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Renewable sources, technology mix, and competition in liberalized electricity markets: the case of Spain*

Aitor Ciarreta, Carlos Gutiérrez-Hita and Nikolaos Georgantzís**

Abstract

The paper addresses the question of how oligopolistic competition is affected by the development of renewable source technologies within the new framework of electricity supply security and reduction of emissions of CO_2. In an oligopoly model where firms own renewable as well as non-renewable source technologies, we show that wholesale prices tend to decline the larger the efficiency achieved by renewable technologies depending also on the feed-in-tariff fixed by regulators. We found however that a high subsidy can distort competition when technical maturity of renewables is large as compared with the costs incurred by fossil sources. Finally, we test the predictions of the model using data from the Spanish electricity market.

Keywords: electricity technology mix, renewable energy sources, technical maturity, feed-in tariffs.
JEL Classification: L13, L51, L94.

Resumen

Este artículo trata el problema de cómo la competencia oligopolística es afectada por el desarrollo de las tecnologías que utilizan energías renovables dentro del marco de reducción de emisiones de CO_2 y seguridad en el mercado eléctrico. En un modelo oligopolístico donde las empresas poseen plantas que utilizan recursos tanto renovables como no renovables, mostramos que los precios en el mercado mayorista decrecen a medida que las tecnologías que utilizan recursos renovables incrementan su eficiencia, hecho que también depende de la subvención fijada por el regulador. Sin embargo, encontramos que un subsidio excesivo puede distorsionar la competencia cuando la madurez tecnológica de los recursos renovables es lo suficientemente alta comparada con el coste de los recursos no renovables. Por último, contrastamos las predicciones del modelo utilizando datos del mercado eléctrico español.

Palabras clave: mix tecnológico eléctrico, recursos energéticos renovables, madurez tecnológica, subvenciones.

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1 Introduction

There is a great concern worldwide on the need for an increase in the use of renewable energy resources (RES, hereafter). The use and exploitation of energy sources is growing and will continue to do so in the near future. Unfortunately, certain uses and transformations of energy have negative local or global externalities, or produce short and long term effects.[1] Therefore, corncerns about global climate change, air quality, and energy security have increased the interest in the potential of renewable energy sources to displace non-renewable ones.

The generation of electricity from renewable sources in liberalized electricity markets is an important energy issue at debate. Liberalization of the electricity sector jointly with the reduction of greenhouse gas emissions are two main targets of energy policy in Europe. The European Union (EU, hereafter) officially started its renewable energy policy through the launching of Research, Development and Demonstration (RD&D) programmes from 1974 onwards. The first steps in implementation-directed policy started in 1994, where the Madrid Conference laid the basis for the first targeted objectives for renewable energy at EU level, later formalised in the RES-E White Paper 'Energy for the future - renewable sources of energy'. According to the Kyoto Protocol and the agreements following it, the EU commits itself to reducing emissions of greenhouse gases by 8% during the period 2008-2012 in comparison to 1990 levels. Concerning the electricity sector, the RES-E White Paper states that if appropriate measures are taken, electricity production from RES could grow significantly by 2010, from the present 14.3% to 23.5%. The 2010 target for electricity was set at 22.1% as a share of electricity produced from RES in the Community.[2] Promotion of renewable sources should lead in the long term to electricity systems based on renewables to a larger extent than today. But increasing the share of renewable sources in the electricity technology mix requires strong and efficient regulatory policy support.

Liberalization of the electricity sector is an ongoing progressive process in all EU member states since the Directive 96/92/EC on the common rules for the internal electricity market. With respect to renewable electricity, liberalization of the market implies both new opportunities and threats. First,

[1] For instance, the emissions of particles from power stations cause a local impact, while emissions of CO_2 cause a global impact; spills at refineries usually have a short-term impact, while the problem of radioactive waste is a long-term issue.

[2] Lowering to 22.1%, compared with the RES-E White Paper projection of 23.5%, was explained in the RES-E Proposal as the result of a new 1999 electricity consumption scenario (EC, 1999) being used in the projections.

in a competitive market, renewable electricity may be less competitive than conventional electricity due to the failure of prices to account for the latter's environmental impact. As a result, an inefficient use of resources may occur. Therefore, efficiency requires that environmental costs are reflected on energy pricing. Unfortunately, the target is hindered by two serious difficulties: incomplete information on environmental costs, and limited experience in the application of internal regulation mechanisms. On the one hand, within a competitive market, the price of electricity is expected to decrease. Accordingly, it may create a very difficult environment for renewable electricity to emerge on the market, since most renewable electricity technologies still carry higher production costs than traditional electricity plants. On the other hand, due to the local characteristics of the renewable energy sources, the renewable electricity generation plants are often decentralized and small. Second, liberalization brings the opportunity for new agents to enter into the market as long as the system operator guarantees free and indiscriminate access to the grid. Moreover, in most countries priority has been granted to the renewable electricity on the grid, as it was specified in the European Directive (96/92/EC).

