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WRIGHT TARIFFS IN THE SPANISH ELECTRICITY INDUSTRY: THE CASE OF THE RESIDENTIAL CONSUMPTION

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Capacity pricing, Wright tariffs, Residential electricity.

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1 Introduction

In markets where the demand is not stable over time and production is not storable, firms must install a level of capacity that meets the highest foreseable levels of demand. This is the case of the electricity market where the operation of its different components must be coordinated in order to meet demand in each time of use with adequate quality characteristics. For these reasons the electric system needs to maintain a maximum generating capacity sufficient to meet the greatest energy demands, but since the behaviour is not stable, some capacity remains idle during offpeak periods.

In order to reduce the costs of idle capacity electric systems install several types of generating equipment. Base load power is meet with equipment having a high cost of acquisition (capital costs) but a low cost of operation. On the other hand, peak-loads are meet with equipment having a lower cost of acquisition and a higher cost of operation. The lower cost adquisition cost of the peaking equipment allows to reduce the cost of idleness in offpeaks periods. This results in higher marginal operating costs when demand peaks.

To account for the particular characteristics of the electric sector, tariffs must be designed to separetely account for capacity and operating costs, and reflect the diferences in these costs among the technologies used. That is, tariffs must be designed in function of the two dimensions of electricity, power and duration. A sort of tariffs of this form are called Wright tariffs in the United States and which are prominently offered by public utility that produces and distributes electric power in France. Wright tariffs attempt to reflect long run cost structure of the utility by setting charges based on the duration of each increment of the load during the year. That is, a unit of power supplied for a specific duration in the long run costs the utility the capital cost of one unit of generating capacity and an operating cost proportional to the duration and the operating cost of that type of generator[1] However, the implementation of these tariffs requires a knowledge of the exact consumption pattern of each consumer through time, for which sophisticated and expensive individual meters would be needed. In some countries like Spain this problem has been solved by approximating individual load-duration curves by the utilization level defined as the ratio of consumption to power used, which allows for the design of tariffs based on individual aggregated consumption.

This paper develops a model for Wright tariff design for the electricity market when the utilization level is used as an approximation to duration. A regulator with an objective of maximizing consumer welfare, with a restriction that the producer must cover its costs, is considered. This model is used to compute an optimal two part tariff for the utilization level of the Spanish residential sector considering several hypothesis on the configuration of the generating equipment. This will allow to estimate the degree optimality of the current tariff and to obtain an aproximation of the efficiency losses attributable to the existing regulatory regime for the case of Spain. This model is an application of Oren, Smith and Wilson (1985) where the duration of consumption is aproximated by the utilization level.

Most studies of the literature derive optimal tariffs for electricity without explicitly considering its multidimensional character. These studies do not consider the existence

[1] See Wilson (1993).

of a capacity and an operating cost, and use the average cost as approximation to the marginal cost (see Dimopoulos (1981) and Buisán (1992)). This work presents electricity as two dimension product and show that, by using utilization levels as an aproximation to duration, the marginal cost is the sum of the capacity and operating cost of the efficient technology for the duration. It is also showed that the costs can be expresed as a function of the consumption of individuals and so, the results with unidimensional prices are applicable.[2]

The assumptions that are common in the literature of non linear pricing in the sense of not considering rent effects and the inability of product resale are adopted. The regulator may supervise the consumption of individuals and he knows the distribution of consumer types and their preferences. It is assumed that the regulator uses the concept of utilization level, defined as the ratio of consumption to power used, as an aproximation to the consumption pattern of the individuals.

The structure of the work is as follows. In the second section the basic framework of the capacity price model is presented. The third section adapts the model for the case in which duration is aproximated by utilization levels. In the fourth section the parameters used in the empirical analysis are specified. The fifth section is dedicated to compute two part tariffs by utilization levels for residential consumers and to efficiency analysis. Finally conclusions are presented.

2 Basic concepts

Load-duration Curve

In the case of services such as electrical power where supply is comparatively stable with respect to demand, this can be described in two ways: by demand at different hours of the day and by the load-duration curve giving the numbers of hours that demand exceed a given level. Figure 1 presents the load-duration curve for 1993.

Insert Figure 1

The two axis of the load-duration curve may be interpreted as the consumption rate and the time duration, and its magnitudes are refered to as capacities. The maximum capacity level represents vertically the maximum consumer demand ("demand peak"), and horizontally, the maximum time interval in which the system operates (for example a year). In the case of electrical energy consumption the dimensions are power and duration, and the load-duration curve can be interpreted as the number of hours $H(l)$ for which the power demanded is at least l, or as the smallest power level $L(h)$ that is demanded for a duration of no more than h hours. $H(\cdot)$ and $L(\cdot)$ are nonincreasing, with $L(0)$ and $L(1)$ denoting peak and load demand respectively, suposing that duration is expresed as a fraction of the time period considered.

The area under the load curve represents the consumption set Q in kilowatt-hours of the individual. In this sense, the load-duration curve may be interpreted as a function of

[2]See Goldman, Leland and Sibley(1984) and Brown and Sibley(1986).

the distribution that determines the probability (in fraction of cycle hours) that the power demand by the individual will be greater than a determined level.

Costs

In order to determine the costs associated to a consumption set Q determined by a load-duration curve it is considered that the generators use different production technologies. In the linear case

$$c_i(h) = f_i + v_i h,$$

is the cost per kilowatt using techonology i for a duration h, where f_i is the unitary capacity cost (amortizated cost of generating equipment per kilowatt of power), and v_i is the operating cost per kilowatthour (kWh). These capacity and operating costs are such that each technology is the most efficient in some range of the duration, as long as there is infinite divisibility.[3]

Projecting the efficiency range of each technology onto the load-duration curve we may obtain the optimal capacity configuration (optimal technology mix), this is, the number of kW of each technology that must be installed in order to supply the energy requirements of the system. Thus in a three technology case, as in figure 2, the low capacity cost technology (I) will be used to satisfy the peak load while the low marginal cost technology (III) will be more appropiate for the base load, and the intermediate technology (II) meets the shoulder load.

Insert Figure 2

The total cost of supply the consumption set Q, determined by the load-duration curve with the optimal technology mix may be obtained for a particular duration range using the cost functions corresponding to the technologies dispatched in that range. It should noted that the efficient operating cost of any generating unit as a function of duration is given by the lower envelope of each technologies particular cost function. This envelope may be interpreted as a nonlinear cost function of capacity use, and its concavity reflects the fact that technologies with low perating costs are assigned to capacity units that are used for longer periods of time. In the linear case the efficient cost envelope will be

$$e(h) = min_i \; c_i(h),$$

wheré $i(h)$ indicates the efficient technology for duration h.

The total cost of the consumption set when horizontal slices are considered can be obtained by adding the costs originated by each kilowatt of power used, which will depend on the technology that has supplied them and on the duration. Thus, for example, in figure 3 it is found that a kilowatt of power l in the interval $L_b < l < L_a$ gives rise to a capacity cost f_2 and a marginal operating cost v_2 since it is supplied by techonology II, which is the most efficient for a kilowatt of duration h, $H_1 < h < H_2$. The total cost associated with a load-duration curve like that of figure 3, with a maximum power demand

[3]With infinite divisivility each kilowatt is produced by a technology and thus an optimally configured generating system may not include technologies that are cost dominated.

of L, when three technologies intervene will be given by

$$C(L) = C_0 + \int_{L_1}^{L_b} (f_3 + v_3 H(x))dx + \int_{L_b}^{L_a} (f_2 + v_2 H(x))dx + \int_{L_a}^{L} (f_1 + v_1 H(x))dx$$

where C_0 represents fixed costs not associated with production (stranded, administrative).[4]

Insert Figure 3

Wright tariffs and utilization level

Wright tariffs fix prices taking into account the number of hours each kilowatt that is demanded is used and, accordingly, they take as reference the horizontal slice costs of the load-duration curve that were analized in the previous section. In this sense these tariffs attempt to adapt to the cost structure derived from the generating equipment in order to meet the load-duration curve. That is, a unit of power supplied for a specific duration in the long run costs the utility the capital cost of one unit of generating capacity and an operating cost proportional to the duration and the operating cost of that type of generator.[5]

Direct implementation of Wright tariffs requires, nevertheless, knowledge of the exact consumption pattern of each individual through time, for which sophisticated and expensive individual measuring equipment would be needed. In some countries this problem has been solved by aproximating individual load-duration curve by the utilization category defined as the ratio of consumption to power used by the consumer, and represents a direct relation with the individuals consumption pattern. Thus it is found that the proportion of consumption in a peak load period is decreasing on the utilization level, while the proportion of consumption in a base load period is increasing.

