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Do distribution companies loose money with an electricity flexible tariff?: A review of the Chilean case

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ABSTRACT

We can get an (energy efficiency) EE improvement if we produce a flatter daily load curve, leading to a higher efficiency of the power system, making better use of the generation and transport electricity chain, thus avoiding over-investment in equipment used just few hours a year. Tariff flexibility of the (Time of Use) TOU type is one of these measures. Generally, TOU systems are designed to minimize total system cost, which may cause losses in distribution companies (DISCOs), generating opposition. On the contrary, the present paper proposes a TOU system for electricity consumption in Chile where optimal prices are obtained in order to maximize total income of DISCOs. In this manner, the proposed TOU system is, by definition, beneficial for DISCOs and it may lead to a win–win situation among DISCOs and consumers. In particular, we show that such a system, implemented in a country like Chile, would allow for DISCOs a total potential benefit of 811.7 millions of dollars for the 3-year study period (2005–2007), considering initiatives that promote a 5% savings in real consumption during on-peak hours, obtained by the spread or difference between the proposed and the current systems.

1. Introduction

Currently, it is underway an ongoing debate in many countries regarding the sources of energy, their generation and use. The sustained increase in global demand for electricity, its direct relationship with countries' economic development, the cost of generating and the impact on the environment that power generation produces, have shown the need to take actions that allow to optimize its use. There are various measures that can be implemented to achieve this goal, some of which are intended to influence the behavior of the end users of electricity, and that could be channeled through the electricity distribution industry. In this way, the debate at the global level has also focused on the design of regulatory mechanisms that encourage (distribution companies) DISCOs to implement (energy efficiency) EE programs. This because they do not have economic incentives to incorporate EE programs to help their consumers to be more efficient in the use of energy if the programs translate into a decrease in sales and income. However, it must be taken into account that the effects of these measures depend on price elasticities, which can vary considerably between one industry and another [1].

Along the same line of thought [1–7], point out the possibility of having a rebound effect. So, while the expected effect should be a rational decrease in energy consumption, in opposite, the increases in technology efficiency from the energy point of view may determine an increase in global energy consumption because of larger aggregate consumption demand [1–7]. As Herring [8] points out: "Advocates of energy efficiency acknowledge that some of the savings from efficiency improvements will be taken in the form of higher energy consumption—the so called 'take-back' or 'rebound' effect. However, there is still intense dispute about its magnitude. It is strongly argued that it is much less than 100%; perhaps in the order of 10–20%."

As well, Laitner [9] states: "Depending on the assumptions of income and price elasticities, as well as the supply/demand interactions within a macroeconomic model, the rebound effect

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might reduce overall savings by about 2–3% compared to a pure engineering analysis. In other words, an economy-wide, cost-effective engineering savings of 30% might turn out to be only a 29% savings from a macroeconomic perspective. Despite the impact of a rebound effect, the net result of energy efficiency policies can be a highly positive one."

Today, the majority of residential consumers of electricity in developing countries are offered a service with a flat tariff scheme, based on the average cost of providing the service. This system does not provide such customers with incentives to modify their pattern of consumption in periods when the cost of producing the electricity rises [10,11]. Thus, demand responsiveness to the information on prices, a critical variable to the proper functioning of markets, is not present in the majority of these energy markets. In contrast, a flexible pricing mechanism is capable of generating such a decrease in the variability of consumption levels among hourly segments during the day, which in turn reduces uncertainty and variability of electricity costs [12]. Thus, flexible pricing offers opportunities to reduce the electricity supply costs and the risk of not satisfying the demand for electricity. In this way, the design of a suitable system of flexible tariff can help to operate a smart grid [13].

Flexible pricing has been implemented generally for large consumers (commercial and industrial). A good example of this is the Georgia Power program, in which more than 1600 of these large consumers face different hourly rates and where close to 850 MW in power demand reduction have been verified [14]. In the case of Chile, Mendez [15] points out the importance of having an efficient pricing system of electrical energy for users in order to send the right signals to the market to make the expansion of transmission lines and the construction of new power generation more efficient within a competitive market.

Generally, TOU systems are designed to minimize total system cost, which may cause losses in DISCOs, generating opposition. On the contrary, the present paper proposes a TOU system for electricity consumption in Chile where optimal prices are obtained in order to maximize total income of DISCOs. In this manner, the proposed TOU system is, by definition, beneficial for DISCOs and it may lead to a win–win situation among DISCOs and consumers.

This paper investigates the results of the design of a flexible pricing system (of the Time of Use, TOU, type) for electricity consumption in Chile, where an optimal pricing model for electricity consumption has been determined by means of price-consumption elasticities, in such way that, for each simulated scenario of the response of users associated with such node, there exists an indicator that shows the price-consumption sensitivity in each price scheme. Thus, we measured the effect of the application of a flexible pricing system (of the TOU type), with optimal prices defined using the elasticities, which would induce the desired behavior in the end consumer of electricity in a way that the consumption and electricity prices can reflect more closely the risk associated with the power generation cost achieving greater efficiency of the electrical system without affecting the profit earned by the DISCOs. We model the response of the demand and the DISCOs' objective following this rationale.

