PEAK LOAD PRICING APPLIED TO DEVERTICALIZED DISTRIBUTION NETWORK USAGE TARIFFS

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ABSTRACT

This paper deals with the application of the classical peak load pricing theory to deverticalized distribution companies (Discos). Since power distribution has become an economic activity related to power transportation between generators and customers, a new economic cost model for this activity must arise, mainly considering capacity over energy costs.

In this scenario, the usual peak load pricing problem will face the classical shifting peak case, due to the large difference found between long and short term marginal capacity costs.

Moreover, algebraic solutions can be very difficult to obtain due to the lackness of reliable short run price elasticities estimations.

This paper proposes a model based on a simple and efficient mechanism of 'wait-and-see', i.e., by measuring and controlling aggregated demand on both peak and off-peak periods until demands are relatively equal and stable.

INTRODUCTION

The classical peak load pricing theory, intensively discussed since the early works of [1] and [2], has been theoretically applied mostly to verticalized Discos, in which energy consumption used to be considered as a part of the companies' short term operational costs.

However, in recent decades, as it the case in Brazil, electricity distribution has become a deverticalized and regulated economic activity linked with electric power transportation.

In such a context, Discos' main product has become no longer energy, but power capacity available to customers and generators connected to the network. This power availability must be offered, however, under regulated power quality conditions, otherwise generators will not be able to deliver energy to costumers.

In this new picture, energy consumption, at least in some countries, has no longer been considered a manageable and direct cost input for Discos, requiring then a new approach for the usual peak and off-peak usage tariffs problem.

Since prices usually differ in peak and off-peak periods due to the system congestion during peak periods, economic theory has shown that differences in prices must follow differences on long and short run marginal costs, as well as the costumers' demand response.

Considering that energy is no longer a cost driver for Discos, differences in marginal costs between periods are enormous, requiring the determination of shadow prices on capacity for both peak and off-peak periods [3].

Under these circumstances, not only a new theoretical cost model for deverticalized Discos is required, but also a more realistic approach for the determination of efficient peak and off peak prices.

ECONOMIC COST MODEL

Empirical studies can be used for the determination of the long term economic cost model of an industry. Combining statistical analysis and the "survival argument" [4] [5], a cross-sectional econometric model was designed for the estimation of the long term cost curves for the power distribution activity in Brazil, using data from 56 (out of 64) Brazilian Discos.

A simplified hypothesis set that the intrinsic economic model of the long term cost curve had a linear shape for the power distribution activity, as presented a long time ago by [6] and [7]. It was also considered that the main cost driver is the Disco's aggregated peak demand. This simplified hypothesis was econometrically validated, as will be further shown.

It might be appropriate to point out that the Brazilian regulatory framework has placed the Brazilian Discos on a price cap regulatory scheme, complemented by additional yardstick competition mechanisms, such as the efficient operational costs determination (see [8] for a better understanding of the Brazilian electricity reform).

Hence, the actual composition of the manageable costs, determined by the Brazilian Regulatory Agency, ANEEL, can be seen in Table 1.

Table 1 – Composition of Discos' manageable costs

Administrative and operational costs
Human resources (administrative/operations/maintenance)
Infrastructure (buildings, furniture and computer systems)
Materials and services
Transportation, overhead and others
Capital costs
Depreciation
Return on assets

Based on regulatory data concerning administrative, operational and capital costs from 56 Brazilian Discos, regarding the second periodic regulatory reviews conducted by the Brazilian Regulatory Agency, a cross sectional regression model was tested relating yearly total costs and maximum aggregated power delivered at the peak periods.

A series of statistical regressions suggest, as foreseen by [6] and [7], a linear adjustment with high coefficients of determination along with strong statistical significance of the angular variable coefficient. Results from one estimation considering all 56 distribution companies can be seen in Figure 1 and Table 2.

Figure 1 – Least square linear regression for 56 Brazilian Discos

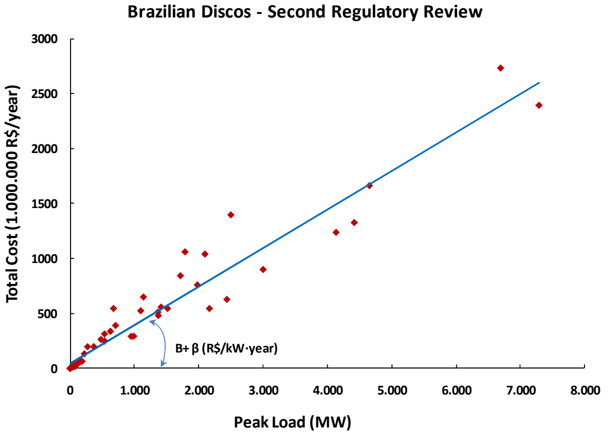


Table 2 shows that the linear coefficient estimation is statistically insignificant in the 95% significance level, which means that the linear coefficient is not statistically different from zero. This result is in absolute agreement with any long run cost curve, since all costs, including capital costs, are variable in the long term [4].