On the other hand, the utilization level summarizes in one variable (quantity consumed) the information of the two dimensions of electrical electricity, power and duration, which allows for the design of tariffs based on individual consumption exclusively. This also explains that in utilization level tariffs one cannot consider usage prices and capacity prices, and that different parts of the tariff contribute to covering usage and capacity costs.

Nevertheless is necesary to note that the use of the utilization level as and aproximation to individual load-duration curves has two important problems. In the first place, it could be treating similarly two consumers that having the same utilization level have a different consumption pattern. In second place, as is noted in Wilson (1993), it is assumed that consumer demands are sincronized with system demand, and then there exist a capacity sufficient to supply the individual power of each consumer. In practice, however, consumer demands are relatively asincronous and equipment that is idle for a particular consumer can be used to serve another, thus the total capacity necesary will be inferior to the sum of the individual maximum power demanded.

[4] In the appendix is presented the case of cost aggregation using vertical intervals. A more general cost formula is presented in Oren, et.al.(1986).

[5] In the short run the cost structure may be modified by demand or operating cost variations, thus period of use tariffs associated with real system demand each hourly period are also used.

3 A theoretical model of utilization level tariffs

Consumption set

The use of the utilization level concept in order to aproximate the duration of the consumption of the kilowatthours used is equivalent to considering the individuals consumption set to be a rectangle of height equal to the power used L and a base equal to the utilization level h_u (see figure 4). That is, each consumer is associated with the most efficient tecnology for a duration range equal to his utilization level.

Insert Figure 4

The cost function

Consider a rectangular load-duration curve $q = [h_u, L]$ that reflects consumption corresponding to L kilowatts of power used for a maximum duration of h_u, which is determined by the ratio between consumption and the power used, $h_u = \frac{q}{L}$.

The cost of supplying consumption set q with an optimal mix of production technologies, that is, when consumption is supplied completely by the efficient technology for duration h_u is

$$C(L) = C_0 + L\ (f_i + v_i h_u),$$

where f_i and v_i represent the unitary capacity cost and the unitary operating cost for the efficient technology for a duration h_u, L are the kilowatts of power used, and C_0 non productive fixed costs.

Using the definition of utilization level ($h = \frac{q}{L}$), the cost function may be expresed by

$$C(q) = C_0 + m\ q,$$

where m represents the marginal cost of consuming an additional good, and may be defined as

$$m = (\frac{f_i}{h_u} + v_i).$$

Thus, for a particular and constant utilization level, h_u, costs are a function of kWh consumption.

It is implicitly assumed that consumers do not vary their consumption pattern and that the only way to raise their consumption is to raise the power used. Under this assumption it makes sense to think of marginal cost as the cost increment caused by using an additional kW of power to be consumed for a duration of h_u. Thus, marginal cost will be the sum of the capacity and operating costs of the efficient technology, as can be seen in the cost function given.[6]

However, the cost of supplying consumption set q depends on the optimal technology mix used to meet the system load-duration curve. In this sense, the costs incurred in

[6]This assumption seems relatively reasonable for the residential sector which is characterized by a homogeneus and constant consumption pattern.

the supply of a consumption set q will result from agregating the costs incurred by the different generating techonologies used. If it is supposed that $j = 1, ..., s$ techonologies are used, with technology s being the most efficient for duration h_u, the costs of supplying consumption set q will be

$$C(q) = C_0 + \sum_{j=1}^{s-1} (\frac{f_j}{h_u} + v_j - \frac{f_s}{h_u} - v_s)q_j + (\frac{f_s}{h_u} + v_s)q,$$

where $q_j = h_u l_j$ are the consumptions supplied by the technologies $j = 1, ..., s-1$, not efficient for duration h_u, with l_j being the power used of each technology.[7]

Individual demands

The heterogeneity of consumers has a central role in nonlinear pricing because the payment structure is designed to induce self-selection between consumers. These differences are reflected in the consumption choices. In this way to increment efficiency the consumers pay different prices in function of their consumption. This heterogeneity is represented by parameter $\theta \in [\underline{\theta}, \overline{\theta}]$ which is characterized by a distribution function $F(\cdot)$. Thus, it is assumed that consumer preferences can be represented by the utility function, $U(q, \theta)$, where $q = [h_u, L]$ is the quantity consumed by an individual with a utilization level h_u who uses L kilowats of power.

Distribution of types

As the current tariff is such that consumers with different preferences demand different amounts of the good, the distribution of observed consumption can be used to approximate the distribution of consumers types (see Castro, et.al., 1997).

Social welfare

Net consumer surplus for each suscriber is defined as a function of consumption q and consumer type θ by

$$S(q, \theta) = \int_0^q p \, dq = \frac{b}{b-1} a^{1/b} \theta^{1/b} q^{(b-1)/b}.$$

If $T(q)$ is the tariff paid for consuming q units of the good, net surplus can be defined as the difference between net surplus and payment,

$$S(q, \theta) - T(q).$$

Social welfare derived from the consumption of the product is defined as the weighted sum of the monetary value of the net surplus of all the consumers

$$W = \int_{\theta_*(T)}^{\infty} [S(q, \theta) - T(q)] u'(\theta) f(\theta) d\theta,$$

where the weight assigned to each suscriber $u'(\theta) = \theta^{-\eta}$ is a function of the consumer type θ and presents a constant demand elasticity η. Thus the larger is η the larger is the weight assigned to the welfare of consumers with low consumption levels. Parameter θ_* identifies the marginal consumer that is indiferent between consuming and not consuming at the given tariff.

[7]This is the case of the residential sector electrical supply in 1993 which is studied in the next section.

Optimal Tariff

A regulated firm that produces only one type of product is considered. This firm has to satisfy a budget constraint, that is, total revenues must be iqual total costs plus an exogeneuosly specified amount, B. This exogenous amount, B, can be positive, in concept of a profit or surplus above costs, zero when the firm must strictly cover costs, or negative when government subsidies are permited. The objective of the regulated firm is to maximize social welfare. The optimal tariff is derived then by maximizing social welfare

$$W = \int_{\theta_*(T)}^{\infty} [S(q,\theta) - pq - A] u'(\theta) f(\theta) d\theta,$$

subject to the firm's budget constraint

$$\int_{\theta_*(T)}^{\infty} T(q(p,\theta))\ f(\theta)\ d\theta - C(Q) - B = 0,$$

and that the marginal consumer θ_* obtain a non negative net surplus

$$S(q,\theta_*) - T(q(p,\theta_*)) \geq 0.$$

Total consumption is defined as

$$Q = \int_{\theta_*(T)}^{\infty} q(p,\theta) f(\theta) d\theta.$$

4 Especification of the parameters

In order to compute the optimal tariff by utilization level for residential consumption of electricity data on consumption, revenues and prices refering to tariff 2.0 for 1993 of the Spanish electricity system have been used (see appendix). The year 1993 is used a base year since it represents a normal year prior to regulatory reform. The tariff 2.0 of the Spanish tariff structure is targeted for consumers with used power in the range 0.77kW to 15kW, practically all residential consumers. In 1993 there where more than 17 million suscribers to tariff 2.0 that represented more than 93% of the total number of consumers, with a contracted power of more than 60690 megawatts (MW) and an aproximate consumption 36960 million kWh through the year, which accounts for 28.8% of total consumption. The total revenue generated by the tariff was more than 747340 million pesetas (ptas), this amounted to 40% of the total revenues of the industry.