In short, the new context of a liberalized electricity market enhances the opportunities for RES to develop, but the production of renewable electricity is, in the short run, less competitive than conventional thermal generation.

The present research aims at modelling liberalized electricity markets where firms are able to use two types of sources into the electricity technology mix. We develop an oligopoly model in which firms submit bids to a mandatory pool. Firms decide a price-quantity strategy, submitting a continous price-quantity auction modelled as a supply function.[3] Then, this paper aims at exploring the interaction among RES, electricity technology mix and liberalization, paying special attention to the resulting policy recommendations in comparison to the existing literature, and providing new insights on these issues. The results obtained in this theoretical framework are tested with the experience of the Spanish Electricity Market using data from the OMEL, the Spanish market operator.

For a general modelling approach of electricity markets the reader can see Stoft (2000) and Newbery (1999). These articles focus on market design and the effects that privatization and regulation rules have on such markets. A survey of the liberalisation and deregulation process in Europe can be found in Jamasb and Pollitt (2003). The issue of renewable energy sources participation in the electricity technology mix has also attracted economists' attention. Painuly (2001) reports empirical evidence and a theoretical model.

[3]For a reference to supply function competition see Klemperer and Meyer (1989).

However, rather than focusing on the competition model, they compare different regulatory regimes.

The rest of the paper is organized as follows. Section 2 describes measures and regulatory framework concerning renewable energy consumption within the EU. Section 3 highlights the current situation. Section 4 develops and solves an oligopoly model addressing the impact of RES on the technology mix and the market outcome. Section 5 reports data from the Spanish electricity market. Section 6 analyzes data. Section 7 concludes and gives some policy recommendations.

2 Economic support systems for renewable energy in the EU

Economic regulation in liberalized energy markets promotes competitive behavior among deregulated firms, and tries to mitigate, as far as possible, the so-called market shortcomings mainly concerning asymmetric information, market power in situations of concentration and the lack of accounting for the environmental costs. Therefore, regulation tends to internalize environmental costs by means of indirect mechanisms aimed at mitigating market imperfections.

Since under the Renewable Directive, member states are free to choose their preferred support mechanism, nowadays many ways to support renewable energy and a broad variety of methods have been implemented in the different Member States. These instruments must be compatible with the liberalised energy market and they should be implemented without negatively affecting competition.

The major categories of relevant policy mechanisms are financial incentives, registering of the national targets concerning the percentage of renewable energy, simplifying the administrative procedures and guaranteeing access to the distribution of electricity from RES. The most prominent ones are the schemes based on direct price support, investment aid or tax exemptions or reductions. In what follows we make an overview of these market support systems.

2.1 Financial instruments

These are economic incentives that encourage technological transformation favouring activities with a smaller envionmental impact.

A. Direct price support schemes: generators of energy from renewable energy sources receive financial support per kWh supplied. There are essentially two categories of direct price support mechanisms within the EU: quota-based systems, and fixed-price systems.

Under quota-based system, producers are obliged to produce a share of renewable energy which is fixed by the government. The support is determined through a competition mechanism. Two different mechanisms operate at present: green certificates and tendering schemes. Under a green certificate system, Electricity from Renewable Energy Sources (RES-E) is sold at conventional market prices. A parallel secondary market of tradable certificates develops where RES producers compete to sell green certificates to suppliers/distributors who wish to buy these certificates at the lowest price. Under a tendering system, the State places a series of tenders for the production of renewable electricity. Producers of renewable energy can put offers for a certain capacity. Producers who submit the lowest price are offered a long-term power purchase agreement (PPA) until the tendered RES-E volume has been reached. The price difference between these contracts and the price for conventional energy is the extra cost for the production of green energy. The extra costs generated by the purchase of RES-E are passed on to the end consumer of electricity through a specific levy.