2. ("Time of Use") TOU pricing system

There are several systems of electricity pricing in the world. Some are fixed, where there is a flat fee regardless of the load curve and the time of consumption (which corresponds to the current Chilean model for residential customers), and some are flexible, whose rate is differentiated on a temporal basis [16]. Within these latter ones, are included the (Time of Use) TOU Pricing, (Critical Peak Pricing) CPP, and (Real-Time Pricing) RTP, which have been detailed by several authors [17–20].

In the specific case of TOU system, both prices and periods of application are known a priori and fixed to some length, typically a season [21]. However, and although the TOU system has different rates for each defined block, these rates do not consider the times of saturation or demand peak of the system and do not capture variations in demand and costs of operation in real time. i.e., uses just one price for the same periods of time, regardless of the status of load on the system or wholesale prices. On the other hand, to try to reflect seasonal variations, a readjustment of prices and/or the duration of the blocks is performed two or three times a year. Faruqui and Malko [19] presented the results of twenty experiences of TOU systems allowing to conclude that:

1. TOU pricing system reduces the consumption in peak periods, however in average or low consumption periods it remains constant or increases in small quantities.
2. A change in the load curve is rarely observed and the TOU system prices cause an overall decrease in the daily consumption.
3. Users who demand power in on-peak periods are more price sensitive than those who do so in off-peak periods.
4. Elasticities for on-peak and off-peak periods vary in a range of 0 to−0.4. These differences in the variations are explained by the various climates, prices and consumption used for the study.

On the other hand, if implementation of the TOU system considered the voluntary association of customers to the program, a problem could arise in the achievement of the improvement objectives of the proposed EE measures, as in this case only those customers who obtain savings related to an overall decrease in consumption or generate one block tariff to another transfer would subscribe to this pricing scheme. This situation may generate a loss of income for the DISCOs due to lower sales associated with consumers who subscribed to the plan; and in that context, these companies will seek to remedy such loss increasing the rates of those consumers not hosting the program, thus determining a zero sum game insofar as the savings achieved in the global system [22].

Therefore, to address the problem of flexible electricity consumption pricing, there should be a consideration of the impacts on two important variables: the revenue earned by electric power distribution companies and the response or variation in consumption response of users to the new pricing of electricity. To combine both effects may generate a win–win strategy, benefiting both companies and end-users.

3. Model of flexible pricing TOU type adapted to the Chilean case

3.1. Background information

The proposed flexible pricing model is applied to the main Chilean electric system, SIC, which covers the majority of the energy consumption of the country. In Chile, energy and power prices for large consumers (with a level of consumption over 2000 kW) are determined by bilateral agreements between parts. However, in the case of energy supply to end-users whose connected power is less than or equal to 2000 kW, the price is established by regulation law. Thus, customers that make up this market segment are called regulated customers.

For regulated customers, the Chilean electricity law distinguishes prices at generation, transmission, and distribution levels. The latter prices are determined as a value added per concept of distribution operations and a charge for using the grid. The generating companies can sell their energy and power both in the large consumer market, where the price of the transaction is agreed freely; and also, in the market of the DISCOs, where the price is regulated based on a "nodal pricing". The price that the DISCOs can charge to regulated customers located in their area of distribution, for the distribution of electricity service, is given by the following expression:

$$P_{\mathrm{f}} = P_{\mathrm{n}} + \mathrm{TCG} + \mathrm{AVD} \tag{1}$$

where:

P_{f}: end-user price
P_{n}: regulated nodal price
TCG: toll charge for grid use
AVD: added value of distribution

While nodal prices are commonly set by market competition, in Chile they are regulated by law. Accordingly, Chilean "nodal prices" are set twice a year, in the months of April and October of each year. These regulated nodal prices have two components: the first, called basic price of energy, which corresponds to the average in the time of the marginal costs of energy from the electric system, operating at the minimum updated cost of operation and rationing, during the period of study; and the second, called the basic price of the peak power, which corresponds to the annual marginal cost of increasing the installed capacity of the electrical system considering the cheaper generating units, determined to provide additional power during the electrical system's peak demand hours of the year, increased by a percentage equal to the theoretical power reserve margin of the electrical system.

For each one of the nodes of the electrical system, energy and power-related penalty factors are calculated, that multiplied by the respective basic price of energy and peak power determines the price of energy and power in the respective node. On the other hand, the (Added Value of Distribution) AVD, is set every four years by the Ministry of Economy, Development and Reconstruction, and corresponds to an average cost that includes all the investment and operation costs of a theoretically efficient business enterprise operating model in the country, with an efficient investment policy and management. However the AVD does not necessarily recognize the costs actually incurred by the DISCOs.

Thus, rates that finally face regulated distributors clients consist of prices of generation, transmission, and added values by distribution costs. Generation prices correspond to the regulated nodal prices determined semi-annually; prices of transmission component corresponds to the toll for the use of backbone transmission facilities; and finally the component distribution, corresponding to the AVD, which represents the payment to the company distributor of their cost of investment, operation and maintenance, losses, and expenses of administration, billing and customer care.

