Turning on the lights: How to remodel electricity in a greener, price-competitive and consumer-oriented market?

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January, 2010

Abstract

This paper emphasizes three current regulatory issues in electricity markets and presents for each a theoretical solution.

The analyzed regulatory concerns are (i) the reduction of pollution emission at the generation level; (ii) the market dominance and lack of investment/ power quality at the transportation level; and (iii) the service quality and final price at the supply level.

I show that the regulatory implementation of (i) the *polluter-competitor principle* presses power generators to invest in less polluting technologies; (ii) a rate-of-return regulation, at the transportation level, indexed to inconveniences cost to consumers induces to the social optimal investment at this stage in the network; and (iii) a wholesale price, at the supply level, indexed to service quality together with a end-user price cap enhances cost efficiency and better service quality provided.

Keywords: Electricity, Competition, Natural Environment, Power and Service Quality, Regulation.

JEL Classification: D42, L43, L51, L94.

1. INTRODUCTION

Electricity is a vital service in the economy, it is an input in the production of nearly all other goods and services, and it is also an important final good, consumed by households.

Over the last two decades, the regulatory environment of the electricity supply industry has begun to change. A few OECD countries have implemented new regulations to stimulate competition by attempting to liberalise the industry, focusing reform efforts on functions that do not possess a natural monopoly component. In particular, some OECD countries have passed legislation to introduce competition in electricity generation and retailing by unbundling these functions from the "wires" part of the business, providing mechanisms for new entrants to access existing networks, and creating markets where price is determined by supply and demand. Even in the case of these early reformers, implementation of reform has been a slow process to actual progress toward competition. Today, OECD countries are on the cusp of liberalization, namely European Union countries, which face the implementation deadlines of the European Commission Electricity Directive to establish a single internal market for electricity in Europe.

The reform programmes adopted by countries have tended to include the following four main elements:

i) Introduction of competition to the sector in order to improve efficiency, customer responsiveness and innovation.

ii) Restructuring the industry in order to enable the introduction of competition. This means breaking up, or *unbundling*, the incumbent monopoly utilities possibly into separate generation, transmission, distribution and supply providers.

iii) Privatisation of the unbundled generators and suppliers. It is expected that entities under dispersed ownership will facilitate competition and that private investors and operators will bring in financial resources and managerial expertise into production and supply, previously dominated by sleepy state-owned monopolies.

iv) Development of a new regulatory framework. State regulation is still required especially of those areas of electricity supply that remain dominated by one or a very small number of operators, to prevent monopoly abuse. Instead of direct regulation by a government department, the establishment of independent or quasi-independent regulatory bodies, in the forms of offices and commissions. Energy supplies and prices are always of interest to politicians because supply failures and sharply higher prices can provoke social unrest. Some form of independent regulation can provide reassurance to investors that prices, outputs and inputs will not be politically manipulated. However, there is an extensive literature on the distorting effects of state regulation even when conducted by dedicated regulatory bodies (Armstrong *et al*., 1994; Guasch and Hahn, 1999).

Most policy makers and economists agree that liberalisation of the electricity sector should enhance consumer welfare by reducing prices;

however, there is no consensus on the specific regulatory reforms most likely to achieve the benefits of competition.

Before I present the main ideas and possible regulatory answers for the electricity sector, first I explain the basic structure of power systems and do an exposition of some issues that regulators face nowadays.

The Electricity supply industry: an overview. Regulation of the electricity supply industry is primarily motivated by the existence of natural monopoly conditions, externalities, and public good characteristics. These result from a number of unique economic characteristics: i) the non-storability[1] of electricity reduces the size of markets according to the time dimension; ii) the size of the market is determined by instantaneous demand rather than demand over a longer time period, as a consequence, it is more likely that a single firm can supply consumers in a given market at minimum efficient scale; iii) the demand for electricity is subject to great cyclical, seasonal, and random variation in both the short and long term; iv) to satisfy customers' expectations, supply must be continuous, reliable, and supplied with sustained frequency and voltage, therefore, electricity producers must maintain "spinning reserve" and "black start capacity".[2] The pairing of variable demand and continuous supply requires that suppliers maintain excess capacity to meet peaks in demand. As the number of customers supplied by a given utility increases, reserve margin requirements decrease because the grouping of heterogeneous consumers

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[1] Chemical storage of electricity such as in lead-acid batteries is too costly to be used to store any meaningful amount of electricity in a system. Technologies do exist to turn electrical energy into potential mechanical energy which is storable such as compressed air or pumped hydro electrical storage.

[2] *Spinning reserve* is a quantity of capacity able to provide energy instantly; a plant in spinning reserve incurs operating costs but does not provide electricity to the network. *Black start* capability is the ability of a generating unit to start up when system power has been lost.

effectively pools risk faced by suppliers, and, as a consequence, operating and capital costs per customer decrease. In short, these conditions lead to increasing returns to scale and cost efficiencies to be realised by a monopoly market structure.

Additionally, externalities occur because the operation, function, and malfunction of each generator affect system conditions throughout the entire interconnected network. Moreover, investment in generating capacity involves difficult dynamic optimization in the face of uncertainty, externalities in the sense that any addition or deletion of capacity affects the entire network, and public good characteristics in the sense that additions to a transmission network benefit all producers and consumers. The externality and public good aspects of electricity suggest the need for planning and co-ordination of the electricity supply network, roles that may also be most efficiently performed by a natural monopolist.

Functional decomposition of the electricity supply industry. While on the whole, electricity supply is characterized by conditions of natural monopoly, externalities, and public goods, some of its functional segments do not possess these economic features.[3] The electricity supply industry can be functionally divided into *generation*, *transmission*, *distribution* and *supply*. This functional division is particularly important for understanding regulatory developments and how to regulate the industry. The different functions are differentiated technologically and economically, and regulatory reform has tended to proceed at this level of disaggregation.

[3] *Natural monopoly* is when a single firm can supply a good at lower total cost than two or more firms. An *externality* is when a consumer or firm is affected by the consumption or activity of other agents in the economy.

Generation is the production of electricity. It involves the transformation of another form of energy into electrical energy. Electricity production may use oil, natural gas, coal, nuclear power, hydro power (falling water), renewable fuels, wind turbines, and photovoltaic technologies. The different generating technologies are differentiated according to cost structure. The main cost components of electricity generation are (delivered) fuel prices, capital costs, and operating and maintenance costs. Costs are also influenced by the performance of the generating technology (capacity factor, thermal efficiency, and operating life)[4].

Transmission and *distribution* comprise the "wires" functions. Transmission is the high-voltage transport of electricity. However, transmission is not merely transportation, but it also involves the management of dispersed generators in a grid to maintain suitable voltage and frequency and to prevent system breakdown. Transmission is a natural monopoly because competition in transmission would result in duplication of the existing network, duplicating high voltage AC networks and competing grid co-ordinators would increase transmission costs.

Co-ordination of generators in a merit-order lies between generation and transmission. From this perspective, integration of generation and transmission would lead to economies if it internalises externalities that result from dispersed generators who make investment and operating decisions that affect the entire network. On the contrary, if generation (itself not a natural monopoly) is integrated with transmission, then it will be subject to the same regulatory challenges and inefficiencies as transmission under rate-of-return regulation.

[4] *Capacity factor* is the utilisation of capacity. *Thermal efficiency* is the ability to generate electricity output per unit of fuel input. *Operating life* is the scheduled lifetime of a plant. IEA (1994) *Electricity Supply Industry,* Paris, p. 65.

Distribution is the low-voltage transport of electricity. Like transmission, it is generally considered to be a natural monopoly; competition would similarly entail duplication of the existing set of “wires”. Unlike transmission, there are no benefits to its integration with generation.

Finally, *supply* of electricity is the sale of electricity to end-users. This includes metering, billing, and marketing, and may be wholesale or retail. Supply is not considered to be a natural monopoly, nor are there significant advantages to its integration with the other functions.