Table 2 – Regression results

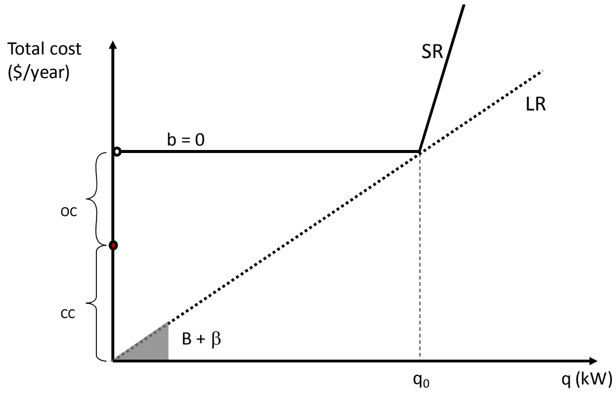
	Estimation	t-Statistc
Linear coeficient	43576816,00	1,84
Angular coeficient	350,24	28,69
Adjusted R2	0,937	

Due to heterogeneity among concession areas in Brazil, another series of estimations were carried out through the classification of Discos according to some defined attributes, such as concession area, average costs and sizes. All results corroborate the linear model obtained from the general estimation seen in Figure 1.

Therefore, since there are no costs related to energy consumption, a possible theoretical model can be proposed for the long and the short terms, as shown in Figure 2.

As can be seen, the proposed short run cost curve is considered to comprise, for demands less than q_0, a null short run marginal cost. At the same time, it is possible to note that when demand reaches q_0 (maximum capacity), it will be necessary to expand the system, increasing total capital and operational costs in proportion to the new assets incorporated to the distribution network.

Figure 2 – Proposed economic cost model for Brazilian Discos



To better understand the economic cost model proposed in Figure 2, it is important to note that Discos' capacity is considered to be efficiently equal to the maximum met power demand, q_0.

Since demand is cyclic, mostly in a daily basis, both peak and off-peak demands are met by the same physical network, which implies no significant marginal costs for meeting an addition MW during the off-peak period.

Equations (1) and (2) describe, respectively, the proposed short (TC_{SR}) and long (TC_{LR}) run cost curves.

$$TC_{SR}(D_{max}, q_0) \begin{Bmatrix} = CC \text{ if } D_{max} = 0 \\ = CC + OC \text{ if } q_o > D_{max} > 0 \\ >> (B+\beta) \cdot q_0 \text{ if } D_{max} \geq q_0 \end{Bmatrix} \quad (1)$$

$$TC_{LR}(q_0) = (B + \beta) \cdot q_o \quad (2)$$

Where:

CC: Capital costs.

OP: Operational costs, including administrative costs.

b: Short run marginal operational cost.

B: Long run marginal operational cost.

β: Long run marginal expansion cost.

q_0: Maximum capacity.

It is interesting to observe that, in spite of the constant long term marginal costs ($B + \beta$), the proposed economic model will, in the short term, still hold the natural monopoly market structure, given that average costs are likely to be much greater than the short term marginal costs.

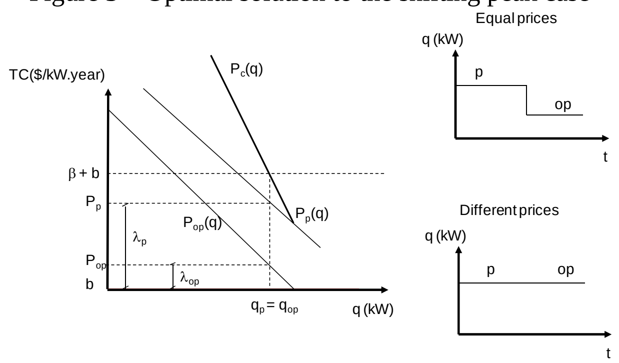
PEAK LOAD PRICING

The peak load pricing theory, initially presented by [1] and [2], and since then by dozens of authors, brought light to the economic design of prices in rigid capacity markets with cyclical demand.