Level of residential utilization

In order to compute the utilization level of residential sector, considering a similar consumption pattern for all the suscribers to tariff 2.0, 61.61% of total power used is considered as power used for residential consumers taking into account that the revenues from power charged amounted to 61.61% of total power used in 1993. Thus, given the 36920 gigawatts-hour (GWh) of residential demand in 1993 an utilization level of 2498 hours is obtained, that is, a short utilization level is obtained.

Costs

In 1993 demand was covered by a mixed thermic-hydrolectric generating system, in which the hydrolectric power represented 31.72% of total installed power, with a production of aproximately 18% of total production.

The hydro technology of the Spanish system has the role of regulating the system meeting demand peaks in all time periods. Thus, it cannot be concluded that hydro technology is responsible for a specific level of utilization. In this sense, it's costs cannot be assigned to a particular consumption, but rather all consumers, regardless of their utilization level, are responsible for covering its costs. In this way, taking into account that consumption of tariff 2.0 in 1993 represented 28.8% of total consumption, it is assumed that 28.8% of hydrolectric production (6705 MWh) has been assigned to meet residential demand.

Technology	Power (MW)	Capacity cost (ptas/kW)	Operating cost (ptas/kWh)	Production (GWh)
Nuclear	7401	46977	1.2494	53538
Soft coal	5961	13691	5.6351	28976
Brown lignite	1950	20674	5.1593	11960
Black lignite	1450	20793	5.8228	8178
Imported coal	1314	17404	3.2560	8601
Gas	7910	4732	4.5871	1795
Hydro	16996	7900	0.7499	23282

Table 1: Technologies data in 1993.[8]

In terms of equipment, the Spanish electric system has several types of generating technologies: nuclear, coal, and gas, all of which were used to cover electrical demand in 1993. In table 1 the most important cost characteristics as well as total ouput of the generating equipment are presented. Capacity costs are obtained considering the standard costs of amortization and retribution, and the fixed costs of operation and maintenance set by the Stable Legal Framework (SLF), the legislative act that regulates the Spanish electricity industry, for each active generating plant. Variable costs are obtained by aggregating fuel costs, and variable costs of operation and maintenance.[9]

Demand

It is assumed that the individual demand function is isoelastic, and depend on the price p paid for each unit consumed and on the parameter θ that identifies each consumer type (this will depend among other things on his income level)

$$q(p, \theta) = a\theta p^{-b},$$

where a is a scale parameter and b represents the price elasticity of demand. Note that the demands are ordered according to the parameter θ, in such a way that if each consumer consumes according to his preferences, a larger valuation for the product (a larger θ) results in higher consumption.

[9]These costs have been obtained considering all active plants in 1993, some of which were fully amortizated and presented a null gross discounted value.

The results of the demand estimation for the Spanish residential sector in Castro (1996), where the price elasticity of demand is estimated to be -1.8, is taken.

Distribution of consumers types

For the estimation of the distribution of consumers types the observed frequencies of consumption for 1993 are used.[10] These frequencies are distributed in a sample space divided into 29 intervals, all of an amplitude of 500 kWh, with the exception of the last one which includes all users with a consumption of 14000 kWh or higher (see Appendix). The observed frequencies will be denoted by $f_i, i = 1, ..., 29$.

The observed consumption distribution presents two distinct patterns, the lower levels of consumption present a clearly linear structure while higher levels of consumption present a slow nonlinear decrease of mass more adequately fitted with a Pareto density. Thus the fitted frequency is given by

$$f_\theta(r,k,\theta_0,\alpha) = \begin{cases} r(\theta-\theta_a) & \text{if} \quad \theta_a < \theta < \theta_0 \\ \alpha k^\alpha \theta^{-\alpha-1} & \text{if} \quad \theta_0 < \theta < \infty, \end{cases}$$

which must verify the following conditions

$$r(\theta_0 - \theta_a) = \alpha k^\alpha \theta_0^{-\alpha-1}$$

$$\int_{\theta_a}^{\theta_0} r(\theta-\theta_a)d\theta + \int_{\theta_0}^{\infty} \alpha k^\alpha \theta^{-\alpha-1} = 1,$$

where θ_a is the smallest type, θ_0 is value of θ where the density function change from linear to Pareto, r is the parameter of the linear part and α, k are the parameters of the Pareto part.

The associated distribution function will then be

$$F_\theta(\theta_0,\alpha) = \begin{cases} \frac{r}{2}(\theta-\theta_a)^2 & \text{si} \quad \theta_a < \theta < \theta_0 \\ k^\alpha(\theta_0^{-\alpha} - \theta^{-\alpha}) + \frac{r}{2}(\theta_0-\theta_a)^2 & \text{si} \quad \theta_0 < \theta < \infty. \end{cases}$$

In order to make the continous theoretical distribution $F(\theta)$ compatible with the discrete sample information, the discrete probabilities that $F(\theta)$ assigns to the 29 consumption intervals for which there exist observed frequencies are obtained. The theoretical probabilities are denoted by $p_i, i = 1, ..., 29$. In terms of $F(\theta)$ wiil be

$$p_i = \begin{cases} F_q(500i) - F_q(500i-500) & si \quad i \leq 28 \\ 1 - F_q(500i-500) & si \quad i = 29. \end{cases}$$

and using the definition of F_q will be

$$p_i(\theta_0,\alpha) = \begin{cases} F_\theta(\frac{p^b 500i}{a}) - F_\theta(\frac{p^b(500i-500)}{a}) & si \quad i \leq 28 \\ 1 - F_\theta(500i-500) & si \quad i = 29. \end{cases}$$

which is a function of the distribution parameters θ_0,α.

[10]This is justified by the fact that the current tariff as of 1993 is self-selective.

Following the discretization, the consumption space can be seen as a discrete 29 point space in which a probability mass function is defined. The observed frequency of each of these points $(f_1, ..., f_{29})$ are available too.

If any of the parameters on which the theoretical distribution function is dependent on is unknown can be estimated by maximum likelihood. An alternative approach is to minimize the χ^2 statistic of the goodness of fit test of the observed frequencies to the theoretical probabilities $p_1, ..., p_{29}$; it is known that this is equivalent to maximum likehood estimation.

Otherwise, the estimated parameters must be compatible with the observed model and data. In this sense, it must be taken into account that the constant term of the demand function, a, depends on (θ_0, α) since it is derived from the relation

$$Q_0 = N \int_{\theta_a}^{\theta_0} a\theta p_0^{-b} r(\theta - \theta_a) d\theta + N \int_{\theta_0}^{\infty} a\theta p_0^{-b} \alpha k^{\alpha} \theta^{-\alpha-1} d\theta,$$

where Q_0 is the anual consumption with the current tariff structure, a two-part tariff with an entry fee A_0 and a marginal price p_0. Thus, the parameter a can be expressed as a function of (θ_0, α)

$$a = \frac{Q_0 p_0^b N^{-1}}{I(\theta)}.$$

with $I(\theta) = \int_{\theta_a}^{\infty} \theta f(\theta) d\theta$.

The parameters (θ_0, α) must give a value of a compatible with the data associated with the current tariff. In particular if θ_a is the smallest individual that participates in the current tariff, its net surplus must be nonnegative. This is,

$$S^N = S(q_0, \theta_a) - p_0 q(p_0, \theta_a) - A_0 = \frac{a}{b-1} \theta_a p_0^{1-b} - A_0 \geq 0,$$

where $p_0 = 15.02$ ptas/kWh and $A_0 = 2725.74$ ptas are the marginal cost and entry fee of the current tariff.[11]

With the previously defined demand, θ is given by $\theta = \frac{qp^b}{a}$, and substituting into the previous equation the following inequality is obtained

$$\frac{q_a p_0}{b-1} - A_0 \geq 0.$$

Taking into account that q_a, the consumption of the smallest type with the current tariff was 200kW this restriction is always verified.

The results of the estimation are presented in table 2.[12]

[11] The entry fee is computed by using the annual power term of tariff 2.0 for a consumer with contracted power equal to the average power used.

[12] A FORTRAN minimization routine with a penalization function was used for the parameter estimation.

Estimated parameters	θ_0	α	θ_a	r	k	Stat.(χ^2)
	1314.62	1.2018	239.95	5.705e-7	942.751	20.26(37.7)

Table 2: Estimated parameters of the consumption distribution.