Literature review. Although the academic literature is broad in scope, most articles fall into two categories. The first category is cost analysis — primarily the measuring of scale economies. That is, researchers attempt to determine where firms are operating on their long run average cost curves and subsequently determine whether production costs can be lowered by having firms increase or decrease their scale of production. The second category, much larger than the first, is analysis of the regulatory aspect of the industry and the unanticipated consequences of those regulations. Relevant regulations involve not only those related to the environmental impact of electricity generation but also those regulating profits by setting the price that firms are allowed to charge for their electricity and the quality of service.

This paper fits in the second mentioned category presenting three regulatory problems, each one on a different functional stage of the electricity production process, and solutions.

The electric utility industry, like most public utilities, is considered a natural monopoly and has faced state and local regulations since the late

1800s.[5] Natural monopolies, by definition, exhibit decreasing average and marginal costs over a wide range of output because of high fixed costs (plants, equipment) and low variable and marginal costs. Thus, one firm can produce most or all of the electricity demanded by consumers more cheaply than could multiple firms. Monopoly pricing (P_M) involves charging a price greater than the marginal cost (MC) of production and producing an output level (Q_M) lower than that under perfect competition (Q_C), therefore resulting in a loss in economic efficiency.

The basic model of monopoly regulation posits that regulators aim to reduce the price charged by the monopolist and expand the monopolist's output. One common approach is to set the price (P_C) equal to the marginal cost of production. This mimics pricing under perfect competition, however, given the cost structure of monopoly, marginal costs are below average costs, so marginal cost pricing often results in a financial loss for the monopolist. Average cost pricing deviates from the competitive price and output level (because average costs > marginal costs), but still results in a price and output level that approximates the competitive solution.

Although in theory the regulation of monopoly pricing is fairly straightforward, in reality it may be difficult to achieve the price and output levels that would exist under perfect competition, given that regulation occurs in political markets. As first discussed by Stigler (1971), consumers and producers have different objectives with regard to monopoly prices — consumers prefer lower prices and greater output, whereas the monopolist prefers higher prices

[5] See Warkentin-Glenn (2006) for a history of the electric utility industry.

and lower output. According to Stigler, it is reasonable to assume that both groups exert political pressure to set regulatory outcomes in their favor.

Stigler's model shows that a vote-maximizing regulator will set a utility's sale price of electricity such that the marginal gain in support from producers is just offset by the loss in consumer votes. Political competition between consumers and producers will ensure that the regulated price will lie somewhere between P_M and P_C and the regulated output will lie somewhere between Q_M and Q_C. The exact location will depend on the relative strengths of consumer and producer groups in exerting political pressure. Given that the cost of organizing producer groups is much less than the cost of organizing thousands or millions of consumers (Olson, 1965; Peltzman, 1976), producers are likely to exert more political pressure than are consumers; as a result, regulation will likely favor producers.

In Borenstein (2001), the author presents the fundamental problem with electricity markets: in nearly all electricity markets, demand is almost completely insensitive to price fluctuations and supply faces binding constrains at peak times. Combined with the fact that unregulated prices for homogeneous goods almost always clear at uniform (or near uniform) price for all sellers, regardless of their costs of production, these attributes necessarily imply that short-term prices for electricity are going to be extremely volatile. Borenstein presents two policies that would mitigate the fundamental trouble: long-term wholesale contracts between buyers and sellers and real-time retail pricing of electricity, which will indicate to the final costumer when electricity is more or less costly to consume. Long-term contracts allow buyers to hedge against price booms and sellers to hedge against price busts. The simplest form is one that simply sets a price and quantity to be delivered at every point in time, and leaves it to the producer to try to increase its profits by meeting that supply commitment in its most cost-efficient manner.

While long-term contracts surely must be part of the solution, they should not be as the entire solution. A much more cost-efficient and environmentally responsible response to the problem combines long-term contracting with real-time retail pricing. The author shows that prices can reflect real-time variation in price of electricity while monthly electricity bills can remain quite stable through the use of long-term contracts. Furthermore, implementing real-time retail pricing could substantially reduce the prices buyers would need to offer to procure long-term contracts. Together, these two policy responses would help to produce an electricity market that operates in a smooth, cost-effective, and environmentally responsible manner.

Another aspect of regulation that has garnered attention in the literature is the potential for unintended consequences as a result of regulation. Unintended consequences are unanticipated effects from policy actions. Examples from other industries include those described by Hall, Propper, and Reenan (2008), who find that regulated pay for medical staff across geographically heterogeneous labor markets results in problems with recruiting, retaining, and motivating high-quality workers, which ultimately affects hospital performance; and Nelson (2003), who finds that the regulation of alcohol advertising initiated to restrict demand for one type of product creates increased demand for other alcoholic products.

Overcapitalization in the electric utility industry is one unintended consequence of regulating the industry. Regulation of transmission typically involves rate-of-return regulation of prices; therefore a firm is motivated to purchase an inefficiently large amount of capital because a regulator ties the firm's allowed profit to its capital stock. Averch and Johnson (1962) argued that privately owned utilities invest in capital beyond the cost-minimizing level in response to the incentives offered by regulation.

Motivation and panorama: three regulatory issues. Climate change has become one of the most pressing political and economic issues in recent years. Scientists point to rising carbon dioxide levels due to human activity as a major contributor to a warming environment. The costs associated with climate change are uncertain, but may be extreme. Governments around the world are implementing environmental regulations that tax or price carbon dioxide emissions or significantly increase renewable energy production. Regulations which reduce emissions in meaningful amounts will have major implications on a country's economy. Increased energy prices due to regulation will lead to different paths of consumption, production, and labor usage.

Some policies have already been implemented to reduce emissions from electricity generation. Since the 90's, solar and wind electricity generators have received production subsidies from the US federal and lately from the Portuguese government, however, despite growth in new carbon free generators, CO_2 emissions from electricity production continue to rise in the aggregate.[6] Legislators are now looking at market based regulations, such as

[6] The CO_2 emission in Portugal passed from 60 million tons in 1990, the year taken as reference in the Kyoto Protocol, to 84,5 million tons in 2004, i.e. a rise of 41%. See *Portugal aumenta emissão de gases in* Jornal de Notícias, 2006-06-23.

cap, trade programs, *Green Certificates*[7] and carbon taxes, which directly price carbon emissions as a potential solution to rising CO_2 emissions.

One of the most important contributions of this paper is the presentation of a new market based regulation such that it takes power generators to compete in investments in greener technologies.

According to Braz and Esteves (2008), during the period 1994 - 2006, demand from power sector in Portugal increased constantly at an average annual rate of about 6% (Figure 1) and is not expected to decrease in the near future.

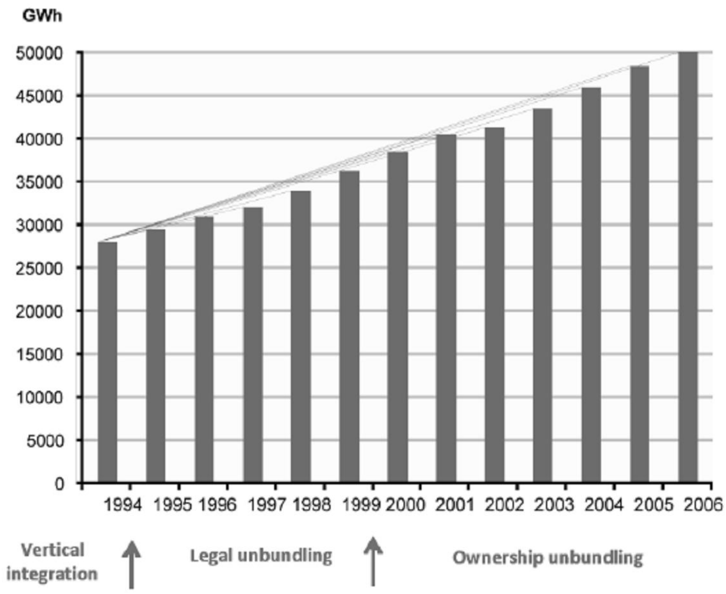

Figure 1: Total Electricity consumption in Portugal. Source: Braz and Esteves (2008).