When fixed-price systems are implemented, no quota or maximum limit is set for renewable energy. Such a limit or quota is, however, created indirectly by the level at which the renewable energy price is set. Different variants of this fixed-price system are currently implemented in several EU countries, notably Germany, France, Spain and Denmark. Feed-in tariffs are characterized by a guaranteed long-term (for a specified period up to 20 years) minimum price, set above the normal market price, which must be paid usually by distributors to domestic producers of green energy. Consequently, the feed-in tariff operates as a subsidy allocated to producers of renewable energy. The additional costs of this system are paid by suppliers in proportion to their sales volume and are passed on to customers through transmission or distribution tariffs. This system has the advantage of stable prices which mitigate an important part of market risks, enhancing investment security, facilitating fine tuning and long and midterm technological strategies. It is a very effective mechanism of supporting the expansion of renewable energy. On the other hand, this fixed-price system is not cost efficient since it does not aim at the lowest price per kWh. It is difficult to harmonise at EU level and may be challenged under internal market principles. Apart from this system, in many countries a feed-in tariff is combined with an exemption of balancing costs for green producers. A variant of the fixed-price scheme is a fixed-premium mechanism. Under this system, the government sets a fixed premium or an environmental bonus, paid above the normal electricity price, to generators of renewable energy. This premium helps to compensate for capital and exploitation costs.

B. Fiscal Incentives. Relatively higher levels of subsidy or tax deductions are given to promote the technological development of some expensive technologies. Granting some form of investment subsidy is a simple way of promoting the technological development of expensive renewable energy techniques. Some Member States also support renewable electricity, directly or indirectly, through tax incentives. This takes the form of tax exemptions or refunds of energy taxes where they exist, tax exemptions for investments in small-scale renewable energy, etc,...favouring indirectly the development of RES. Government support is also given to almost all forms of renewable energy through subsidies for Research and Development, and serve to stimulate the research and development on renewable energy technologies.

2.2 Indirect support schemes

Complex administrative and licence procedures are some of the most important obstacles concerning renewable energy projects. For some projects it takes years to acquire the necessary licences. Simplification of administrative procedures and giving priority to renewable energy projects are therefore important factors.

3 Renewable energy consumption. The status quo

Renewable energy consumption is expected to increase from 1400 Mtoe in 2002 to 2200 Mtoe in 2030; however, the aggregate share in total energy consumption will remain unchanged, about 14% of total demand. This is the result of rapid increase in consumption of non-renewable resources coming mainly from developing countries. Non-hydro renewables are expected to increase from 2% in 2002 to 6% in 2030. Most of this increase will take place in OECD European countries. As a result, it is expected that RES will increase their share in the technology mix.

Renewable energy technologies are becoming popular because of source availability, fossil fuel independence, modularity, and their environmental characteristics. Modularity may help to relax market power exerted by large firms as long as ownership does not remain under the dominant firms. Therefore we wonder whether it is feasible to increase the share of renewable energy sources in the electricity technology mix. IEA previsions for 2030 include two posibles scenarios. A reference scenario in the IEA's Word Energy Outlook (WEO) 2005 assumes a continuation of the present policies implemented by governments and no breakthrough in technology. New-renewable energy supply would increase up to would 6%. An alternative scenario in WEO 2005 explores the impact on the global energy future if countries implement policies under the present discussion including efforts in efficiency and increase the use of renewables. New-renewable energy supply increase up to 9%. Figure 1 depicts non-hydro renewables in electricity generation under the reference and the alternative scenario by regions according to IEA's predictions.

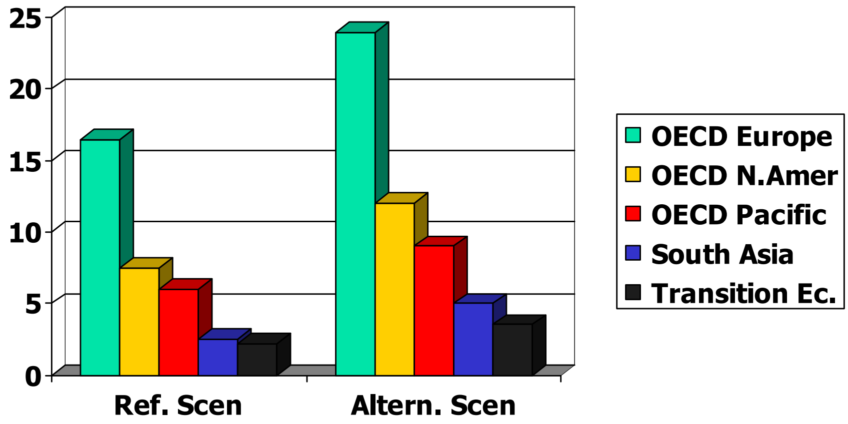

Figure 1. European Community Targets by 2010 in Non-hydro renewables under the reference and the alternative scenario by regions. Source: IEA and own construction.