5 Optimal tariff and welfare

To conduct efficiency comparisons with the current tariff, a two-part tariff pricing structure $T(q) = A+pq$, with a constant marginal price, p, per unit purchased and a fixed charge, A, per period, is considered. Both p and A are the same for all consumers. With the functional forms introduced in the previous section, the social welfare derived from consumption is given by

$$W = \int_{\theta_*(A,p)}^{\theta_0} [\frac{a}{b-1}\theta p^{1-b} - A]\theta^{-\eta} r(\theta - \theta_a) d\theta + \int_{\theta_0}^{\infty} [\frac{a}{b-1}\theta p^{1-b} - A]\theta^{-\eta} s\theta^{-\alpha-1} d\theta.$$

Profits can be defined as

$$B = A \int_{\theta_*(A,p)}^{\theta_0} r(\theta - \theta_a) d\theta + A \int_{\theta_0}^{\infty} s\theta^{-\alpha-1} d\theta + pQ - C(Q),$$

where Q represents the total output and is defined by

$$Q = \int_{\theta_*(A,p)}^{\theta_0} a\theta p^{-b} r(\theta - \theta_a) d\theta + \int_{\theta_0}^{\infty} a\theta p^{-b} s\theta^{-\alpha-1} d\theta.$$

In this section three alternative scenarios are considered in order to analize the efficiency of the Spanish electric system. In a first escenario it is taken as given the generating equipment and the assigment of output to the different technologies. In this framework a first aproximation to the efficiency losses asociated exclusively to the current 1993 tariff versus an optimal tariff is obtained. In a second scenario it again is taken as given the generating equipment but a change in the assigment of output to the different technologies is allowed. This gives a second aproximation to the possible efficiency gains from an optimal tariff and an optimal output allocation versus the current 1993 tariff and output allocation. Finally in a third scenario it is simulated the optimal generating equipment with the current technologies available in 1993. It is considered, too, the posible efficiency gains derived when none of the system characteristics are taken as given.

5.1 Non adapted generating equipment

5.1.1 Non optimal allocation of technology

In order to compute the optimal tariff in the non optimal allocation of technology scenario, 1993 production costs will be assigned to each consumer type. For this a particular production mix must be assigned to each consumer. If a consumer has a constant utilization level then the production of the optimal technology for this utilization should be assined to that consumer. In the case of residential consumers the optimal technology is gas, thus all gas production for 1993 is assigned to residential consumers. Given that residential consumption for 1993 is greater than the gas production for this year other technologies to meet the remaining residential demand must be considered. These technologies are assigned according to a second best criteria, that is, the next best tecnology given the constant utilization level of residential consumers. Following this assigment procedure until total residential demand is covered the following production assignment for 1993 residential consumption is obtained: gas (1795 GWh), imported coal (8601 GWh), black lignite (8178 GWh), brown lignite (11641 GWh), and hydro (6705 GWh).[13] The average cost for a residential consumer derived from this assingment is 8650 ptas. Non productive fixed costs plus profits associated to residential consumption are 11783 ptas which are obtained as the difference between tariff revenues and productive costs.

According to the definiton of marginal cost as the sum of the capacity and operating costs of the efficient technology the marginal cost of residential consumption in 1993 is 6.75 pesetas, which is marginal cost of gas tecnology.

Parameter	Item	Value
Price elasticity	b	1.8
Marginal cost (ptas/kWh)	c	6.75
Pareto elasticity	α	1.2018
Constant demand	a	109.3764
Average consumption (kWh)	$\overline{q}$	2141.15
Utilization level (hrs.)	h_u	2498
Average power used (kW)	$\bar{l}$	0.8572
Smallest type	θ_a	239.9452

Table 3: Parameters of base case.

The value of all parameters that are used in the computation of the different tariffs for the base case are presented in table 3.[14]

In table 4 the values of (p, A) for the current (c), optimal (o) and universal service tariff (s) are presented as well as the associated participation level (PL), and per consumer consumption level $(\overline{q})$, average power used $(\bar{l})$, and welfare $(\overline{W})$. The universal service tariff maximizes welfare maintaining the participation level of the current tariff.[15] In all cases optimal tariffs are computed subject to a restriction of maximum power demanded by the residential sector. This restriction is determined allowing consumers a proportion the system's overcapacity equal to their proportion total system contracted power. This restriction limits a residential consumer to a maximum consumption of 3183 kWh.

[13]Given the role of hydro technology as system regulator it cannot be attributed to a particular utilization level so it is assigned proportionaly to the consumption of each consumer type.

[14]The demand parameters are obtained using the IMSL multivariate minimization subroutines.

[15]The model is solved by means of GAMS (see Brooke et al(1988).

Tariff $q_{max} = 3183$	p (ptas/kWh)	A (ptas)	PL (%)	$\bar{q}$ (kWh)	$\bar{l}$	$\overline{W}$
$\eta = 0$						
v	15.02	2725	100.00	2141.15	0.857	37539
o=s	12.051	3561	100.00	3183.00	1.274	44470
$\eta = 2.91$						
v=o=s	15.02	2725	100.00	2141.15	0.857	1.4408E-5

Table 4: Tariffs with non adapted generating equipment.

As can be seen in Table 4, if the regulator is only concerned with efficiency thus giving all consumers an equal weight in total welfare function ($\eta = 0$), with a tariff structure similar to the current one it is possible to achieve a greater efficiency level while maintaining universal service. On the other hand, greater η values give more importance to distributive concerns. For a large enough value of this parameter ($\eta = 2.91$) the current tariff is optimal.

q_{max} $\eta = 0$	Tariff	p (ptas/kWh)	A (ptas)	PL (%)	$\bar{q}$ (kWh)
4183	o	10.354	5360	99.994	4183
	s	10.633	4950	100.00	3986
5183	o	9.190	7810	99.726	5183
	s	10.633	4950	100.00	3986
6183	o	8.326	10802	98.939	6183
	s	10.633	4950	100.00	3986
7183	o	7.649	14335	97.475	7183
	s	10.633	4950	100.00	3986
8183	o	7.155	17989	95.437	8064
	s	10.633	4950	100.00	3986

Table 5: Tariffs for several levels of maximum consumption.

In order to analize the influence of the maximum power restriction, in table 5 the optimal tariff and the universal service tariff for several levels of maximum allowed consumption are presented. Table 6 presents the efficiency gains for all cases considered when the welfare function weight is $\eta = 0$. When the maximum power demanded is determined by the installed generating system, the optimal tariff increases welfare by more than 18% maintaining universal service. These welfare gains increase with the maximum allowed consumption, achieving welfare gains of 47% if there is no maximum power constraint. However, the participation level is reduced by 95.5% with respect to the current tariff, that means that more than 780000 subscribers would not consume. In this case of no maximum power constraint the universal service tariff achieves welfare gains of 28.3% with respect to the current tariff.

q_{max} $\eta = 0$	$\overline{W}$ (Current)	$\overline{W}$ (Optimal)	$\Delta\overline{W}$ (%)	$\overline{W}$ (Univ. serv.)	$\Delta\overline{W}$ (%)
3183	37539	44470	18.46	44470	18.46
4183	37539	48904	30.27	48161	28.30
5183	37539	51934	38.35	48161	28.30
6183	37539	53919	43.63	48161	28.30
7183	37539	55041	46.62	48161	28.30
8183	37539	55363	47.48	48161	28.30

Table 6: Welfare associated with new tariffs for several levels of maximum consumption.

In order to verify the robustness of the results several alternative hypothesis for the base case parameters, which are given in Table 7, are analysed. The optimal and universal service tariffs, as well as the participation level and the average consumption and power levels for each case are given in Table 8 (with $\eta = 0$). Case b^- computes the tariffs for a low elasticity assumption, this results in a lower fixed fee and a higher marginal price. This is because the more inelastic demand is, the smaller is the welfare gain and the greater the revenue loss from a price reduction. In this sense a higher elasticity (case b^+) will result in a higher marginal price and a lower fixed fee.