Moreover, the demand for electricity is almost perfectly inelastic in the short-run; very few consumers of electricity are willing or able to adjust consumption in response to changing market conditions, even a very large

7 A *Green Certificate* is a tradable commodity proving that certain electricity is generated using renewable energy sources. Typically one certificate represents generation of 1 Megawatt hour of electricity. Green certificates represent the environmental value of renewable energy generated. The certificates can be traded separately from the energy produced.

carbon tax would lower emissions by only a small percentage in the short run.[8] The solution for the pollution problem should not focus on reducing electricity production/consumption but instead, with the right investments, turn the production into a clean process.

This paper also concerns about two other issues in the electricity supply industry. One of them is related with the design of a rule to incentive investment in power quality at the distribution level. This issue is important because electricity is fundamental to economic performance and international competitiveness of almost all economic sectors. Competitive economies are strongly dependent on reliable, secure and high quality electricity services.

One of the most important components of power quality is the continuity of power supply since any outage can have significant impact on the production costs of industrial production sites. More recently, continuity of power supply gained importance due to the continuous growing importance of information and communication technology in industry, services and households. Furthermore, domestic consumers are also strongly dependent on electricity which is considered an essential good, and electricity outages are not compatible with our society way of life. Another component of power quality is related to disturbances involving characteristics of the supplied voltage, known as voltage quality. Affecting specific kinds of equipments, these phenomena are critical on certain types of industrial facilities.

Power quality responsibility is assumed by network operators that must assure an equal power quality for all consumers, at the same network location.

[8] In Cullen (2008) the author shows that total emissions from the electricity industry in US do not change significantly when faced with carbon tax rates at the levels currently under consideration by legislators. A very large carbon tax of ten times that of expected price levels lowers emissions by only 9% in the short run.

On the other hand, each consumer wants to have at their disposal the amount of electricity they need, when they want and with the quality allowing their appliances to run properly. Since the operators' investments must be remunerated and the revenues of network operators come from the regulated access tariffs paid by all consumers, the operators' decision process is a permanent trade-off between the level of power quality targeted and investments costs to be incurred in order to reach this target, Figure 2. Price and quality always come together.

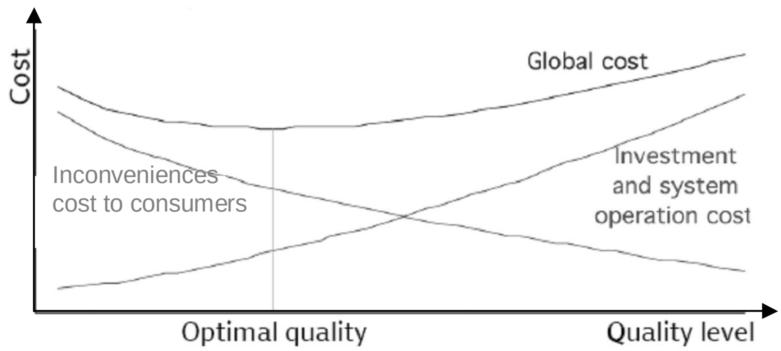

Figure 2: Trade-off between power quality level, investment costs and inconveniences to consumers. Source: Barros, Cristina, Clara, Maria José, *et al* (2008).

In theory, from the system overall, an optimal power quality value could be defined by taking into consideration the evolution of the investment costs (increasing with the quality level value) together with the inconveniencies cost to consumers (decreasing with the quality level value).

One solution that regulators used, namely in U.S., to motivate investment in the electricity transportation while regulating prices is the rate-of-return regulation of prices. However, if the allowable rate is too high, the consequence of this is overcapitalization as claimed by Averch and Johnson (1962). To avoid overcapitalization I propose an indexed rate of return to the inconveniences cost to consumers. Hence, if an exogenous event changes the inconveniences cost structure to consumers this will be taken into account (positively or negatively) in the rate-of-return so that the chosen investment level by the firm matches the social optimal. Note that if inconveniences cost is higher (lower) it means that consumers are willing to pay more (less) for investments in the network, then investors will be rewarded (penalized) with higher (lower) rates-of-return, recovered in terms of charged prices.

To conclude the paper, I discuss a strategy of wholesale price indexation to service quality that can be followed by the regulator with the aim to promote the service quality faced by end-users.[9] The gradual liberalization of the markets of the electric sector in the European Union has lead to a bigger interest and visibility of the aspects related with the quality, more concretely the *quality of service* of the supply of the electric energy. Face to the constitution of the Iberian Electricity Market (MIBEL) this element assumes particular importance for the involved countries, Portugal and Spain. It is a concern for regulators that the service to the final consumer[10] satisfies consumers' specific needs and be offered in an efficient way.

Summarizing Goals and Results: a guide for regulators. This paper seeks to provide practical regulation answers to three issues in the electricity market which are listed below.

i) A power generation issue. Electricity producers are the leading emitters of CO_2 and other pollutants putting in danger the sustainability of the current economic and social models, namely due to the environmental damage

[9] Other strategies to improve service quality are presented in the conclusions with base in CEER (2001, 2008).
[10] It is considered a *consumer* any entity that receive electric energy for own use.

motivated by energy consumption and the long run economy of energy resources.

To solve this problem I change the well-known *polluter pays principle* giving it a competitive dimension among firms in the electrical generation segment. Specifically, the paper proposes a *polluter-competitor principle* where the firms that pollute relatively more (i.e. present higher levels of CO_2 emission per unit produced of electricity) have to pay those that pollute relatively less. This principle raises incentives for each firm to invest in the reduction of pollution and get paid for the others who have invested less i.e. that have pollute more by each unit of electricity produced. The bottom line is that with the polluter-competitor principle the regulator is adding a new stage of competition in cleaner technologies in the electricity generation phase. The equilibrium outcome from the implementation of this principle is that electricity generators will invest more in greener technologies and thus reduce CO_2 emission.

ii) A transmission/transportation/distribution issue. Network services of transmission/transportation and distribution are natural monopolies that might take advantage of its market power to inflate prices imposing heavy restraints on electricity consumption and make fewer investments in the network *vis-à-vis* the social optimal amount.

In order to correct this, I propose an indexed rate-of-return to the inconveniences cost to consumers. Specifically, the firm is rewarded according to a rate-of-return over its investment; hence, the higher the investment the higher will be the return. However, to make sure that the firm is sensible to the curve of inconveniences cost to consumers (Fig. 2) and not only to investment and system operation cost (Fig. 2), the rate of return is indexed to the curve of consumers' inconveniences, increasing (decreasing) when the inconveniences are higher (lower) such that (dis)incentives the investment till reach the social optimal level. The rate-of-return is paid by consumers in terms of higher or lower electricity price.

iii) A supply issue. Despite the fact that the supply segment is not a natural monopoly and there is room for competition, it is important to raise incentives for a better service quality and to keep prices close to the cost structure. The paper heeds strategies that can be followed by the regulator with the aim to guarantee and promote price competition and service quality in the end-user supply segment. The novelty here is a policy where the final price is cap regulated and the wholesale price paid to distributor is indexed to service qualities of each competitor. Specifically, the wholesale price paid by supplier *i* it should be decreasing in its own quality but increasing in competitors' quality. The main feature of the proposed wholesale price indexation is that it enhances service quality competition among suppliers and simultaneously keeping a price ceiling.

2. MODELLING THE REGULATORY POLICY SOLUTIONS

In this section I construct a model to deal with each regulatory issue and formalize the claimed benefits above from the proposed solutions.

2.1. The polluter-competitor principle

The polluter-competitor principle is a payment scheme, defined by the regulator, among firms that generate pollution in the production process where those who release less pollution by unit of output receive a subsidy from those who pollute more by unit of output.