It is common sense, though, that electricity prices should

be higher during peak hours, since distribution networks have fixed capacity, at least in the short run.
Considering that price-elasticities are zero, the most efficient pricing scheme should be the application of long and short run marginal costs to peak and off-peak periods, respectively.
As the case might be, non zero elasticities will act reducing demand on peak hours and increasing demand on off-peak hours, leading eventually to what is known as the shifting peak case [2].
In your model, since short run marginal costs are likely to be zero, and certainly price-elasticities are considerable, the only possible situation that rises is the classical shifting peak case.
References [9], [2] and [3] have shown, through different approaches, that the optimal solution for the shifting peak case is the application of different prices for the peak and off-peak periods in such a way that peak and off-peak demands result equal and stable.
Figure 3 shows a graphical solution, as initially proposed by [2], in which a fictional 'demand for capacity' curve, Pc, is used to determine peak and off-peak prices (P_p and P_{op}).

Figure 3 – Optimal solution to the shifting peak case



In Figure 3, λ_p and λ_{op} represent the shadow prices on capacity for the peak and off-peak periods, respectively. Disregarding cross-price elasticities, [3] shows that the shifting peak case problem can be solved through the optimization of the social welfare. For this, demand functions for the peak (p) and off-peak (op) periods are defined as $q_p(p_p)$ and $q_{op}(p_{op})$, with $q_p(p) > q_{op}(p)$ for any given price p.
Hence, the maximum social welfare, L^*, considering the proposed economic model, can be analogously given by Equation (3).

$$L^* = S(q_{\text{p}}) + S(q_{\text{op}}) - (B+\beta)\cdot q_0 - b(q_{\text{p}} + q_{\text{op}}) + \lambda_{\text{p}}(q_0 - q_{\text{p}}) + \lambda_{\text{op}}(q_0 - q_{\text{op}}) \quad (3)$$

Where:

q_p: Demand in the peak period.
q_{op}: Demand in the off-peak period.
q_0: Maximum capacity.
$\mathrm{S}(\mathrm{q_p})$: Customer surplus in the peak period.
$\mathrm{S}(\mathrm{q_{op}})$: Customer surplus in the off-peak period.
λ_p: Shadow price on capacity for the peak period.
λ_{op}: Shadow price on capacity for the off-peak period.

The first order conditions, remembering that $\frac{\partial s_i}{\partial q_i} = p_i$, are given by the set of equations in (4).

$$\begin{aligned} p_p - b - \lambda_p &= 0 \\ p_{op} - b - \lambda_{op} &= 0 \\ \lambda_p + \lambda_{op} - (\beta + B) &= 0 \end{aligned} \quad (4)$$

With complementary slackness conditions given by (5).

$$\begin{aligned} \lambda_p \cdot (q_0 - q_{op}) &= 0 \\ \lambda_2 \cdot (q_0 - q_2) &= 0 \end{aligned} \quad (5)$$

The solution for the two given systems of equations can be seen in (6). It is interesting to note that the maximum efficiency is given when both demands are the same.

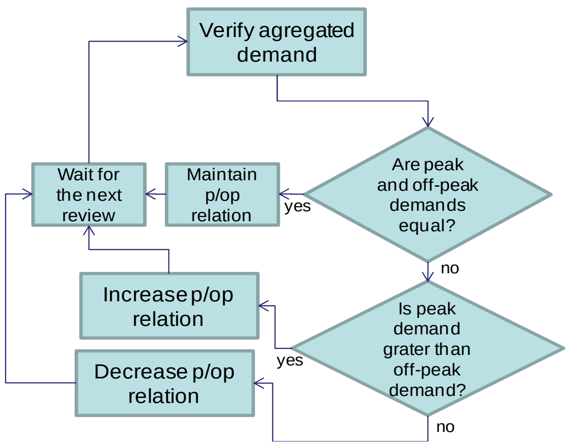
$$\begin{aligned} p_p &= \lambda_p \\ p_{op} &= \lambda_{op} \\ \lambda_p + \lambda_{op} &= \beta + B \\ q_p &= q_{op} \end{aligned} \quad (6)$$

