subsidized the other two markets. It happens that when the more inelastic market is network access, then DISCO pricing policy also has a predatory effect on the others who need access services to provide a complete service to final users; situation that can emerge under Price Cap regulation.

A way to diminish predatory behavior, is setting a price floor and a price ceiling, as Baumol and Willig has suggested the price floor can be set as the marginal cost and the price ceiling as the stand-alone cost. Here we do a Physical Cap experiment setting a price floor where prices cannot be smaller than the marginal cost. Since the Physical Cap restriction assures for DISCO as a whole at most the average regulated price, setting the price floor as the marginal cost, automatically sets the stand alone cost as the ceiling price when services are priced according to marginal cost since the other services should recover the fixed costs. Also we run a Price Cap experiment setting price floors and ceilings but turned that for the Price Cap these constraints were not binding, since already in the unrestricted optimum the fixed cost is distributed within the three services. The results of the two experiments are given in Table 5.

<b>Table 5: Bounded Discrimination Results (Price floor and ceiling)</b>		
<b>Var.</b>	<b>Max <math>\Pi_1</math> st: Physical Cap <math>\alpha_i \geq 0.85</math></b>	<b>Max <math>\Pi_1</math> st: Price Cap <math>\alpha_i \geq 0.85</math></b>
$\alpha_1$	1.068	1.028
$\alpha_2$	0.850	0.968
$\alpha_3$	0.850	0.877
$p_1$ \$/kWmonth	9.6	9.4
$p_2$ \$/kWmonth	7.2	7.8
$p_3$ \$/kWmonth	10.4	10.6
$a$ \$/kWmonth	6.9	7.1
$q_1$ kW	861,989	861,989
$q_2$ kW	299,955	299,953
$q_3$ kW	99,702	99,700
$Q$ kW	720,693	720,690
$Q_M$ kW	645,916	645,915
$\eta_1$	0.0000060	0.0000058
$\eta_2$	0.0000643	0.0000699
$\eta_3$	0.0012404	0.0012663
$\Delta \Pi_1$ \$/month	15.5	0.0
$\Delta \Pi_2$ \$/month	0.0	0.0
$\Delta$ Consumer Surplus \$/month	-9.7	6.0
$\Delta$ Social Surplus \$/month	5.8	6.0

The factors  $\alpha_i$  has as a floor a value of 0,85, equivalent to the variable part of the distribution cost, as it was determined in the calibration of the model. As it was pointed out, the results of the firm optimum with a Price Cap and price floor didn't change, since the new constraint is not active. On the other hand, in the case of the firm subject to the Physical Cap, the results improve ostensibly from a social point of view. The price balance is achieved with market 1 priced up to its stand alone cost and market 2 and access priced at their marginal costs. With regard to the base case, this solution implies an increase in social welfare of \$ 5.8, only slightly inferior to the gain obtained under Price Cap social optimum of \$ 6.0. The increase of the social welfare obtained thanks to the demarcation of prices, of \$ 5.8 is compared positively and significantly with the unrestricted Physical Cap case that gave a welfare loss of \$ 327.9.

The bounded Physical Cap has an additional advantage, if it is considered that in practice the regulator doesn't have perfect information to determine a priori discriminatory prices that show the way to the social optimum, thus, neither it can determine the optimal weights of the Price Cap polynomial. In this case, the best result that can be obtained with a Price Cap is the one previously obtained under information asymmetries with a welfare increase of \$ 4.6. The Physical Cap doesn't have the information requirements that the Price Cap has, because the information asymmetries have not affected the result that we already obtained.

### **Constrained Access Charge**

Another way to avoid some possible predatory practice in the access charge, is eliminating price discrimination of access charges by setting its price equal to the variable cost. In table 6 are shown the results of the firm optimum under Physical Cap and Price Cap, but setting the factor  $\alpha_3 = 1$ .

Under the constrain  $\alpha_3 = 1$ , in the case of the Price Cap the gain in social welfare decreases notably with regard to base case, while in the case of the Physical Cap the social loss decreases, compared to the base case. The structure of the solution is similar to the original one, in the variable parameters; the distribution price is made zero for the more elastic market, and the more inelastic markets recover the remainder of the costs not covered by the access charge, fixed at mean cost, since  $\alpha_3 = 1$ .