3.2. Model assumptions

The flexible pricing model to be proposed seeks to implement a rating system, where the residential end-users of energy (regulated clients, in the Chilean case), assume a larger cost if their main daytime energy consumption takes place in slots of congestion or larger aggregate consumption of the system. Thus, economic incentives are generated for users to reduce or "move" consumption in congestion (on-peak demand) sections to stretch medium or low level consumption, making them sensitive to higher costs of generation, transmission and distribution in on-peak schedule.

Mathematically, and as an assumption for the tractability of this model, the SIC's system of nodes complies with the properties of set covering and set packing, by which all tariff solutions comply with the condition of set partitioning and therefore, the optimal rate of the system will be the sum of the best of the partition. Given this configuration, the model will work in a first phase on the basis of a particular node, to later generalize the analysis to the rest of the selected nodes and to the whole SIC system.

To analyze the income received by the DISCOs and the variation in the form and schedules of customer's consumption, there will be a comparison of these variables between the current scenario and the scenario with the proposed scheme. The model will consider the implementation of a flexible hourly charging system comprised by three daily tariff segments (on peak, middle peak and off peak), characteristic of each node. Thus, for each of the nodes that make up the SIC, analysis of their profile of time consumption and the marginal costs of generation associated with that profile will be carried out. On the other hand, as a measure of sensitivity of customers' consumption is not available to variations in the price of electricity, to simulate their response to changes in pricing, we generate different scenarios representing the variation of customers' consumption.

Therefore, each scenario will be a simulation of a possible "turnover" of consumption between each time segment. Thus a study of the current pattern of customer consumption response will be possible for each schedule section, with its corresponding duration and price, in the face of variations in pricing of energy. This model assumes that each node of the SIC reflects the consumption characteristic of the zone in which is located, so that the behavior and consumption of each node may give an account of the behavior of customer consumption in that geographical area. In addition, in this comparative analysis both competing schemes charging periods will be compared during October–April period of each year of study, in order to not only realize the effect of daily and hourly variations in consumption in certain segments, but also of those variations that are a product of seasonality.

Assuming that eventually there may be energy transfers among different nodes of the SIC, there applies the idea of risk polling,[1] with which, for the purposes of this model, is considered marginal to the distorting effect of possible transfers of energy on the pattern of overall consumption of the system's clients. On the other hand, the variations in price of each segment will be determined, as a measure of sensitivity, establishing a role of consumption-cost elasticity characteristic of each node, so that, for each user's response to prices scenario differentiated by segments, there will be an indicator to show sensitivity in each consumption-cost associated to a schedule section. It should be noted that for each simulated scenario, there is a characteristic consumption per node, which directly determines the role of elasticity price-consumption in the specific time segment. This function is therefore built by comparing the consumption of each node in each fare segment, with the price level of electricity in this segment.

3.3. The model

The model used in this study can be described as a methodology of seven steps, each of which was applied to all nodes in the main Chilean interconnected power system, SIC. Each of these steps is detailed below. In order to illustrate the implementation over the nodes of the specific step that is being detailed, we use a prototype

[1] Risk pooling is an important concept in the management of the supply chain, which suggests that the variability of demand is low considering the aggregate demand, because the aggregation occurs in different locations. Thus, by introducing inter-decadal with different backgrounds, the effect on aggregate demand is minimized. For further reference see Ref. [23].

node (called *Pan de Azucar*). This is made only to explicit the description of the methodological procedure. Fig. 3 shows a schematic picture of the whole methodology used here.

3.3.1. Step1: obtaining and validating data

For each node belonging to the main Chilean interconnected power system (from now onwards SIC), data regarding both consumption characteristics of each bar and the marginal generation costs associated with that consumption pattern were collected for the years 2005, 2006 and 2007. The information was obtained from the Center for Economic Load Dispatch of the SIC, CDEC-SIC, and from the Chilean National Energy Commission, CNE [24–27].

The information collected was inspected and validated, because in some cases exhibited abnormalities (e.g., negative consumption values), which were excluded from the database.

3.3.2. Step 2: selecting nodes

Once validated information was available, we selected those nodes of the SIC that had enough information about marginal costs and consumption characteristics of the bars associated to such nodes. Specifically, the criteria for selection of these nodes were two: (i) that they belong to the backbone of the SIC (main nodes), and (ii) that the node has available information regarding the extent of consumption and the marginal costs of the energy in each tariff segment (the latter being needed to quantify the income variation of the DISCOs as a result of the application of the model). To analyze the system, 22 representative nodes of the SIC were chosen. The 22 nodes selected are: Quillota, Carrera Pinto, Valdivia, Los Vilos, Itahue, Rancagua, Huasco, Polpaico, Las Vegas, Paine, Puerto Montt, Punta cortes, Cardones, Pan de Azucar, Charrua, Rapel, Chillan, San Fernando, Cholguan, San Vicente, Concepcion, and Temuco.