To illustrate how the principle works and its features, suppose there are *n* generators indexed by $i = 1,\dots,n$ and the representative generator solves

$$\max_{I_i} \Pi_i = \left(\overline{P} - c\right)\overline{q_i} - F + \theta_i \overline{q_i} - I_i \qquad (1)$$

where $\overline{P}$ denotes the price (exogenously given) of one unit of electricity in the market and $\overline{q_i}$ is the contracted amount of electricity to be produced by firm *i*, exogenously defined for simplification. Regarding the cost structure, *F* corresponds to the fixed cost of running the generator, *c* denotes de marginal cost per unit of electricity produced and I_i is the investment level in greener technologies. There's a regulation function θ_i which works as a premium or punish to generator *i* depending if it's polluting relatively less or more than other generators.

Let θ_i be defined by

$$\theta_i \equiv f\left(\sum_{j \neq i} q_{c,j} \cdot \frac{s_j}{1 - s_i} - q_{c,i}\right) \equiv f\left(d_i\right) \qquad (2)$$

where $q_{c,i}$ denotes the quantity of CO_2 per unit of output from firm *i* and s_i is the market share of firm *i*. The expression inside brackets is the difference between the weighted[11] average of CO_2 per unit of output in the sector

[11] The weights correspond to the market shares.

excluding firm *i* and the carbon quantity per unit of output from firm *i*. For expositional ease I define the difference in CO_2 per unit of output as d_i. I assume that $q_{c,i}$ can be reduced if firm *i* invests in a more efficient technologies. The quantity of CO_2 per unit of output from firm *i* is defined as a decreasing and convex function in technological investment,

$$q_{c,i} = g(I_i),$$
$$g'(I_i) < 0,$$
$$g''(I_i) > 0.$$

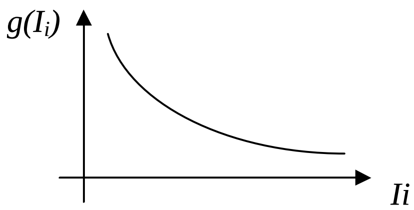

Figure 3: CO_2 reduction per unit of output with investment in technology.

The function *f* is defined by the regulator and should have the following properties in order to implement the polluter-competitor principle,

(i) *upward sloping*[12] for any d_i, i.e., the less CO_2 is released by generator *i* per unit of output relatively to the rest of the market average, the higher will be the reward;

(ii) $f(d_i) > 0$ if $d_i > 0$, which implies a *reward* for generators who release CO_2 below the rest of the market average.

(iii) $f(d_i) < 0$ if $d_i < 0$, which implies a *punishment* for generators who release CO_2 above the rest of the market average. If $d_i = 0$, then $f(d_i) = 0$.

For simplification assume that the regulator defines

$$f(d_i) = \phi_i d_i$$

[12] Mathematically $f'(d_i) > 0$.

which satisfies properties (i), (ii) and (iii) for strictly positive parameters ϕ_i, i = 1,…,n. Note that I'm not restricting the regulation parameter to be equal for all generators; in fact, it may differ from generator to generator depending on individual specificities.

The timing of the model is as follows.

1. The regulator defines the list of regulatory parameters $\{\phi_i\}_{i=1}^{n}$.
2. Each generator *i* solve the profit maximization program in (1).

The Subgame Perfect Equilibrium (SPE). In order to find the SPE the model is solved backwards. At stage 2 the representative generator solves the profit maximization problem

$$\max_{I_i} \Pi_i = \left(\overline{P} - c\right)\overline{q_i} - F + \underbrace{\phi_i d_i}_{f(d_i)=\theta_i} \overline{q_i} - I_i$$

and using the first-order condition (FOC) we get

$$\frac{\partial \Pi_i}{\partial I_i} = \phi_i \frac{d(d_i)}{dI_i}\overline{q_i} - 1 = 0 \Leftrightarrow \phi_i\left[-g'(I_i)\right]\overline{q_i} - 1 = 0 \Leftrightarrow I_i^* = g'^{-1}\left(\frac{1}{-\phi_i \overline{q_i}}\right).$$

The second-order condition (SOC) is satisfied for a maximum since

$-\phi_i g''(I_i)\overline{q_i} < 0$, due to the convexity of *g*.

Hence, the investment solution from the FOC is the *i*'s profit maximizer.

Result 1: *Under the polluter-competitor principle, generator i's optimal investment in greener technologies,* I_i^*, *is increasing both in the regulator's parameter* ϕ_i *and the output level,* $\overline{q_i}$.

Proof: All the proofs in appendix.

On one hand, the generator *i*'s optimal level of investment under the polluter-competitor principle is increasing in the regulator's parameter since the larger is ϕ_i the larger (smaller) will be the reward (punishment) due to investment. On the other hand the larger the output also the higher will be incentive to invest in the pollution reduction; this happens because the reward/punishment is attributed by unit of output, therefore there's a scale effect affecting the incentive to invest in cleaner technologies. Generator *i* knows that the larger is the output, the larger will be the reward (punishment) depending on how good (bad) is its pollution release per unit of output relatively to other generators in the market. Hence, regardless of being above of below the average polluter it is a dominant strategy for generators to invest more when it produces more electricity (either to increase reward or avoid punishment).

In general, solving the program (1) without further assumptions we reach,

$$FOC: \frac{\partial \Pi_i}{\partial I_i} = \frac{\partial \theta_i}{\partial I_i}\overline{q_i} - 1 = 0 \Leftrightarrow \frac{\partial \theta_i}{\partial I_i} = \frac{1}{\overline{q_i}} \qquad (3)$$

$$SOC: \frac{\partial^2 \theta_i}{\partial I_i^2}\overline{q_i} < 0,$$

where the SOC can be assured under the condition $\frac{\partial^2 \theta_i}{\partial I_i^2} < 0.$[13]

Result 2: *Under the polluter-competitor principle, investment levels are strategic complements as long* θ_i *satisfies* $\partial^2 \theta_i / \partial I_i \partial I_j > 0$, *for i≠j.*

The following graph depicts result 2.

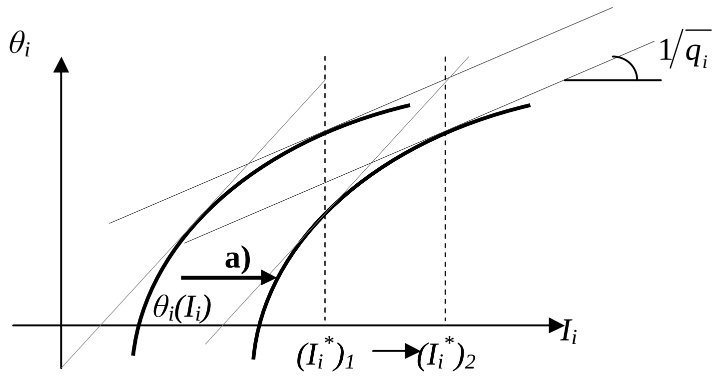

Figure 4: Effect arrow a) represents the increase in the investment of a generator *j ≠ i* over *i*'s regulatory function.

Condition $\partial^2 \theta_i / \partial I_i \partial I_j > 0$ states that there is an increase in the derivative of *i*'s regulatory function when a generator *j* increases investment. For instance, at $I_i = (I_i^*)_1$ in Fig. 4 the tangent in *i*'s regulatory function (bold) before the effect a) is flatter than the tangent at the same point in the regulatory function (bold) after the effect a). This effect can be understood as *i*'s regulatory function move to the right (arrow a)). Note that *i*'s initial optimal investment is given by $(I_i^*)_1$ but the increase in *j*'s investment pushed *i*'s regulatory function to the right. Since the optimal solution is characterized by the FOC in (3), the

[13] Note that although the regulation parameters depend directly on the pollution levels per unit of output of each generator, recall that pollution levels can be written as functions of the investment levels done by each generator using the *g* function.

derivative of θ_i must match $1/\overline{q_i}$, then the new optimal investment for generator *i* is $(I_i^*)_2 > (I_i^*)_1$.

I conclude from the analysis that with the right definition of the regulatory functions it's possible to spur technological competition in the reduction of CO_2 emission per unit of electricity produced.