THE PROPOSED PRACTICAL APPROACH

As expected, efficient peak and off-peak prices should be equal to shadow prices on capacity for each period, given null short run operational costs. However, the presented solution depends essentially on peak and off-peak demand curves, and consequently on price elasticities of demand.
Markets are expected to react to adjustments in time-of-use prices in the short run. In Brazil, for instance, price structures are allowed to change in an average time period of four years.
Usually, studies intended to quantify price-elasticities are accomplished from long term time series, generally using econometric models that explain demand behaviour not only from prices, but also from income and electric equipment prices [10].
However, price and cross-price elasticities, in the short term, are still very difficult to obtain, making it necessary for Discos and Regulators to follow a more empirical and straightforward approach.
Foremost, it is necessary to point-out that the main objective of time-of-use prices is to balance large differences in aggregated peak and off-peak demands measured in systems, sub-systems or regions of interest.
Since the choice of the target systems, sub-systems or regions of interest is set, it is easy to verify the aggregated demands on different periods and decide

whether it is necessary or not to readjust the relation between peak and off-peak prices. A very simple flowchart of a proposed 'wait-and-see' approach can be seen in Figure 4.

Figure 4 – Simple 'wait-and-see' flowchart



Given that electricity markets are divided by voltage levels, it might be interesting to readjust prices relation (peak/off peak = p/of) separately, observing, through typical load profiles, which markets have been responding more efficiently to the previous or current price signals.

It is common sense, as well, that low voltage customers are less elastic than high voltage costumers, what makes it more economically efficient, according to the Ramsey rule [11], to tighten prices relation a bit more on low voltage levels than on high voltage levels.

Finally, it is necessary to evaluate that price stability is something valuable in any regulatory regime. Therefore, any chances in prices relations must be done in a precautious manner, mainly through small and controlled changes considering the regulatory lag.

CONCLUSIONS

This paper presented a new theoretical cost model for deverticalized Discos, considering economic cost functions for the short and long terms. At the same time, econometric estimations have supported the proposed linear model, which provides constant returns to scale cost structure for the power distribution activity in Brazil.

On the other hand, in spite of the constant long term marginal costs, the model will still hold the natural monopoly market structure in the short run, since average costs are likely to be much greater than short term marginal costs.

That happened mainly because energy has no longer been considered a cost driver for power distribution companies, whose main product has become power availability to costumers and generators.

In this situation, the peak load pricing problem faces the classical shifting peak case, in which off-peak demand will be greater than peak demand if prices follow this huge difference between marginal costs.

The classical solution has shown that, in such cases, peak and off-peak prices should be equated to shadow prices on capacity, depending mostly on demand functions.

Nevertheless, short term price-elasticities of power consumption, and even cross-price-elasticities between periods, are still very difficult to obtain, and also very uncertain.

Still a difficult problem at first glance, one simple and reasoned solution came from a simple and efficient regulatory mechanism of 'wait-and-see'. I.e., by measuring and controlling demand responses ex-post on both peak and off-peak periods, it is possible to readjust, ex-ante, a more efficient relative price signal for the next regulatory lag until both peak and off peak demands are equal and stable.

REFERENCES

[1] M. Boiteux, 1960, "Peak-Load Pricing". *The Journal of Business*. Vol. 33, 157-179.

[2] P. O. Steiner, 1957, "Peak Loads and Efficient Pricing". *The Quarterly Journal of Economics*. Vol. 71, 585-610.

[3] M. Lootty; M. Szapiro, 2002, *Economias de Escala e Escopo*. [book auth.] D. Kupfer and L. Hasenclever. *Economia Industrial*, 43-70. Elsevier, Rio de Janeiro, Brazil.

[4] J. Mincer, 1983, "George Stigler's Contributions to Economics". *The Scandinavian Journal of Economics*, Vol. 85, 65-75.

[5] J. H. Drèze, 1964, "Some Postwar Contributions of French Economists to Theory and Public Policy; With Special Emphasis on Problems of Resourse Allocation", *The American Economic Review* 4, Vol. 54, 2-64.

[6] D. N. De Salvia, 1969, "An Application of Peak-Load Pricing", *The Journal of Business - The University of Chicago Press*, Vol. 42, 458 - 476.

[7] A. F. Mendonça; C. Dahl, 1999, "The Brazilian electrical system reform", *Energy Polic*, 27, 73-83.

[8] P. L. Joskow, 2005, *Regulation of Natural Monopolies*, Handbook of Law and Economics, Elsevier, Massachussets, USA.

[9] C.C Eckel, 1987, "Customer-Class Discrimination by Electric Utilities". *Journal of Economics and Business*, Vol. 39, 19-33.

[10] C. A. Schmidt; M. A. Lima, 2004, "A demanda por energia elétrica no Brasil", *Revista Brasileira de Economia*, Vol. 58, 68-98.

[11] S. J. Brown; D. S. Sibley, 1986, *The Theory of Public Utility Pricing*, Cambridge University Press, Cambridge, UK.