Figs. 1 and 2 show the daily average marginal costs and energy consumption during the years 2005–2007, for the Pan de Azucar node (prototype node). These figures reveal the existence of low, medium and high levels of power consumption and marginal cost throughout the day, suggesting the use of a flexible pricing to generate a more bounded behavior of electricity demand for certain critical costs and consumption segments.

3.3.3. Step 3: generation of base case

For each of the 22 selected nodes, the payment of the DISCOs to the generation firms (expenditures) and the profits of the DISCOs

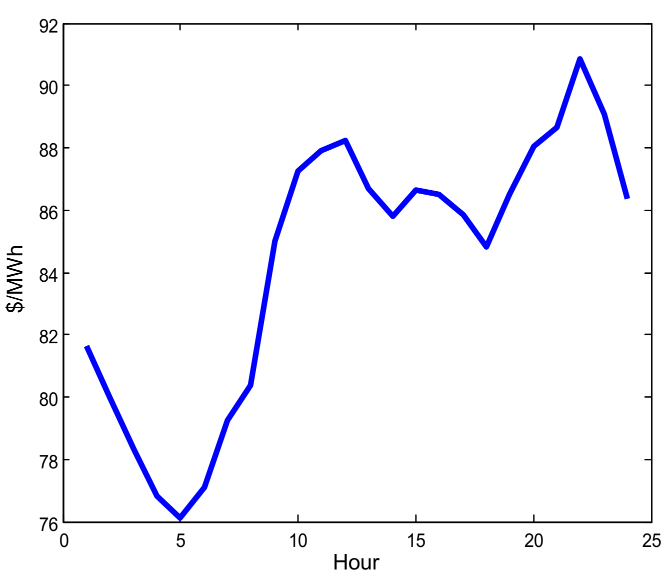

Fig. 1. Daily average marginal costs of the prototype node.

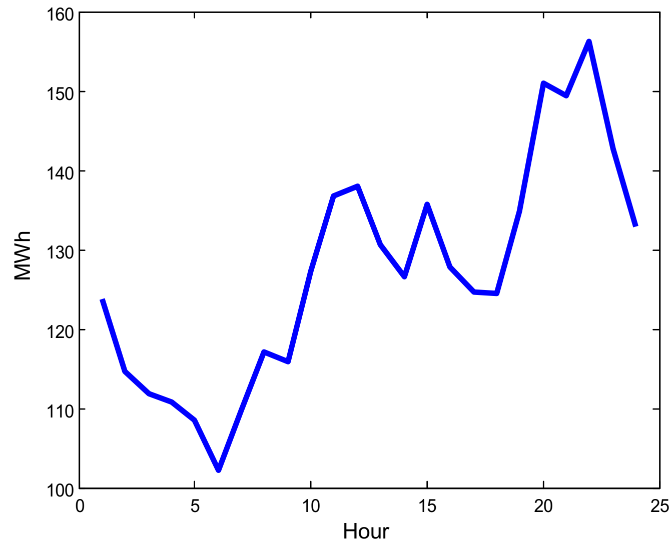

Fig. 2. Prototype node characteristic average consumption.

were determined in the base case, corresponding to the current pricing system (fixed-tariff system), during the analysis period, 2005–2007.

i. Payment of the DISCOs to the generation firms in the base case

The payments of the DISCOs to the generation firms in the fixed charging system (base case) are determined. For this, the consumption at each node selected is multiplied by the regulated nodal price of electricity. Recall that the regulated nodal price is updated biannually

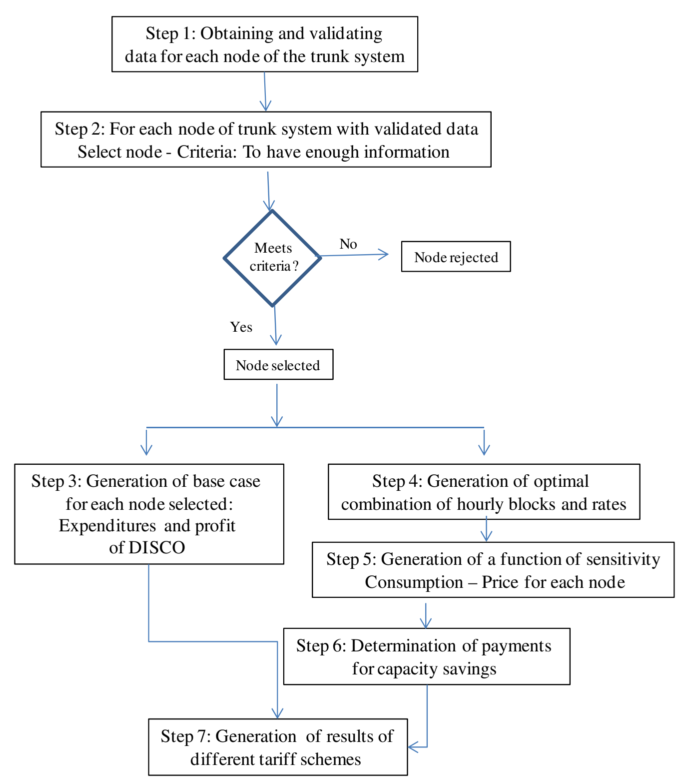

Fig. 3. Methodology of the model.