Case	b	c	α
Base	1.8	6.75	1.2018
b^-	1.7	6.75	1.2018
b^+	1.9	6.75	1.2018
c^-	1.8	6.4	1.2018
c^+	1.8	7.1	1.2018
α^-	1.8	6.75	1.1518
α^+	1.8	6.75	1.2518

Table 7: Parameters values for several hypothesis.

With respect to the marginal cost it can be seen that a larger difference between marginal cost and average cost (defined as the ratio between total cost and total residental consumption), results in a need to fix a marginal price closer to marginal cost and verify the budget constraint with a larger fixed fee. When the marginal cost is larger the marginal price is closer the marginal cost. This result holds while the fixed fee is restricted to nonnegative values.

Case $\eta = 0$	Tariff	p (ptas/kWh)	A (ptas)	PL (%)	$\bar{q}$ (kWh)	$\bar{l}$ (kW)
base	o	7.155	17989	95.437	8064	2.876
	s	10.633	4950	100.00	3986	1.596
b^-	o	7.488	16203	94.570	6925	2.722
	s	10.643	5462	100.00	3846	1.539
b^+	o	6.839	20379	96.147	9472	3.791
	s	10.473	4617	100.00	4248	1.700
c^-	o	6.776	18675	95.526	8896	3.561
	s	9.959	5216	100.00	4486	1.795
c^+	o	7.530	17318	95.395	7354	2.943
	s	11.253	4731	100.00	3601	1.441
α^-	o	7.126	18219	95.395	8123	3.251
	s	10.633	4950	100.00	3987	1.596
α^+	o	7.181	17789	95.465	8013	3.207
	s	10.633	4950	100.00	3987	1.596

Table 8: Optimal and universal service tariffs under several hypothesis.

Regarding the variation of the Pareto elasticity for the distribution of consumption, α, a higher elasticity values result in a lower fixed fee and a higher marginal price, while lower values of α will result in a marginal price that approaches marginal cost. This is due to the fact that higher α values imply a higher proportion of consumers with low consumption values, and thus, raising the fixed fee in order to lower marginal price will strongly reduce market participation. Low α values, on the other hand, imply a smaller proportion of consumers with low consumption values and thus higher fixed fees cause relatively smaller efficiency losses in terms of a low participation level. For sufficiently low α values, marginal price may equal marginal cost.

Case	$\overline{W}$ (Current)	$\overline{W}$ (Optimal)	$\Delta\overline{W}$ (%)	$\overline{W}$ (Univ.serv.)	$\Delta\overline{W}$ (%)
Base	37539	55363	47.48	48161	28.30
b^-	43230	58826	36.08	53035	22.68
b^+	33192	53706	61.80	45126	35.95
c^-	37539	57934	54.33	50753	35.20
c^+	37539	53098	41.45	46029	22.62
α^-	37560	55515	47.20	48198	28.27
α^+	37522	55232	47.80	48129	28.32

Table 9: Efficiency gains under the different hypothesis.

Table 9 presents the efficiency gains derived under the optimal and universal service tariff with respect to the current tariff under the different hypothesis considered. In all the cases analized the optimal tariff raises welfare by more than 36%, and can be as high as 61% in the high demand elasticity case. In any case it must be borne in mind that the level of participation is never greater than 96.147% of the one acheived with the current tariff. The universal service tariff, on the other hand, limits the efficiency gains attainable to a range from 22% to 35%.

5.1.2 Optimal allocation of technology

If the generating system is optimally configured given the different technologies that are in use in the Spanish electric system in 1993, the technology that is responsible for covering residential demand for a constant duration of 2498 hours would be gas.

Tariff	p (ptas/kWh)	A (ptas)	PL (%)	$\overline{q}$ (kWh)	$\overline{l}$	$\overline{W}$
$\eta = 0$						
o	6.750	10724	99.569	9030	3.195	65764
s	7.247	6727	100.00	7950	3.183	65450
$\eta = 0.229$						
o=s	7.240	67274	100.00	7950	3.183	9931

Table 10: Optimal and universal service tariffs for a generating system optimally configured.

Table 10 presents the optimal and universal service tariffs for this case, without imposing any restrictions on capacity. The considerable reduction in costs when the generating system is optimally configured implies a significant reduction both in the marginal price and the fixed fee of the optimal tariff, and thus a high participation level (99.569%). In terms of efficiency, the welfare improvements are greater than 15% both for the optimal tariff and the universal service tariff.

Technology	Capacity cost (ptas/kW)	Operating cost (ptas/kWh)
Nuclear	49126	1.2494
Soft coal	17488	5.6351
Dun lignite	22625	5.1593
Black lignite	26907	5.8228
Imported coal	20313	3.2560
Gas	9203	4.8571
Hydro	7900	0.7499
Combined cycle	12081	3.9550

Table 11: Technologies costs for plants installed after 1980.

On the other hand, to measure the distorsions derived by the use of a non adapted generating system it is necesary to consider the evolution of the Spanish electricity industry with a strong investment in gas-oil plants in the sixties and the seventies that are not used after the oil crisis, and that at the current international prices are again efficient given the installed generating system. The current generating system is composed mainly of very old plants, some of which are amortized, which results in a infravaluation of the capacity cost of the installed generating system. Table 11 presents the cost data of generating plants that came into service since 1980.

Tariff	p (ptas/kWh)	A (ptas)	LP (%)	$\bar{q}$ (kWh)	$\bar{l}$ (kW)	$\overline{W}$
$\eta = 0$						
o	8.614	10348	99.012	5817	2.328	52629
s	9.668	5342	100.00	4732	1.894	51973
$\eta = 0.9$						
o=s	10.943	1579	100.00	3786	1.516	39.850
$\eta = 1.5$						
o=s	11.741	0	100.00	3335	1.335	0.457

Table 12: Optimal and universal service tariffs for an optimally configured generating system with plants installed after 1980.

Considering the data from table 11 gas is still the most efficient technology to serve residential consumption, and the cost function in this case is given by a fixed cost of 10678 per consumer and a marginal cost of 8.54 ptas. The optimal and universal service tariffs for different values of η are given in table 12 and will allow to make efficiency comparisons with respect to an adapted generating system.

5.2 Adapted generating equipment

Table 13 presents the optimal and universal service tariffs for residential consumers when an adapted generating system is considered, that is, a system composed by the most efficient technologies available and operating in an efficient way. This scenario reflects a situation of long run equilibrium in a competitive generation market. In particular combined cycle technology not present in the 1993 generating system is the most efficient technology to serve residential consumption. The cost that are associated with this technology were obtained from European manufacturers and are estimated to be 11084 ptas per installed kilowatt of capacity and 3955 ptas per hour of duration. This results in a marginal cost for the level of residential utilization of 8.39.[16]

Tariff	p (ptas/kWh)	A (ptas)	LP (%)	$\bar{q}$ (kWh)	$\bar{l}$ (kW)	$\overline{W}$
$\eta = 0$						
o	8.456	10379	99.065	6015	2.407	53537
s	9.453	5438	100.00	4927	1.972	52913
$\eta = 0.9$						
o=s	10.751	1449	100.00	3909	1.565	40.624
$\eta = 1.5$						
o=s	11.450	0	100.00	3490	1.397	0.466

Table 13: Tariffs for adapted generating equipment.

An approximation of the regulatory distortions in the Spanish system as of 1993 can be obtained comparing the welfare derived from the tariffs computed with a non adapted

[16]These figures were obtained from CSEN, the Regulatory Comission of Spanish electricity industry, and REE, the National Grid Company in Spain.

generating system, where gas and coal technologies are serving residential consumers, which follows from the costs studies in the MLE, and the welfare derived with the optimal tariffs that are obtained when residential consumption is served by combined cycle and coal technologies. In Table can be seen that the efficiency gains derived from the use of combined cycle technologies are greater than 1.70% for the optimal tariff.

Case	$\overline{W}$ Gas	$\overline{W}$ Combined cycle	$\Delta\overline{W}$ (%)
$\eta = 0$			
o	52629	53537	1.70
s	51973	52913	1.78
$\eta = 0.9$			
o=s	39.850	40.624	1.91
$\eta = 1.5$			
o=s	0.457	0.466	1.93

Table 14: Efficiency gains derived from the use of combined cycle technologies.