<b>Table 6: Non Discriminatory Access Charge Results</b>		
<b>Var.</b>	<b>Max <math>\Pi_1</math> st: Physical Cap <math>\alpha_3 = 1.00</math></b>	<b>Max <math>\Pi_1</math> st: Price Cap <math>\alpha_3 = 1.00</math></b>
$\alpha_1$	1.302	1.033
$\alpha_2$	0.000	0.891
$\alpha_3$	1.000	1.000
$p_1$ \$/kWmonth	11.1	9.4
$p_2$ \$/kWmonth	2.6	7.4
$p_3$ \$/kWmonth	11.6	11.6
$a$ \$/kWmonth	8.1	8.1
$q_1$ kW	861,988	861,989
$q_2$ kW	299,967	299,954
$q_3$ kW	99,688	99,688
$Q$ kW	720,688	720,682
$Q_M$ kW	645,922	645,916
$\eta_1$	0.0000069	0.0000058
$\eta_2$	0.0000233	0.0000662
$\eta_3$	0.0013854	0.0013854
$\Delta \Pi_1$ \$/month	8.7	0.0
$\Delta \Pi_2$ \$/month	0.0	0.0
$\Delta$ Consumer Surplus \$/month	-40.0	0.5
$\Delta$ Social Surplus \$/month	-31.2	0.5

## V CONCLUSIONS

The electric sector in the world as well as in Chile, more than technological have experienced deep structural and institutional changes. An important effort is made to improve the existent regulation, finding the activities that are potentially competitive and promoting the opening of the markets.

In the beginning of the restructuring process the electric sector was disintegrated in generation, transmission and distribution. However, today it is also identified the commercialization activity as another independent and potentially competitive activity. To enhance the commercialization activity, is recognized that a key ingredient is the open access into the transmission and distribution networks with an access charge pricing policy that should not block the entry of the energy brokers.

Diverse methodologies have been developed to regulate network industries, as well as particular mechanisms for the regulation of the access service. The biggest advances are appreciated in the field of the local telephony. Although it is a network industry, it presents some differences with the electric case, as the by-directionality of the flows for example, and consequently the reciprocity effect that exists among the agents in a telecommunications network that doesn't happen in the electric case. Another example is on information technology, where in the telephony industry is easier to measure the use of the infrastructure by each agent than in the electric industry.

Here we intend a regulatory model to set tariffs and access charges in distribution, designed specifically for the electric industry that takes advantages of the practical characteristics of it. The structure used is able to accommodate different existent regulatory mechanisms. We find that the discrimination of final prices or of access charge lead to higher social welfare compared with a symmetric cost allocation within the different markets.

The yardstick competition methodology that at the moment is applied in Chile, to determine the prices of each one of the markets in distribution, is effective to incentive cost efficiency. However, to determine the prices for each market requires the allocation of a common cost to all the markets what is made based on a fully distributed cost criteria that is not necessarily efficient from an economic point of view. Also, with the information with which the regulator counts to distribute the costs, that is usually inferior to the one that possesses the regulated firm, in general is not possible to carry out a perfect cost allocation. The social optimum is achieved setting Ramsey prices, considering cost and demand functions data, where is socially efficient to increase proportionally more the prices of those markets with more inelastic demands than those markets with more elastic demands. However, to determine Ramsey prices implies a bigger requirement of information than in a simple costs allocation situation, since the regulator would also require knowing the price elasticity of demand for each market.

Taking advantage of the information with which it counts the regulated firm, we look at a model where is the own firm who defines the prices subject to a Price Cap constraint. It was confirmed that when the prices weights used to set the Price Cap are appropriately chosen, the optimal solution of the firm converges to the socially optimal solution, being determined by Ramsey prices. However, to determine those precise weights, it also required a large degree of information, and it implies knowing the demand functions to foresee the socially optimal quantities and to fix them as weights.

Finally, an original restriction, denominated Physical Cap is designed, delimiting the discrimination of prices to a maximum of the stand alone cost and a minimum of the marginal cost. It is demonstrated that with this model, social welfare increases, when compared with the direct costs allocation situation, although it is not optimal, and moreover it also increases if it is compared with a case where costs allocation are deviated from real costs due to the asymmetries of information among the regulator and the regulated firm.

The designed model, yardstick competition with enclosed Physical Cap, adapts to the effective regulatory structure in Chile, since it doesn't need to change the form how Distribution Value Added is calculated, defined in the law, and it only changes the tariff formulas that at the moment are under the responsibility of the National Energy Commission. A degree of freedom is granted to the DISCOS to define its tariffs and access charges, subject to a restriction that is technically easy of measuring, as it is in the balance of power. In this way, the regulator requires smaller amount of information, usually very difficult to obtain, while on the other side the DISCO uses the best information that has to move closer to the socially optimal prices. Additionally, was evaluated the effect of impeding access charge price discrimination, being concluded that this carries to a social loss. At the end, the use of any of the analyzed models depend on the available information and the degree of discrimination that it is allowed.

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