in April and October of each year, to account for variations in cost and consumption due to seasonality and other factors. Therefore, for the period of study, a vector of nodal prices was generated, whose weighted vector of consumption times price on the relevant dates delivers a proxy indicator to the expenditures of the DISCOs with the current pricing system, which will be subsequently compared with the results of the application of the flexible charging system.

ii. Determination of profits of the DISCOs for the base case

On the other hand, DISCOs' profits are obtained by multiplying nodal consumption and the corresponding (added value of distribution) AVD, corresponding to the period 2004–2007. It should be noted that this mechanism leads to the profits of the DISCOs being linked to their level of sales of electricity, which becomes an obstacle to the successful application of differentiated sections pricing, to induce a net decrease of electricity consumption at the residential level and the consequent adverse impact on the economic interests of these companies.

3.3.4. Step 4: generation of an optimal combination of hourly blocks and rates per node

To establish a three-segment flexible pricing system, we sought the optimal combination of time segments for each selected node. The desired goal was to maximize the revenue of DISCOs, given the characteristic behaviors of each bar consumption, the cost-based power rating existing in Chile, and subject to the constraint that each time segment has a minimum duration of 3 h.

The revenue of the DISCO was computed by multiplying the characteristic consumption and the rate for each tariff block. Accordingly, it is necessary to establish, for each node, the optimal duration and the rates for each tariff block.

i. Rates for each tariff block

A reference price is obtained for each tested rate segment (On peak, Middle peak and Off peak), which is calculated by applying a commercialization margin to the average cost of this segment (which for this study was considered 10%). The average cost, for each time block of each assignment, is obtained as the average of the costs in the pricing section. Thus, the unit selling price corresponds to:

$$P_{s(i,j)} = C_{av(i,j)}*(1+M_d) \tag{2}$$

where:

$P_{s\ (i,\ j)}$: price of tariff segment i in the combination j of time segments
$C_{av\ (i,\ j)}$: average cost of tariff segment i in the combination j of time segments
M_d: Margin of commercialization

The idea of using a commercialization margin on the cost environment, rather than using the final price to the consumer of electricity, is to measure the impact of variations in consumption on the variations of marginal costs and these variations in the final price to the consumer. In this way, the variation of the final price will be a function of consumption and not the value added of distribution variation and/or tolls of the core system.

ii. Duration of segments of each tariff block

The income of the DISCO is calculated by multiplying the price of the corresponding segment and the hourly consumption of each segment, for each tested rate segment, and summing up over all the segments, subject to the constraint that there is a minimum duration of 3 h per segment. That is,

$$I_d(j) = \sum_{i=1}^{N} P_{s(i,j)}*\left(\sum_{h=1}^{D} C_{(i,h)}\right) \tag{3}$$

where:

$I_d\ (j)$: income of DISCOs with the j combination of tariff blocks
N: number of daily segments
D: duration in hours of segment i
$P_{s(i,\ j)}$: price of tariff segment i in the combination j of time segments
$C_{(i,\ h)}$: consumption in the tariff section i which has a period of h hours ($h \geq 3$).

That is, the income of the DISCO, with the tariff blocks j combination, shall be equal to the sum of products of prices in the segment i allocation j, times the sum of consumption in the tariff section i which has a period of h hours ($h \geq 3$).[2]

Finally, we choose the hourly tariff blocks combination that maximizes the income of the DISCOs, given the new scenario of prices per block. For example, for the prototype node, three tariff blocks were optimally determined, which start at hours $h = 0$, $h = 9$ and $h = 19$.

3.3.5. Step 5: generation of a function of sensitivity consumption – price for each node

For each node and optimal tariff segment, it was generated a consumption-price sensitivity function, as a proxy to the sensitivity of the consumption of the respective bar, with respect to changes in prices generated from transfers (to be simulated in this model) among blocks with different tariffs. The idea is to obtain bounds on the effects that could be set on consumption in each simulation of energy transfers among tariff blocks and, therefore, determine the energy savings and the effect on revenue of DISCOs.

This sensitivity function was generated from the analysis of daily consumption during the years 2005–2007, ranked by every consumption segment (Off Peak, Middle Peak and On Peak), using the least squares method to establish a linear relationship between price and consumption for the seasonal periods included in the horizon. This yields an index of consumption-price sensitivity for each of the time segments (Off Peak, Middle Peak and On Peak) for the period from October to April and for the period from April to October (A total of six values for each one of the 22 nodes).