Finally, since the solution of the representative generator *i* from stage 2 (optimality condition (3)), the regulator solves

$$
\begin{aligned}
& Max_{\{\theta_i\}_{i=1}^n} W \\
& s.to \\
& \text{(BB) Budget Balance}: \sum_{i=1}^n \theta_i \overline{q_i} \leq 0 \\
& \text{(N - N) Generators' Profit non - negativity}: \prod_i \geq 0, \text{ for } i = 1,\dots,n \\
& \text{(i's FOC)}: \frac{\partial \theta_i}{\partial I_i} = \frac{1}{\overline{q_i}}, \text{ from generators' problem, eq. (3).}
\end{aligned}
$$

where *W* stands for regulator's objective function. Depending on the goal the function will have different functional forms, some examples follow below.

i) $W = \sum_{i=1}^{n} I_i$, if the goal is maximize total investment, regardless of the generator.

ii) $W = \sum_{i=1}^{n} \alpha_i I_i$ if the goal is to maximize total investment but attributing differentiated weights, $\alpha_i > 0$, to generators. The investments from firms with higher weights in *W* are more valuable in the regulator's perspective.

iii) $W = -\sum_{i=1}^{n} \left(q_{c,i} - q_c^O\right)^2$, if the goal is to implement the closest possible level of pollution to q_c^O .

In section 3 I discuss the concerns regarding implementation of the polluter-competitor principle namely the required set of information that the regulator needs to have access.

2.2. Indexed rate-of-return to the inconveniences cost to consumers

The indexed rate-of-return to the inconveniences cost to consumers is a regulatory method that encourages the monopolist in the transport/distribution segment to make the social optimal investment. This feature is achieved when the rate-of-return is correctly adjusted to match consumers' needs, i.e. the allowed rate-of-return varies in the same way as the inconveniences cost to consumers. When inconveniences to consumers are higher it's reasonable to infer that their willingness to pay is increased to avoid that inconveniences. Therefore, the regulator should allow the monopolist to receive more from the consumers as long it improves the energy quality (measured for instance in the frequency of blackouts).

The following model illustrates the features of this regulatory method. Consider the functions $C_p(k)$ and $C_c(k)$ representing producer's and consumers' costs, respectively, for an energy quality of level k. Graphically this corresponds to Figure 2.

Assumptions. I assume that $C_p(k)$ is increasing and convex,[14] while $C_c(k)$ is decreasing and convex.[15] Both cost functions are differentiable in k.

[14] Typically, interest rates increase more than proportionally with the investment level. This might be related with the risk that is not spread as the monopolist concentrates investment in the infrastructure.

[15] The convexity of $C_c(k)$ is explained by the *Law of Diminishing Marginal Utility*. A small increase of quality when k is low is much more appreciated by consumers then when the quality is already high.

Next I present the social optimal and free market outcomes as benchmarks. Then I show how the introduction of an indexed rate-of-return over the free market equilibrium pushes the monopolist's quality choice towards the social solution.

The social optimal solution. The social optimal solution for the energy quality is found solving the following program,[16]

$$
\begin{aligned}
&Min_k \{C_p(k) + C_c(k)\} \\
&FOC : C_p^{'}(k^O) + C_c^{'}(k^O) = 0 \Leftrightarrow C_p^{'}(k^O) = -C_c^{'}(k^O) \\
&SOC : \underbrace{C_p^{''}(k^O)}_{>0} + \underbrace{C_c^{''}(k^O)}_{>0} > 0.
\end{aligned}
\tag{4}
$$

The free (unregulated) market outcome. If we were in the presence of an unregulated market the monopolist would maximize profit choosing the lowest possible cost allowing him to serve $\overline{Q}$ units of electricity at unitary price $\overline{P}$ already defined. Mathematically, the monopolist would solve the following program,

$$
\begin{aligned}
&Max_k \Pi_i = \{\overline{P}\overline{Q} - C_p(k)\} \\
&s.to \;\; Q(k) \geq \overline{Q}
\end{aligned}
$$

and would choose the lowest *k* level allowing to produce $\overline{Q}$, $k^* = Q^{-1}(\overline{Q})$.[17]

The rate-of-return, s_k, policy. Let s_k be the allowed rate-of-return by the regulator, i.e. the monopolist's total revenue is defined by the rate times the

[16] k^o stands for the *social optimal level* of quality/network investment.
[17] For simplification, I assume the price and quantity to be previously fixed by the firm and *k** is the minimum level of investment (quality) allowing the monopolist to operate, i.e. the private optimal solution.

invested amount in the network, *k*, instead of the price times the quantity. Under the rate-of-return policy the monopolist solves,

$$Max_k \Pi_i = \left\{ s_k k - C_p(k) \right\}$$

$$\begin{aligned} FOC &: s_k = C_p^{'}\left(k^*\right) \\ SOC &: -\underbrace{C_p^{''}\left(k^*\right)}_{>0} < 0. \end{aligned} \qquad (5)$$

Result 3: *Under the rate-of-return policy the monopolist chooses to implement the quality level k* such that:*

i) $k^* < k^o$, *if* $s_k < -C'_c(k^o)$; *[Undercapitalization]*

ii) $k^* = k^o$, *if* $s_k = -C'_c(k^o)$; *[Social Optimal Solution]*

iii) $k^* > k^o$, *if* $s_k > -C'_c(k^o)$. *[Overcapitalization]*

The social optimal rule comes from equation (4) where the quality marginal cost is equated to consumers' marginal gain (inconveniences reduction). Therefore, if the regulator sets the firm's marginal revenue equal to consumers' marginal gain at k^o the firm will choose to implement k^o when equates marginal revenue and marginal cost.

We conclude from Result 3 that whilst the regulator is able to correctly index the rate-of-return, s_k, to consumers' marginal gains the social optimal quality level, k^o, will be implemented by the monopolist. If the rate of return is defined below (above) the marginal gains, then the implement quality level by the firm will be also below (above) the social optimum, k^o.[18]

[18] Some virtues and flaws of the indexed rate-of-return regulation approach are discussed in section 3.

2.3. Wholesale Price indexation to service quality

The service quality is an important issue in the electricity market. Consumers are highly sensitive to all aspects of service quality and value the speed and accuracy with which their requests are handled, the reliability of the electricity supply, and the characteristics of the supply voltage.

Both theory and empirical evidence indicate that when a regulator chooses to regulate prices using price or revenue caps, a company's incentives to deliver efficient levels of service quality tend to drop. In this context the *wholesale price indexation to service quality* works as a regulatory policy with the ultimate goal to increase service quality competition among electricity suppliers.

The following model illustrates the features of the proposed regulatory method in this subsection. Suppose the electricity market is regulated with a price cap, $\overline{P}$ and there are two identical suppliers labelled *i* and *j*.

Supplier *i* faces the problem,

$$Max_{k_i} \Pi_i = \left(\overline{P} - w\left(k_i - \alpha k_j\right)\right) Q_i\left(k_i - \alpha k_j\right) - k_i \qquad (6)$$

where $k_{h=i,j}$, $w(.)$, and $Q_i(.)$ denote the investment amount done by supplier $h=i$ or $h=j$, the wholesale price and the demand function faced by supplier *i*, respectively. For expositional ease I denote the investment difference as $\delta_i \equiv k_i - \alpha k_j$ where $\alpha > 0$.[19] I assume that *i*'s demand function is increasing and

[19] The *w* function could be defined more generally as $w(k_i - \beta k_j)$, for some $\beta > 0$ but the results would be the same as with α also used in the demand function argument. Hence, for the sake of mathematical simplification I adopt $w(k_i - \alpha k_j)$.

concave in δ_i.[20] Note that under the wholesale price indexation proposed *w* is a function of δ_i, while without indexation *w* is fixed.

By wholesale price indexation the regulator defines *ex-ante* the *w* functional form, and then suppliers choose their investment levels, k_i and k_j. As usual, the equilibrium is solved by backward induction: first solving the suppliers' problem and then regulator's.