6 Conclusions

Tariff discrimination by utilization level attempts to attain the efficiency gains associated with the use of capacity tariffs based on duration, by using information on consumption and used power. In this sense it incorporates the optimality concerns of a capacity price structure, but it relys on an assumption of homogeniety in the consumption duration patterns of different individuals.

In the case of the Spanish electricity industry two other factors may weaken the optimality objective of the tariff structure. First, the tariff establishes a limited number of utilization ranges based on the distribution of consumers and not the different costs of the technologies used in order to supply these consumers. Second, an objective function for the regulator is not specified.

In this paper several two part tariff for residential usage level are computed considering several alternative hypothesis on the installed generating system. Taking as given the generating equipment and the output assigment to the different technologies, the optimal tariff increases welfare by more than 18% maintaining universal service. On the other hand, the welfare losses associated to a non optimal mix of production technologies are larger than 1.7%. These welfare losses are larger when the regulator is concerned not only with efficiency but also with distributive issues. In any sense, this means that the smaller consumers are penalized with the current regulatory framework.

It would be interesting to complement the current Spanish tariff structure based on utilization levels with time of use tariffs. These would allow to capture the divergences in demand and operating costs in the short term. For this, a multiproduct formulation would be more usefull.

7 Appendix

7.1 Agregated costs in time periods

In the costs agregation by vertical intervals the consumption costs for each time period are beeing considered. Figure 5 shows, for example, that each hour h in which the consumer's load $L(h)$ is in the range $L_2 < L(h) < L_1$ is identified with the source II that is the marginal generator in that hour. The marginal cost of energy es therefore v_2, but in addition the inframarginal units of power are generated with the source III. The total cost of consumed energy in hour h is the sum the marginal costs of energy from the sources used.

Insert Figure 5

The total costs to meet the customer's load-duration curve can be derived by integrating by parts the formula for the total cost of the consumption set when horizontal intervals are considered, and can be written in the case of three tecnologies as

$$C(H) = C_0 + f_1(L_0 - L_a) + f_2(L_a - L_b) + f_3(L_b - L_1)$$

$$-v_1 H_1 L_a + v_2(H_1 L_a - H_2 L_b) + v_3 H_2 L_b$$

$$+ \int_0^{H_1} v_1 L(x)dx + \int_{H_1}^{H_2} v_2 L(x)dx + \int_{H_2}^{H_3} v_3 L(x)dx.$$

7.2 Two part tariff problem

7.2.1 Social Welfare (W)

The social welfare derived can be written as

$$W = \int_{\theta_*(A,p)}^{\theta_0} [\frac{a}{b-1}\theta p^{1-b} - A]\theta^{-\eta} r(\theta - \theta_a)d\theta$$
$$+ \int_{\theta_0}^{\infty} [\frac{a}{b-1}\theta p^{1-b} - A]\theta^{-\eta} s\theta^{-\alpha-1} d\theta$$

With this ecuation the social welfare can be written as

$$W = \frac{a}{b-1}p^{1-b} r[\frac{\theta_0^{3-\eta}}{3-\eta} - \frac{\theta_a\theta_0^{2-\eta}}{2-\eta} - \frac{\theta_*^{3-\eta}}{3-\eta} + \frac{\theta_a\theta_*^{2-\eta}}{2-\eta}]$$

$$-Ar[\frac{\theta_0^{2-\eta}}{2-\eta} - \frac{\theta_a\theta_0^{1-\eta}}{1-\eta} - \frac{\theta_*^{2-\eta}}{2-\eta} + \frac{\theta_a\theta_*^{1-\eta}}{1-\eta}]$$

$$+\frac{a}{b-1}p^{1-b} s\frac{\theta_0^{1-\eta-\alpha}}{\alpha+\eta-1}$$
$$-As\frac{\theta_0^{-(\alpha+\eta)}}{\alpha+\eta}$$

7.2.2 Profit (B)

The profit can be defined as

$$B = A\int_{\theta_*(A,p)}^{\theta 0} r(\theta-\theta_a)d\theta + A\int_{\theta_0}^{\infty} s\theta^{-\alpha-1}d\theta + (p-m)Q - cf$$

where Q represents the total output consumed and is defined as

$$Q = \int_{\theta_*(A,p)}^{\theta_0} ap^{-b}\theta^d r(\theta-\theta_a)d\theta + \int_{\theta_0}^{\infty} ap^{-b}\theta^d s\theta^{-\alpha-1}d\theta$$

Sustituing and solving the integral the profit can be written as

$$\begin{aligned} B = \; & Ar[\frac{\theta_0^2}{2} - \theta_a\theta_0 - \frac{\theta_*^2}{2} + \theta_a\theta_*] + AK^{\alpha}\theta_0^{-\alpha} \\ & + (p-m)ap^{-b}r[\frac{\theta_*^{d+2}}{3} - \frac{\theta_a\theta_0^2}{2} - \frac{\theta_1^3}{3} + \frac{\theta_a\theta_*^2}{2}] \\ & + (p-m)Nap^{-b}s\frac{\theta_0^{d-\alpha}}{\alpha-d} - cf \end{aligned}$$

7.2.3 Marginal Consumer Surplus (EC_1)

The marginal consumer θ_* can be defined as the consumer with a null net surplus. This surplus can be defined using the last ecuation as

$$EC_* = \frac{a}{b-1}p^{1-b}\theta_*^d - A.$$

Then, the marginal consumer will be

$$\theta_*(A,p) = \left(\frac{b-1}{a}\right)^{\frac{1}{d}} A^{\frac{1}{d}} p^{\frac{b-1}{d}}.$$

7.2.4 Problem

It is the result of the following optimization program

$$[P] \equiv \begin{cases} \max_{\{A,p\}} W & \\ s.a. & B \geq 0 \end{cases}$$

where W and B are the functions defined above. The theoretical solution to problem is as follows

$$\frac{p-m}{p} = \frac{\alpha}{e_p(p,\theta_*)}\left[1 - \frac{q(p,\theta_*)}{\overline{Q}(p,\theta_*)}\right],$$

$$\frac{A+(p-m)q(p,\theta_*)}{A} = \alpha\frac{[1-F(\theta_*)]}{A\; f(\theta_*)\; \partial\theta_*/\partial A},$$

where $\alpha = \frac{\lambda - 1}{\lambda}$, with λ as Lagrangian multiplier, and

$$e_p(p, \theta_*) = -\int_{\theta_*}^{\infty} \frac{\partial q}{\partial p} f(\theta) d\theta \frac{p}{Q},$$

$$\overline{Q}(p, \theta_*) = \frac{\int_{\theta_*}^{\infty} q(p, \theta) f(\theta) d\theta}{\int_{\theta_*}^{\infty} f(\theta) d\theta},$$

$$Q(p, \theta_*) = \int_{\theta_*}^{\infty} q(p, \theta) f(\theta) d\theta,$$

The explicit solution to p and A have to be computed with numerical computation because it depends if the value θ_* is in the linear or Pareto part of the types distribution.