3.3.6. Step 6: determination of payments for savings in power capcity

For each node under analysis, it is necessary to compare the changes in the revenue of the DISCO produced by potential savings to be gained by the decline of investment in generation capacity, due to the change in the customers pattern of consumption, so as to evaluate if the whole system is more efficient from the energy point of view when reducing the variability of daily consumption. To achieve this comparison, it is necessary to create a proxy indicator to account for the payments for capacity and energy, which DISCOs pay for to the generators, as a way to estimate the savings associated to the peak demand reductions. This proxy indicator will be built as the average value of capacity payments in the study period so that, for every MW decreased during the peak working hours,

[2] The minimum duration of 3 h for any block tariff was chosen for simplicity reasons and for realism of practical implementation of this pricing system.

there is a proportional payment to this drop in consumption. To be able to quantify the potential savings to the system, as a result of decreases in consumption at peak times, reference capacity payments in the Chilean SIC market were considered, contained in the October 2007 nodal price report [26]. In addition, a vector of capacity payments was obtained corresponding to the periods October 2004 to April 2007, which was weighted by the savings simulated between hourly tariff segments of the node in analysis. Therefore, for each simulated variation of consumption between hourly slots, there will be a characteristic capacity savings value.

To quantify the simulated power savings in this exercise, a scenario of change for each node is defined. This scenario is characterized by inducing percentage variations in the behavior of consumers, from increased consumption to lower consumption segments, successively. The idea behind this structuring of scenarios is to account for users' different sensitivities depending on the season in analysis. Users are less sensitive (in their behavior) to price in the April–October period than in the October–April period, because of the winter cold and the lesser amount of light in this period day. Thus, for instance, for the prototype node, we simulate a scenario where there is a 10% transfer in the nodal consumption from on-peak segment to middle-peak segment and a 10% transfer from middle-peak segment to off-peak segment, as a result of the implementation of the new tariff.

3.3.7. Step 7: generation of results of different tariff schemes

With the information generated in the above steps, for each selected node, it was determined the payments that consumers make to DISCOs under the flexible pricing scheme, the payments that DISCOs make to generators for the energy provided, the profits of DISCO in both the base case and in the case of flexible pricing and the spread between the two systems, considering also the savings in power capacity.

These calculations were performed considering two flexible pricing schemes: one called the asymmetric case, where the price paid by end-consumer varies by segment, but the price that DISCOs perceive is maintained under a fixed schedule, and another scheme called the symmetric case, where consumers and distribution companies face different prices per segments. In the case of the prototype node, the results obtained are shown in the next section.

4. Results obtained in the prototype node

The overall results for the prototype node, where different charging mechanisms are compared through the access of the distributors, are shown in Table 1.

Table 1 shows that the payment made by consumers to the distributors, under the flexible pricing scheme ($365.66 millions), is larger than the payment of the distributors to the generators ($335.9 millions). This difference is a proxy for added value distribution plus tolls per use of the backbone transmission system. On the other hand, the utility obtained by DISCOs is superior in the scheme of flexible pricing than in the base case, with a constant energy price, only updated by seasonality (winter & summer rates) factor, thereby creating a positive spread of flexible pricing in relation to charging fixed (current) pricing. The explanation of this behavior lies in the shape of the node's curve and the simulated scenario consumption (10% transfer of energy consumption among on-peak, middle-peak and off-peak hours, respectively). This situation determines that benefits of the pricing scheme vary from node to node.

Now, if the effect of the consumption variability is not only absorbed by the distribution company, but it is also "transferred" to the whole electricity supply chain, this creates a communication link between the final consumers of energy and the generators. In this way, if there are variations in the costs of generation caused by different reasons (such as a possible period of drought, increases in cost of fuels and other inputs of the power generation process chain, or problems of a contractual nature and/or dispatching), it will be quickly reflected in the amount of energy consumed by the regulated customers. There are several ways to convey the sensitivity of consumption, one of them is through the current setting of a fixed nodal price, which collects the variability, but with a lead time or gap of almost 6 months. Another way is the generation of a nodal price which is differentiated by time, similar to the flexible pricing scheme previously mentioned, where different slots with a different price/charge each is faced by end users. A hypothetical situation in which there could be a symmetrical flexible pricing on "both sides of the distribution chain", that is where there is a flexible pricing to consumers to the distributors, and these in turn have a flexible payment scheme based on the latter to the generators, and where each node could be charged differently according to a defined pattern of consumption, would give the following results.

Table 2 shows an increase of 6.81 millions of dollars between different pricing models for the system, by effect of transmitting the variability of electricity consumption supply chain, considering the 2005–2007 period. This is explained by the typical consumption pattern in the node; reason why, this greater bonanza for effect of flexible pricing that is transferred to the supply chain, can vary from node to node.

5. Results obtained in the general application of the model

The procedure described above was applied to a set of 22 nodes of the (central interconnected system) SIC. The selection criteria of these nodes (that generalize the results) are the belonging to the core/backbone system and the adequacy of the marginal costs and

Table 1
Comparison of utilities with flexible pricing model and profit under current model for prototype node: 2005–2007 period (asymmetric case).

	Results for the prototype node	Millions of $
A	Payment made by consumers to the distributors, under the flexible pricing scheme (price tariff blocks * consumption in blocks)	365.66
B	Payment of the distributors to the generators (nodal price * consumption in blocks)	335.9
C	Utilities of distributors, under the flexible pricing scheme (A–B)	29.76
D	Profit under current model for node model (AVD * consumption in blocks)	11.62
E	Spread (C–D + saving for payment power)	18.67

Table 2
Comparison of utilities and profits under flexible pricing model and transmitting the variability of electricity consumption supply chain for node model: 2005–2007 period (symmetric case).