Solving *i*'s problem in equation (6) we get

$$FOC: \frac{\partial \Pi_i}{\partial k_i} = 0 \Leftrightarrow \underbrace{-w'(\delta_i) Q_i(\delta_i)}_{\text{Regulatory Term}} + \left(\overline{P} - w(\delta_i)\right) Q_i'(\delta_i) = 1 \qquad (7)$$

The wholesale price indexation added a *regulatory term* to the left hand side of equation (7), i.e. the regulatory term has changed the perceived benefits to supplier *i* from investing in service quality. In order to influence suppliers choose to invest more in service quality the regulatory term must be positive. Thus the first analytical property that the regulator should choose to *w* is to be *decreasing* in δ_i. In other words, the *i*'s wholesale price should decrease in its own service quality and increase in *j*'s. Formally, I derive the following result.

Result 4: *If and only if* $w'(\delta_i) < 0$, *electricity suppliers will choose to invest more in service quality under the wholesale price indexation to service quality regulation rather than without it.*

However, it is required to check the SOC of *i*'s problem to guarantee that it comes out a maximizer from (7). Now, I present Lemma 1 that provides the sufficient conditions to assure the validity of (7) and Result 4.

[20] Mathematically, $Q_i'(\delta) > 0$ and $Q_i''(\delta) < 0$.

Lemma 1: *The solution from (7) will be a maximizer to (6) if:*

i) $w''(\delta_i)$ *> 0 and*

ii) $-\frac{w''(\delta_i)}{w'(\delta_i)} < 2\frac{Q_i^{'}(\delta_i)}{Q_i(\delta_i)}$.

From condition *i)* it comes out the second property that the regulator should choose for *w*. Condition *i)* together with $w'(\delta_i)$*<0* tells that the wholesale price charged to *i* should decrease less as the difference in investments, δ_i, among suppliers gets larger. This implies that, ceteris paribus, a supplier that invests relatively less in service quality will have more incentives to raise investments than the other.

Condition *ii)* also brings an intuitive message. The condition can be re-written as $-\frac{w''(\delta_i)}{w'(\delta_i)} < 2\frac{Q_i^{'}(\delta_i)}{Q_i(\delta_i)} \Leftrightarrow -\frac{\delta_i}{2}\frac{w''(\delta_i)}{w'(\delta_i)} < \varepsilon_{Q_i,\delta_i}$, where $\varepsilon_{Q_i,\delta_i}$ denotes the service quality - demand elasticity, i.e. it tells how much percent will vary *i*'s demand if the difference in suppliers' quality (investment) changes by 1%. Intuitively speaking, if the elasticity decreases it means that consumers do not change supplier so easily (demand is more inelastic) and the market is providing less incentives to suppliers to invest in quality. Suppliers know that when demand is more inelastic an increase in investment will not be so rewarding because consumers are not so responsive to service quality. Therefore, it must be the regulator to provide further incentives. That extra encouragement from regulation might take the form of a decrease in the negative value of $w'(\delta_i)$, i.e. the wholesale price decreases (increases) faster with own investment (competitors' investment) or a decrease in the positive value of $w''(\delta_i)$.

On another hand, if there's an increase in the elasticity of demand it means the market is more sensitive towards differences in quality and so the regulator can relax its incentives. When elasticity of demand is already high the market demand by itself will work as a vigorous discipliner for suppliers in terms of investment in service quality.

Result 5: *Under the wholesale price indexation to service quality, investments in service quality are strategic complements.*

If demand does not respond to service quality and there's no wholesale price indexation to service quality there's no strategic complementarity among investments; in fact, it's a dominant strategy for suppliers to invest nothing in quality. However, under the wholesale price indexation to service quality even if demand does not respond to quality differences among suppliers,[21] the indexation generates incentives for suppliers to compete in quality. The wholesale price indexation becomes each supplier willing to invest in quality in order to reduce marginal costs and gain a competitive advantage. So, if supplier *i* invests more in service quality, *j*'s best response will be to increase its service quality, otherwise *j* will suffer from a competitive disadvantage facing a higher marginal cost than *i*. We conclude from the analysis that under the wholesale price indexation, regardless the service quality-demand elasticity, service quality investments are strategic complements.

[21] It might be difficult for consumers to switch supplier, for instance due to geographic market segmentation (each supplier only sells on a given region) or due to the lack of information provided to consumers. This issue is discussed in more detail in section 3.3.

Finally, the regulator solves

$$\begin{aligned}
&MaxW_{\{c(\delta_h)\}_{h=i,j}} \\
&s.to \\
&(i)\ \ c''(\delta_h) > 0,\ \ h = i, j \\
&(ii)\ \ -\frac{w''(\delta_h)}{w'(\delta_h)} < 2\frac{Q_h^{'}(\delta_h)}{Q_h(\delta_h)},\ \ h = i, j \\
&(iii)\ \ c'(\delta_h) < 0,\ \ h = i, j \\
&(iv)\ \ s_k.k \leq c(\delta_i)Q_i(\delta_i) + c(\delta_j)Q_j(\delta_j)
\end{aligned} \tag{8}$$

where *W* denotes the regulator's objective function. In order to maximize *W* the regulator will choose the marginal cost functional form as function of δ_i, respecting restrictions *(i)* and *(ii)* from Lemma 1, (iii) from Result 4 and inequation *(iv)* that is the budget balance since the sum of the payments (costs) from suppliers must cover, at least, the rate-of-return to the upstream monopolist in the transport/distribution segment. Depending on the objective function the marginal cost functional form might come different.

Note that regulator's problem is challenging from the information point of view since it is required to recognize each supplier's demand function, namely, how it changes with service quality difference and the demanded quantity for each δ_i.

Section 3 discusses further features and problems regarding the wholesale price indexation policy.

3. DISCUSSION

Three regulatory policies were presented and modelled in the previous section. The present section intends to go further on these policies and discuss if they are compatible to be used simultaneously, the set of information required by the regulator for implementation and some pros and cons of the policies.

3.1. The polluter-competitor principle: market share asymmetries and information issues

The presented polluter-competitor principle is based on transfers per unit of output and this trait might create some unintended consequences.

Suppose there are only two generators, the market leader with 90% market share and a competitor with the remaining 10%. This pushes the leader, in order to receive a premium (instead of paying) for each unit produced, by Result 1, to investment more in greener technologies than the small competitor. Hence, in equilibrium it is expected the small competitor to pay the leader for each unit of output which leads the leader to strength its position and eventually become a monopolist. So, in the presence of vast asymmetries among generators the implementation of the polluter-competitor principle might not work properly without the due adjustments.

There is also an informational issue for the regulator. From the model in the section 2.1, if the regulator intends to encourage generators to invest an amount I^o in pollution reduction per unit of output then, in order to correctly define the regulatory parameter ϕ_i will have to learn the technology function g which basically tells how much pollution per unit the generator will produce for each investment level.[22] Therefore, the regulator will have to estimate this function before deciding about $\phi_{i=1,\ldots,n}$. The regulator also will have to be acquainted with the output produced by each generator but usually this information is available.

3.2. Indexed rate-of-return to the inconveniences cost to consumers: information issues and capital market reward

The fundamental issue regarding the rate-of-return indexation is how to obtain information about the inconveniences cost to consumers as function of the transportation quality. In order to overcome this information problem the regulator might construct surveys to get feedback from consumers about how their costs change with electricity quality. Besides that the regulator has to be aware of firm's cost structure in order to determine the optimal investment level.

Another issue with this regulatory approach is that it does not take into account other markets investment opportunities, i.e. the capital market reward. If the capital market reward goes above s_k, the monopolist might opt to deviate a significant part of its investment to the market rather than used it in the network. Thus, the capital market reward might affect the implementation of the social optimal investment level in the network and by that it also should be taken into account in the moment when s_k is defined.

[22] It is important the regulator to know the technology function, *g*, since generators make their investment decisions supported on that function. Therefore, depending on the technological state the regulatory parameter should be adjusted.