7.3 Data

7.3.1 Frequencies of consumption

Interval		Frequency (%)	Interval		Frequency (%)
0	500	8.61	7501	8000	0.36
501	1000	19.17	8001	8500	0.28
1001	1500	18.70	8501	9000	0.21
1501	2000	14.73	9001	9500	0.17
2001	2500	10.79	9501	10000	0.13
2501	3000	7.71	10001	10500	0.10
3001	3500	5.48	10501	11000	0.08
3501	4000	3.90	11001	11500	0.07
4001	4500	2.80	11501	12000	0.05
4501	5000	2.03	12001	12500	0.04
5001	5500	1.48	12501	13000	0.04
5501	6000	1.10	13001	13500	0.03
6001	6500	0.82	13501	14000	0.02
6501	7000	0.61	14001	14500	0.02
7001	7500	0.47			

7.3.2 Tariff 2.0 in 1993

Parameter	Item	Value
Suscribers (thousands)	N	17243
Power used (MW)	P	60690
Consumption (GWh)	Q_0	36920
Billing (mil.ptas)	I	747340
Price (ptas/kWh)	p_0	15.02
Fixed fee (ptas)	A_0	2725.74
Power charge (ptas/kW,year)	P.C.	265

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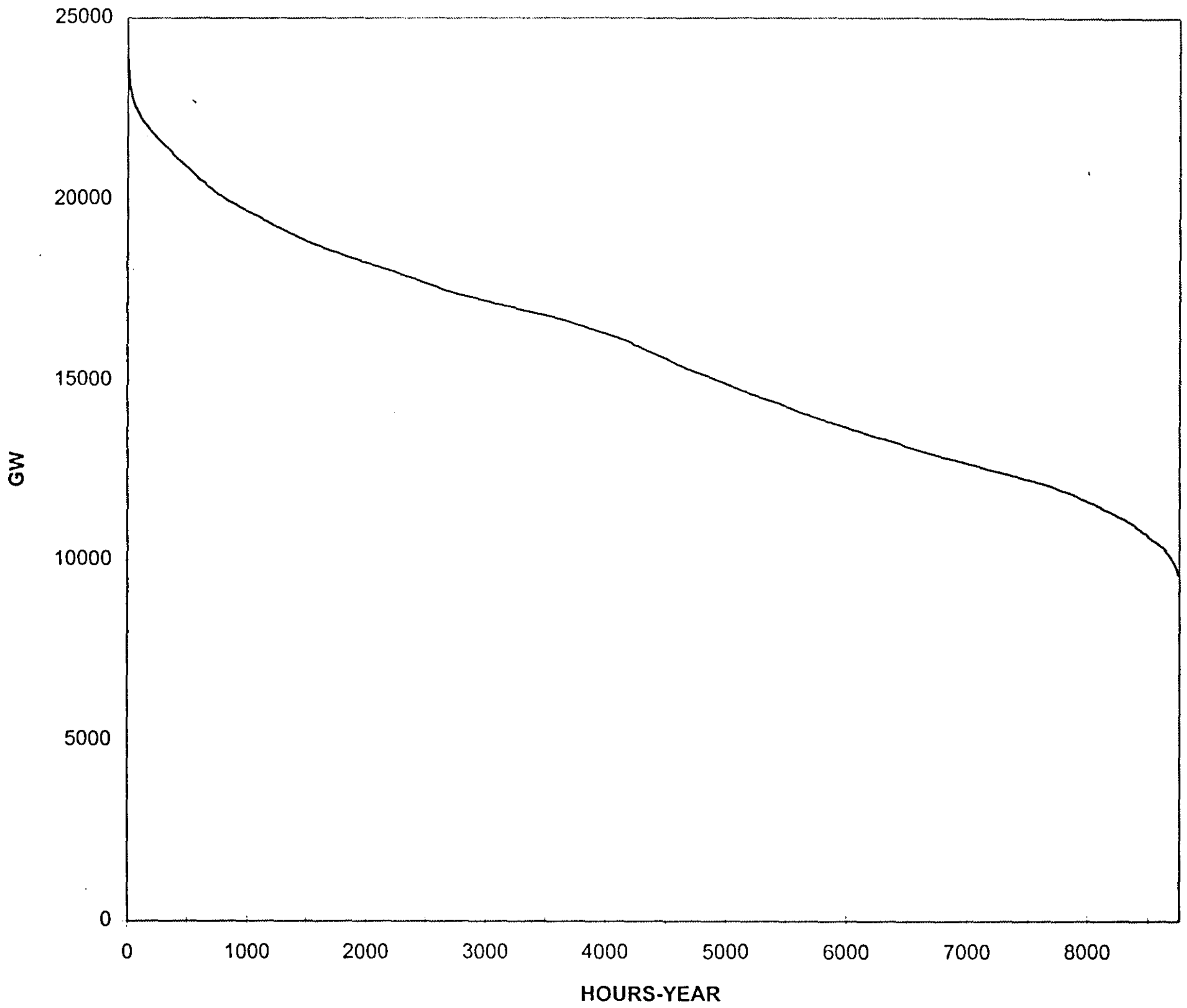

Figure 1: Load-duration curve, 1993 (CSEN).

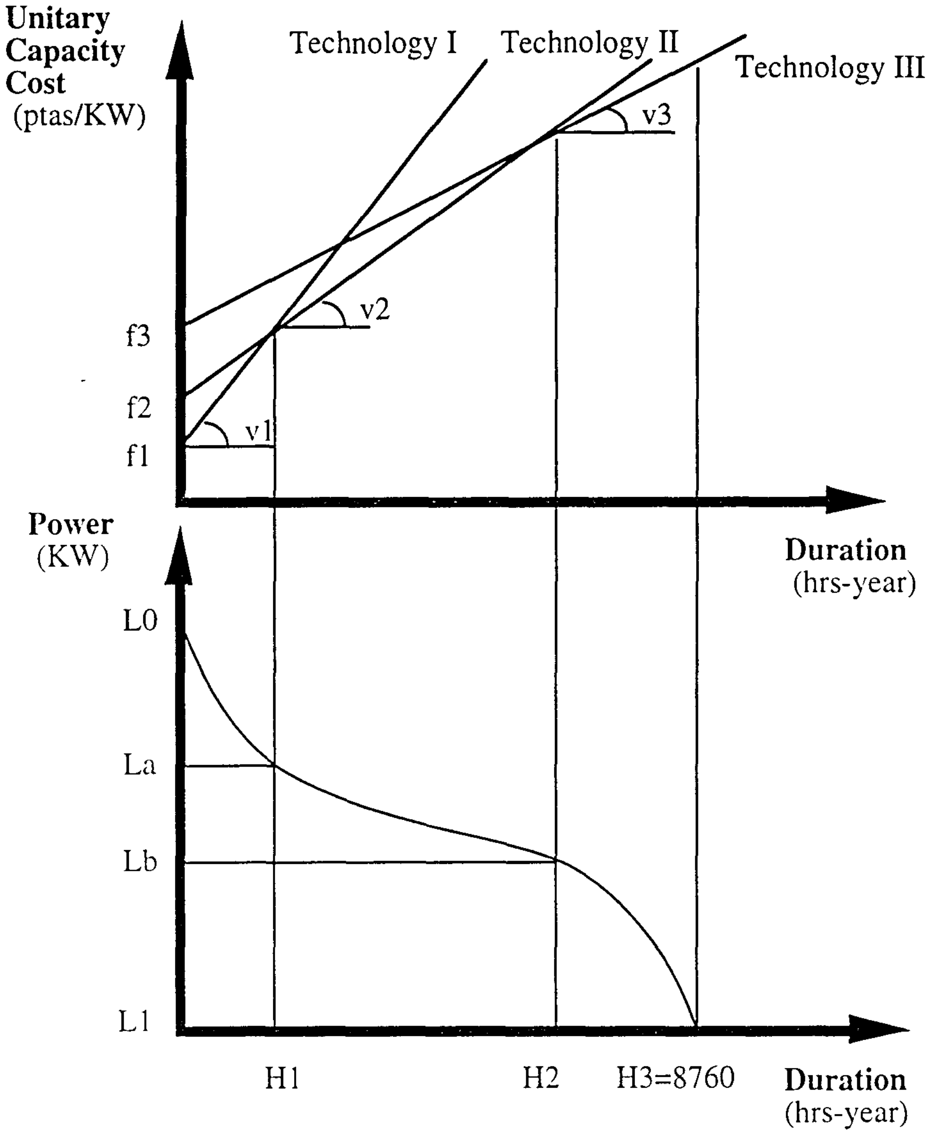

Figure 2: Optimal mix of production technologies.