	Results for the prototype node	Millions of $
A	Payment made by consumers to the distributors, under the flexible pricing scheme (price tariff blocks * consumption in blocks)	365.66
B	Payment of the distributors to the generators, under the flexible pricing scheme (Gen. price tariff blocks * DISCOs use in blocks)	329.09
C	Utilities of distributors with flexible pricing model (A–B)	36.57
D	Profit under current model for node model (AVD * consumption in blocks)	11.62
E	Spread (C–D + saving for payment power)	25.48

consumptions data in the study period. These nodes,[3] as a whole, represent 27,714.42 GWh of electric power consumption and 64.15% of the total energy consumption of the SIC which corresponds to 43,198.70 GWh. Given this representation of the system, a scale factor of 1.6 was used for the entire SIC which accounts for the fraction of energy considered in the study. This factor allows us to amplify the results obtained in the implementation of the entire model, considering that the system involved behaves in a manner similar to the sample selected, with respect to their costs and consumptions.

Furthermore it was considered that the annual savings/dissaving obtained annually due to the variation in the pricing of electricity consumption, constituted under conceptual and academic assumptions, a perpetual annuity, by which corrected to a discount rate of 8%, the present value of the change in the pricing model is obtained.

It was also considered in this extension of the pricing model, that the variability of consumption, expressed in income variability of distributors, is transmitted throughout the entire chain of electrical supply, i.e., that both the payment of end consumers to DISCOs as well as payments of these companies to power generation and transmission is differentiated into three tariff slots triggering a nodal price differentiated for the three slots and dependent on the geographic area; a case referred to as symmetric pricing.

The results obtained from the general application of the model of flexible pricing applied to the Chilean case, for the symmetric charging scheme, are illustrated in Table 3, where the spread of the charging system in relation to the present case, has been grouped according to the minimum percentage savings for the winter and summer periods.

The generalization of the results in the application of the model of symmetrical pricing has several consequences, among them we can mention:

1. The total absorption of the variability of consumption allows the behavior of end users to influence the cost structure of the generating companies, across levels of consumption. In turn, the variability in the cost structure of the generating companies influences the consumption behavior of end users, through the price of energy in the different hourly slots. That is you get a mutual influence among the different players who participate in the system.
2. Electricity supply chain communication is performed through the price of it, the costs of generation and levels and forms of consumption end users. This translates into the variability of costs, both seasonal and daily, which have an impact on the price paid by end users for the electrical energy. With this scheme then, it is not necessary to wait 6 months to internalize fully in the price the changes in the behavior of customers consumption, which allows that the users' response to the variation in prices be absolutely consistent with the structure and evolution of the costs of generation.
3. The necessary savings effort on peak demand slots is marginal, in relation to the base case (current pricing system) if one wishes that symmetric pricing allows for a change in the pattern of consumption of users in this period, and at the same time, generate a positive spread on the income of the DISCOs. In fact, symmetric pricing allows us to obtain a positive spread almost independently of the level of response of the end users.

Empirically it is possible to reflect this situation through the next mantle of relations:

The mathematical relationship between percentage savings and the spread of pricing systems, for the symmetric case, is given by:

$$S_{ps} = 803.57 + 66.18 * W_s + 96.3 * S_s \quad (4)$$

where:

S_{ps}: spread of pricing system
W_s: percentage of winter savings
S_s: percentage of summer savings

In equation (4), the coefficients of the percentage savings in winter and summer seasons represent the elasticity spread v/s percentage of savings. Given the values of these coefficients, you can see that the sensitivity of the users is lower in the winter period. On the other hand, the mantle of solutions that allow to establish a win–win situation, in which the minimum necessary savings in summer and winter to achieve a change in the pattern of consumption of users is expressed, and at the same time, a positive spread between pricing systems, exhibit the following relationship:

$$-803.57 = 66.18 * W_s + 96.3 * S_s \quad (5)$$

where:

W_s: percentage of winter savings
S_s: percentage of summer savings

This mantle of solutions explicitly shows that the minimum necessary savings for the symmetric pricing system to have a positive spread must be negative, implying that for any level of savings from the peak demand hourly slot to a medium level, the system manages significant benefits in relation to the base case (Some characteristic values of the equation (5) are given in Table 3).