3.3. Wholesale Price indexation to service quality: demand information, market share asymmetries and geographic market segmentation

The major issue with the implementation of the wholesale price indexation is related with demand information, namely, the regulator has to estimate how the demand faced by each supplier reacts to service quality differences among suppliers. The estimation is important to make sure the incentives in terms of wholesale price indexation are correctly calibrated.

Another issue is related with large asymmetries in market shares among suppliers within a given market. Under such asymmetric scenario the larger suppliers will invest more in service quality than smaller ones taking the outcome to be potentially more asymmetric than the *status quo* because larger suppliers will benefit from smaller marginal costs while smaller suppliers will have to pay higher marginal costs than without the policy. Like in the polluter competitor principle, in the presence of significant market share asymmetries the wholesale price indexation should go through adaptations to avoid such asymmetric outcomes, namely to avoid monopolies and competition ruin.

In case of geographic market segmentation consumers in each region are exclusively served by the local monopolist supplier. In this case the wholesale price indexation is especially relevant because demands can be very inelastic (due to soaring switching costs), suppliers do not compete in quality and so the equilibrium service quality is low without a regulatory policy. One of the most relevant features of the wholesale price indexation to service quality is that even if market is split in independent monopoly segments this regulatory policy will create incentive for monopolists to compete with each other in service quality than other way they would do.

But are these three regulatory policies compatible? The answer is positive if there is coordination between the last two.

The polluter competitor principle is an independent principle from any other policy in the remaining segments of the industry concerning only the generation efficiency in terms of pollution produced by unit of output.

However, the rate-of-return indexation in the transport/distribution segment must be integrated with the wholesale price indexation policy for suppliers. This happens since the rate-of-return indexation defines the allowed revenue that the monopolist in the distribution can charge to the supplier segment. Suppliers must at least cover distributor's revenue, correspondent to constraint *(iv)* of the problem in equation (8). Under the wholesale price indexation to service quality, suppliers who invest relatively less in service quality will contribute more to distributor's revenue than suppliers who invest relatively more but the sum of the payments must be always at least $s_k.k$. Thus, the last two policies need to be managed in an integrated fashion.

The next section concludes the work.

4. CONCLUSIONS AND FINAL NOTES

More and more countries are thinking of or have already undertaken reforms in their electricity industry, with the objectives of increasing private capital, promoting competition and introducing new regulatory structures. In more detail the reform measures implemented usually involve unbundling existing utilities, possibly into separate generation, transmission, distribution and supply providers; privatising state-owned incumbents; introducing competition among operators, especially in the generation sector; and establishing new regulatory bodies to regulate the remaining monopoly infrastructure. The main purposes of electricity reform include improving the efficiency of the electric power sector, expanding private investment in infrastructure building and relieving government from ever-increasing budgetary pressures.

The diffusion of new technologies is putting a strong demand pressure on the electricity sector. Moreover, the development of the economies will require tremendous investments in electricity generation in future years. There are also key environmental dimensions related to the pollution externalities and the pressure on electricity demand from the adaptation to climate change. All these elements make it critical to achieve a high degree of economic efficiency in the production, distribution and supply of electricity.

The Council of European Energy Regulators (CEER) formed a working group on quality of electricity supply, aimed at comparing quality levels, standards and regulation strategies for electricity supply in European countries. Taking into account the CEER (2001, 2008) study, some strategies are drawn to promote service quality.

i) The commercial quality can be ensured by *regulation or codes* as long a regulatory entity verifies its implementation. General conditions of energy supply contracts establish rights and duties which aim to guarantee adequate commercial quality. Performance standards are beneficial in ensuring that customers receive certain minimum levels of quality of service.

ii) *Penalty payments*. Whenever guaranteed standards are not met, companies should make penalty payments to the customers affected.[23]

iii) *Provide consumers with more information*. This takes the demand faced by each supplier to be more sensitive towards the service quality, which incites suppliers to compete more in service quality. Methods of information provision include the publication of leaflets, newspapers, Internet sites and providing data with electricity bills.[24]

iv) *Customer participation*. Strategies to encourage customer participation can include: diverse ways of contacting companies (customers centres, call centres, etc)[25]; standards associated with time of response to claims and requests for information; active participation of consumers' associations in the development of electricity sector regulation.[26] Customer participation might be relevant for regulators in the process of obtaining information about the demand and thus produce more accurate rules.

v) Provide better and faster access to *justice/ conflict solution*, e.g. endow regulatory bodies with powers in the resolution of disputes; use extrajudicial mechanisms such mediation and conciliation; create conflict resolution centres specialising in disputes in the electricity sector.

[23] In Spain the payment to costumers is automatic, what does not happen in Portugal where clients have to complain and request a compensation payment, in case of power failure.

[24] For instance, the last 12 months' consumption must be included in bills, as well as the average daily expenditure.

[25] "During recent years (due to the development of the telecommunications sector), a restructuring of the ways for maintaining contact with customers (mainly mobile communication) could be observed. In the place of personal and written contacts, major relevance is taken by call centres, and there is a growing need for the possibility of on-line administration", CEER (2008).

[26] In Portugal and Spain, consumer associations are represented in the regulatory bodies' consultative councils.

This paper emphasizes three current regulatory issues in electricity markets and presents for each a theoretical solution. The analyzed regulatory concerns are (i) the reduction of pollution emission at the generation level; (ii) the market dominance and lack of investment/ power quality at the transportation level; and (iii) the service quality and final price at the supply level.

The paper shows in three steps/regulatory implementations how to remodel electricity in a greener, price-competitive and consumer-oriented market. First, the *polluter-competitor principle* presses power generators to invest in greener technologies. Second, a rate-of-return regulation, at the transportation level, indexed to inconveniences cost to consumers induces to the social optimal investment at this stage in the network. Third, a wholesale price, at the supply level, indexed to service quality together with end-user price cap enhances cost efficiency and better service quality provided.

The regulator may use the results as a starting point and induce firms to reveal more information, reducing in this way the information asymmetry between regulator and firms.

The discussion section alerts for the problem of *information asymmetry* between regulator and firms. However, the international cooperation between regulators is a powerful instrument in the reduction of the information gap. The firms control most of the specific information needed for regulatory purposes and have little interest in sharing this information unless they have an incentive to do so. As more comparable is the information from different countries more effective will be this form of "competition" and more easily will be to each regulator to strengthen the application of its regulatory mechanisms.

As future research it would be worthwhile to study extensions of the discussed models, namely, to model regulator's information constraints or market share asymmetries and study the impact over the regulator's parameters and functions.

5. REFERENCES

[1] Apolinário, I., *Technical Efficienty in The European Electricity Distibution Industry*, Nº: 33/2008, ERSE.

[2] Armstrong, M., Cowan, S. and Vickers, J. (1994) *Regulatory Reform: Economic Analysis and British experience*, Cambridge, Mass.: MIT Press.

[3] Averch, Harvey and Johnson, Leland J. *Behavior of the Firm under Regulatory Constraint*, *American Economic Review*, December 1962, *52*(5), pp. 1052-69.

[4] Barros, Cristina, Clara, Maria José, *et al*., *Some Regulation Perspectives for Power Quality*, Nº: 11/2008, ERSE.

[5] Borenstein, S., *The Trouble With Electricity Markets (and some solutions)*, January 2001.

[6] Braz, J. and Esteves, J., *Transmission Network Unbundling Evidence from Portugal*, Nº: 25/2008, ERSE.

[7] Council of European Energy Regulators, *Quality of Electricity Supply: Initial Benchmarking on Actual Levels, Standards and Regulatory Strategies*, 2001.

[8] Council of European Energy Regulators, *4th Benchmarking Report on Quality of Electricity Supply, 2008*.

[9] Cullen, Joseph A., *Dynamic Response to Environmental Regulation in the Electricity Industry*, December, 2008.

[10] Deleste, F., Fumagalli, E. and Schiavo, L., *Service quality regulation in electricity distribution and retail*, Springer 2007.