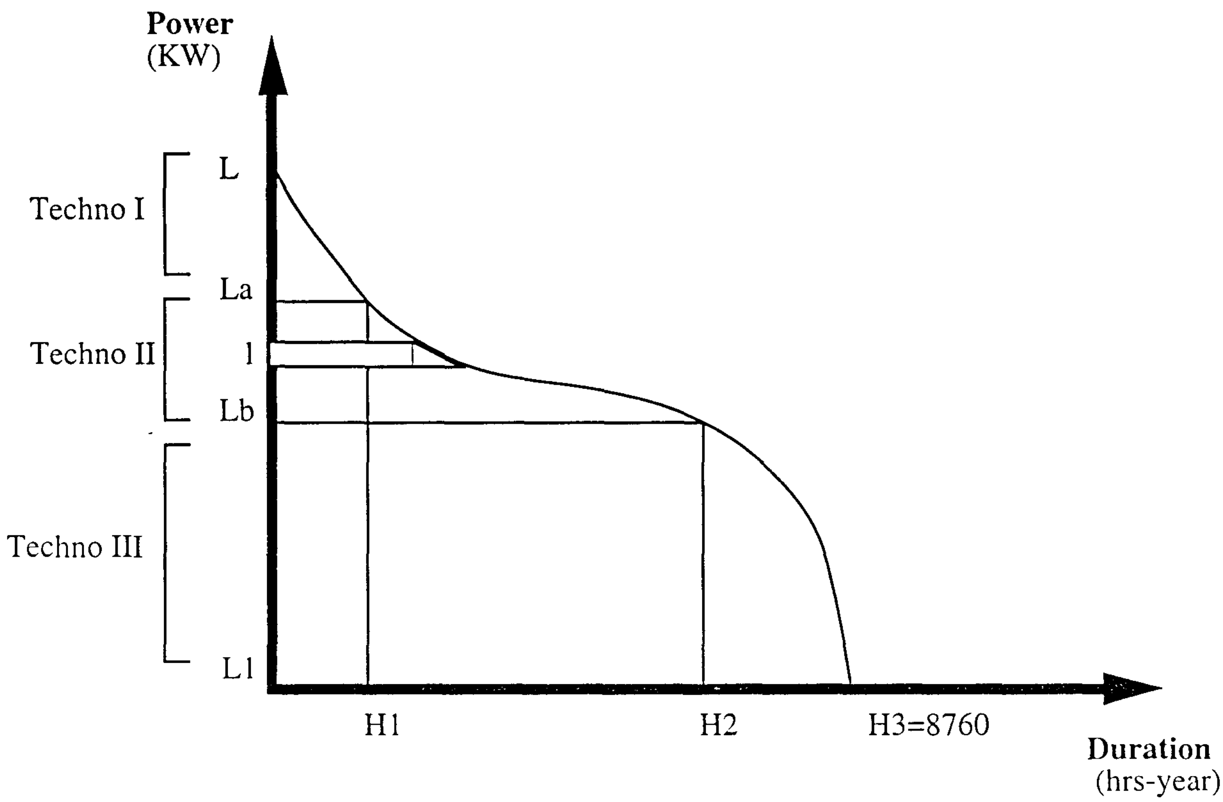

Figure 3: Horizontal slice costs of load-duration curve.

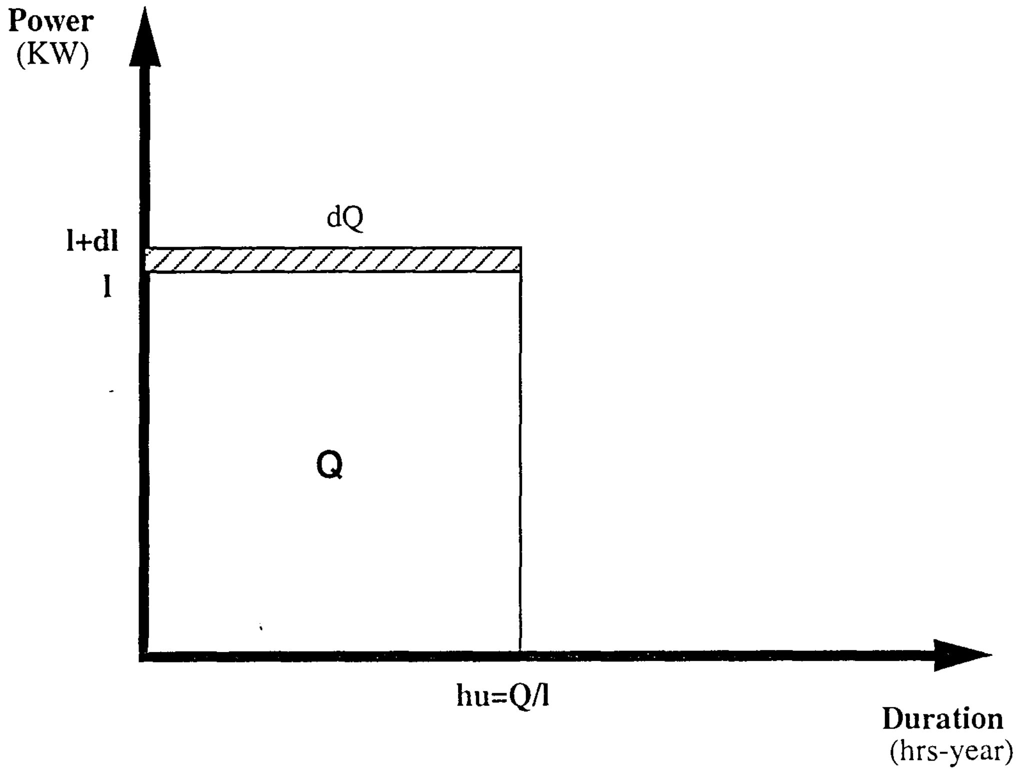

Figure 4: Rectangular load-duration curve for an utilization level hu.

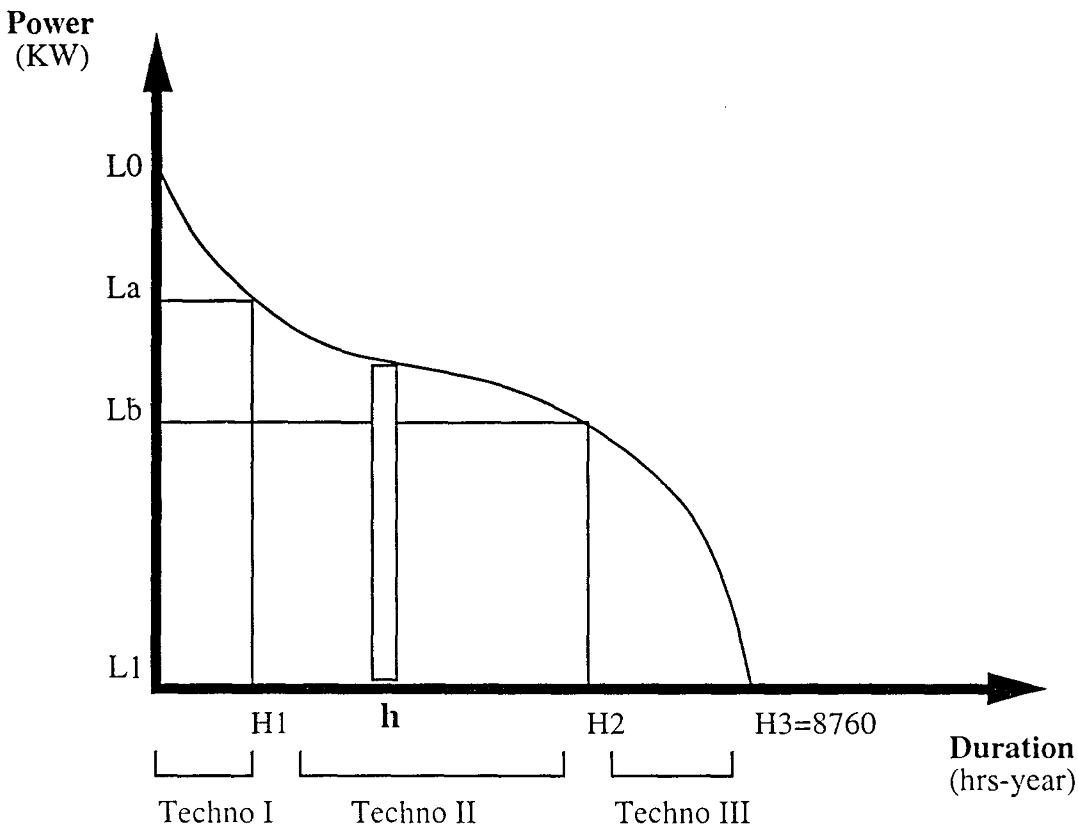

Figure 5: Vertical slice costs of load-duration curve.