From the symmetrical flexible tariff model applied to the Chilean SIC we can obtain the following results:

i. Considering initiatives that promote a 5% savings in real consumption during on-peak hours, during both winter and summer, the spread or difference between the proposed and the current systems is of $811,7 millions in the 3-year study period. Considering an annual discount rate of 8%, we obtain that the profit for DISCOs of implementing the proposed flexible tariff system with three price segments is $3260 millions.
ii. The spread obtained by DISCOs under the two tariff schemes is affected by the percentage of consumption savings in a different manner during winter and summer. Equation (5) provides the details of the corresponding factors. Accordingly, for example, under a 1% variation in the consumption savings during summer, the impact in the spread is of $0.96 millions instead of the $0.66 millions observed during winter.
iii. In order to produce an additional benefit of $43.3 millions in the spread, it is needed having both an effort in consumption savings equivalent to transfer 45% of the on-peak consumption to the medium-peak block during summer and an effort in consumption savings equivalent to transfer 5% during winter.
iv. The spread variation among winter and summer corresponds to a difference of 9% for values of energy consumption savings; in a range of 5%–50%. This represents an upper bound of

[3] Nodes considered in the analysis are: Quillota, C.Pinto, Valdivia, Los Vilos, Itahue, Rancagua, Huasco, Polpaico, Las Vegas, Paine, P. Montt, Punta cortes, Cardones, Pan de Azúcar, Charrua, Rapel, Chillan, San Fernando, Cholguan, San Vicente, Concepción, and Temuco.

Table 3
Characteristic values of the spread in symmetric case. The formation of prices by block in April 2005 is function of marginal costs project in this period, in which the marginal costs in the middle schedule were larger than the peak schedule marginal costs.

Savings% winter	Savings% summer									
	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	811.7	816.5	821.3	826.2	831.0	835.8	840.6	845.4	850.2	855.0
10%	815.0	819.8	824.6	829.5	834.3	839.1	843.9	848.7	853.5	858.3
15%	818.3	823.1	828.0	832.8	837.6	842.4	847.2	852.0	856.8	861.6
20%	821.6	826.4	831.3	836.1	840.9	845.7	850.5	855.3	860.1	864.9
25%	824.9	829.7	834.6	839.4	844.2	849.0	853.8	858.6	863.4	868.3
30%	828.2	833.1	837.9	842.7	847.5	852.3	857.1	861.9	866.7	871.6
35%	831.5	836.4	841.2	846.0	850.8	855.6	860.4	865.2	870.0	874.9
40%	834.8	839.7	844.5	849.3	854.1	858.9	863.7	868.5	873.4	878.2
45%	838.2	843.0	847.8	852.6	857.4	862.2	867.0	871.8	876.7	881.5
50%	841.5	846.3	851.1	855.9	860.7	865.5	870.3	875.2	880.0	884.8

the effects expected when implementing the proposed pricing scheme.

v. If we only consider the energy consumption change from on-peak blocks to medium-peak blocks, the critical percentage allowing that the symmetric flexible tariff system has a positive spread is negative. This gives a positive lower bound of the expected profit for DISCOs of implementing the proposed pricing scheme; and this occurs for any level of energy consumption transfer from on-peak to medium-peak blocks.

6. Conclusions

This work has established the potential benefits of having a TOU system for electricity consumption where optimal prices are obtained in order to maximize total income of DISCOs, as opposite to minimize total system cost. We show that the proposed TOU system may lead to a win–win situation among DISCOs and consumers.

To show this, we simulated alternative scenarios representing feasible responses by consumers when facing variations in the energy pricing scheme. The results show that it is possible to incentivize DISCOs in order to incorporate flexible tariff schemes, but that the intensity of the incentive depends on the consumption profile of the considered nodes.

Given this situation, as future work, it would be interesting the development of a flexible tariff pilot project that considers some representative nodes of the SIC and empirically measures the regulated consumers' response when facing a variation in the energy pricing scheme. Such variations should not only consider the resulting prices coming from the consumption profiles at every node, but also the seasonality and the hourly congestion blocks. In such a way, it could be feasible to quantify the sensitivity of the consumers' response, the consumption transfers among time blocks, the impact over DISCOs' income and the aggregate effect over the system efficiency.

Appendix

Prices, consumptions and costs for prototype node, Pan de Azucar, with a flexible tariff model

Price by block for prototype node ($/MWh)
Schedules between 9 and 19 h

Period/block	Off peak	Middle peak	On peak
Oct-04	84.90	93.15	96.23
Apr-05	36.98	44.56	43.85[a]
Oct-05	35.00	39.70	40.23
Apr-06	104.99	93.32	101.23
Oct-06	75.65	89.11	89.13
Apr-07	128.13	146.87	148.18
Oct-07	170.39	190.39	193.58

[a] The formation of prices by block in April 2005 is function of marginal costs project in this period, in which the marginal costs in the middle schedule were larger than the peak schedule marginal costs.

Consumption by block for prototype node (MWh)

Period/block	Off peak	Middle peak	On peak
Oct-04	30.38	35.62	40.15
Apr-05	30.00	31.41	33.44
Oct-05	29.40	35.35	40.96
Apr-06	165.31	190.26	220.56
Oct-06	234.96	269.11	289.42
Apr-07	136.52	160.61	185.31
Oct-07	119.51	144.48	160.56

Cost by block for the prototype node ($/MWh)

Period/Block	Off peak	Middle peak	On peak
Oct-04	77.18	84.68	87.48
Apr-05	33.62	40.51	39.87
Oct-05	31.82	36.09	36.58
Apr-06	95.44	84.83	92.03
Oct-06	68.77	81.01	81.03
Apr-07	116.49	133.52	134.71
Oct-07	154.90	173.08	175.99

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