[11] Douglas, S., Garrett, Thomas A., and Rhine, Russell M., *Disallowances and Overcapitalization in the U.S. Electric Utility Industry*, Federal Reserve Bank of St. Louis *Review*, January/February 2009, *91*(1), pp. 23-31.

[12] Felizardo, N., *Mercados De Certificados Verdes. Avaliação da Possibilidade de Aplicação em Portugal*, Nº: 21/2008, ERSE.

[13] Guasch, J.L. and Hahn, R.W, *The Costs and Benefits of Regulation: Implications for Developing Countries*, 1999, *The World Bank Research Observer*, 14 (1), 137-158.

[14] Hall, Emma P.; Propper, Carol and van Reenen, John. *Can Pay Regulation Kill? Panel Data Evidence on the Effect of Labor Markets on Hospital Performance,* NBER Working Paper No. 13776, National Bureau of Economic Research, February 2008. www.nber.org/papers/w13776.

[15] IEA, *Electricity Supply Industry,* 1994, Paris.

[16] Nelson, Jon P., *Advertising Bans, Monopoly, and Alcohol Demand: Testing for Substitution Effects Using State Panel Data*, Review of Industrial Organization, February 2003, 22(1), pp. 1-25.

[17] Olson, Mancur, *The Logic of Collective Action: Public Goods and the Theory of Groups*. Cambridge, MA: Harvard University Press, 1965.

[18] Peltzman, Sam, *Toward a More General Theory of Regulation, Journal of Law and Economics, August 1976, 19(2), pp. 211-40.*

[19] *Portugal aumenta emissão de gases,* Jornal de Notícias, 2006-06-23.

[20] Santos, V., *A Regulação Do Sector Energético Em Portugal: Balanços e Novos Desafios*, Nº: 1/2008, ERSE.

[21] Steiner, Faye, *Regulation, Industry Structure and Performance in the Electricity Supply Industry*, OECD Economic Studies No. 32, 2001/I.

[22] Stigler, J. George, *The Theory of Regulation*. *Bell Journal of Economics and Management Science*, Spring 1971, *2*(1), pp. 3-21.

[23] Tirole, J., *The Theory of Industrial Organization*. MIT, 1988.

[24] Warkentin-Glenn, Denise, *Electric Power Industry: In Nontechnical Language*. Second Edition. Tulsa, OK: PennWell Corporation, 2006.

6. APPENDIX

Proof of Result 1: Applying the Implicit Function Theorem (IFT) to *i*'s FOC we get

$$\frac{\partial I_i^*}{\partial \phi_i} = -\frac{\partial^2 \Pi_i / \partial I_i \partial \phi_i}{\partial^2 \Pi_i / \partial I_i^2} = -\frac{g'(I_i)}{\phi_i g''(I_i)} > 0,$$

since *g* is decreasing and convex in the investment level and $\phi_i > 0$.

By the IFT we also get that

$$\frac{\partial I_i^*}{\partial \overline{q_i}} = -\frac{\partial^2 \Pi_i / \partial I_i \partial \overline{q_i}}{\partial^2 \Pi_i / \partial I_i^2} = -\frac{g'(I_i)}{\overline{q_i} g''(I_i)} > 0 .$$ *Q.E.D.*

Proof of Result 2: Applying the IFT to *i*'s FOC we reach

$$\frac{dI_i}{dI_j} = -\frac{\partial^2 \Pi_i / \partial I_i \partial I_j}{\partial^2 \Pi_i / \partial I_i^2} = -\frac{\partial^2 \theta_i / \partial I_i \partial I_j}{\partial^2 \Pi_i / \partial I_i^2} \overline{q_i},$$

which is positive if $\partial^2 \theta_i / \partial I_i \partial I_j > 0$, provided that the denominator is negative by the SOC of the program. *Q.E.D*.

Proof of Result 3: The social optimal solution comes from equation (4), $C_p^{'}\left(k^O\right)=-C_c^{'}\left(k^O\right)$, while the private solution comes from (5), $s_k = C_p^{'}\left(k^*\right)$. i) If $s_k < -C'_c(k^o)$ <=> $s_k < C'_p(k^o)$, hence $s_k = C'_p(k^*)$ for a $k^* < k^o$ since $C'_p(k)$ is increasing by the convexity of $C_p(k)$. ii) If $s_k = -C'_c(k^o)$ <=> $s_k = C'_p(k^o)$, hence it must be that $k^* = k^o$. The proof of part iii) is in everything similar to i) but with the reverse inequality – the convexity of $C_p(k)$ is sufficient to prove the result. *Q.E.D.*

Proof of Result 4: Take the FOC, equation (7), and re-write it as

$$R+\left(\overline{P}-w\left(\delta_i\right)\right)Q_i^{'}\left(\delta_i\right)-1=0\,,$$

where R stands for the *regulatory effect* and is positive *iff* $w'\left(\delta_i\right)<0$. By the IFT,

$$\frac{dk_i}{dR}=-\frac{\partial(.)/\partial R}{\partial(.)/\partial k_i}=-\frac{1}{\partial(.)/\partial k_i}>0,$$

since $\partial(.)/\partial k_i$ < 0 by the SOC (otherwise the solution wouldn't be a maximum). Hence, suppliers choose to invest more under the regulatory incentive, $R > 0$, than without it. *Q.E.D*.

Proof of Lemma 1: Taking the second derivate in order to k_i we get

$$SOC:\frac{\partial^2\Pi_i}{\partial k_i^2}=0\Leftrightarrow \underbrace{\alpha}_{>0}\left[\underbrace{-\underbrace{w''\left(\delta_i\right)}_{>0,\ by\ i)}\underbrace{Q_i\left(\delta_i\right)}_{\geq 0}-2\underbrace{w'\left(\delta_i\right)}_{<0}\underbrace{Q_i^{'}\left(\delta_i\right)}_{>0}}_{<0,by\ \ ii)}+\underbrace{\left(\overline{P}-w\left(\delta_i\right)\right)}_{\geq 0}\underbrace{Q_i^{''}\left(\delta_i\right)}_{\leq 0}\right]<0.$$

Condition *i)* from the Lemma 1 guarantees the first term negativity, i.e.

$$-w''\left(\delta_i\right)Q_i\left(\delta_i\right)<0.$$

Condition *ii)* from the Lemma 1 guarantees

$$-\frac{w''(\delta_i)}{w'(\delta_i)} < 2\frac{Q_i'(\delta_i)}{Q_i(\delta_i)} \Leftrightarrow -w''(\delta_i)Q_i(\delta_i) - 2w'(\delta_i)Q_i'(\delta_i) < 0 .$$

The term $\overline{P} - w(\delta_i)$ is non-negative because otherwise the firm would prefer to go out of the market and $Q_i''(\delta_i)$ < 0 by assumption. *Q.E.D.*

Proof of Result 5: From the Implicit Function Theorem we have,

$$\frac{dk_i}{dk_j} = -\frac{\partial\Pi_i^2 / \partial k_i k_j}{\partial\Pi_i^2 / \partial k_i^2},$$

where $\frac{\partial^2\Pi_i}{\partial k_i \partial k_j} = \alpha\left[w''(\delta_i)Q_i(\delta_i) + 2w'(\delta_i)Q_i'(\delta_i) - \left(\overline{P} - w(\delta_i)\right)Q_i''(\delta_i)\right] = -\alpha\frac{\partial^2\Pi_i}{\partial k_i^2} > 0$,

since *α > 0* by assumption and $\frac{\partial^2\Pi_i}{\partial k_i^2} < 0$ by the SOC (Lemma 1).

Hence, $\frac{dk_i}{dk_j} = -\alpha\frac{\partial\Pi_i^2 / \partial k_i k_j}{\partial\Pi_i^2 / \partial k_i^2} = -\frac{-\alpha\partial\Pi_i^2 / \partial k_i^2}{\partial\Pi_i^2 / \partial k_i^2} = \alpha > 0$. *Q.E.D.*