Spain is making an effort to cope with Kyoto's targets on emissions of CO_2. The process of liberalization of the electricity market began with the Law 54/1997. Competition was introduced in generation and comercialization whereas transmission and distribution remained regulated. At that time, the structure of the industry was highly oriented towards non-renewable generation. The White Paper of 1997, started a program to promote the use of renewable sources implementing different policy instruments. The most relevant is the modified Aid for Electricity Generated from Renewable and CHP Sources. It is effective from 2004 by means of the Real Decreto 436/2004 (passed in march of 2004). It is set up to fit into the existing general framework supporting RES-E as set out by the Electricity Act 54/1997, which is still in force. It provides incentives for new installed capacity of renewable energy sources. It requires evaluation of costs and impacts as RES gain in popularity and strigency. However, little consensus seems to have emerged among analysists particularly with respect to its effects on consumer surplus.

Many economic models for climate and energy policy analysis find that RPS's policies aimed at reducing greenhouse gas emissions from the electricity sector raise economic costs and electricity prices, as in Palmer and Burtraw (2005). Other studies find that these policies can actually result in lower consumer prices (see Clemer et al., 1999). They argue that additional renewable energy displace gas-turbine generation and the subsequent decrease in demand lowers the price or natural gas and finally, the final electricity price.

The Spanish Electricity System has been succesful in increasing the share of renewables in total electricity generation.[4] Before 2007, the special regime works as follows. At the beginning distributors were obliged to purchase all the electricity generated by renewable technologies at a fixed price. As the amount of energy generated became more important, a fraction of the total had to be offered at the pool at the system marginal price. The way the fixed price was set followed an estimation of the fixed cost of production by the regulatory board.

4 The Model

We set up a duopoly model in which firms use different energy sources to generate electricity: non-renewables and renewables. By using different sources, firms implement two types of technologies. Then, this technology mix yields differences in the cost structure arising from two sources:

- Technical efficiency and cost-savings: despite the fact that RES are still less efficient than fossil fuels they are experimenting a growing efficiency. Research plans in the last decade have provided improvements both in the amount of megawatts produced by unit of source and the modularity (complementarity) between different renewable sources.
- Environmental and social costs: fossil sources have an environmental impact with may result in climate change. In addition, aesthetic impact and health damages produced by energy plants located near cities and villages become more frequent over the last years. Therefore, regulators account for such costs when assessing the total impact of using fossil sources.

[4] Actually, spanish regulation aims to cope with the main target of Directive 2001/77/EC by 2010: at least 29.4% of total electricity consumption should come from renewable sources.

In our model, fossil (F) and renewable (R) sources are inputs that yield a final product: electricity. Firms minimize costs in each plant:

$$\begin{array}{ll} \underset{F}{MIN}\ \frac{c_F}{2}F + K & \underset{R}{MIN}\ \frac{c_R}{2}R + K \\ s.t:\ K \cdot F = q_i^F, & s.t:\ K \cdot \left(\frac{R}{\phi(e)}\right)^{\frac{1}{2}} = q_i^R, \end{array}$$

where the function $\phi(e)$ specifies technical maturity: It depends on the degree of efficiency achieved by renewable technologies. We assume $\frac{\partial \phi(e)}{\partial e} < 0$; if there is an improvement in the parameter e a higher cost reduction is achieved. Formally,

$$\phi(e) \begin{cases} > 1 & if \quad e \in (-1, 0) \\ 1 & if \quad e = 0 \\ < 1 & if \quad e \in (0, \infty) \end{cases}$$

where e is the efficiency parameter. K represents fixed (and sunk) costs incurred by each firm in each plant. Let us assume without loss of generqality $K = 1$. The total amount of electricity produced is $\sum_{j=F,R} \left(\sum_{i=1,2} q_i^j \right) = Q$. These technologies yield a cost function given by $C_i(q_i) = \frac{c_f}{2}\left(q_i^F\right)^2 + \frac{c_R \phi(e)}{2}\left(q_i^R\right)^2$.

The demand function is $D(\omega) = 1 - \omega$, where ω is the wholesale price. We assume firms compete in supply functions. Therefore, each firm submits a supply function $S_i(\beta_i) = \beta_i^F \omega + \beta_i^R \omega(1+\tau)$, $i = 1, 2$. where $\beta_i = (\beta_i^F, \beta_i^R)$, $i = 1, 2$. As we want to explore the impact of regulation on the model, it is supposed that the regulator may incentive each kilowatt generated by renewable sources and traded at the pool with an extra feed-in-tariff $0 < \tau < 1$. Then, the total payment for the energy produced by renewables is $\omega(1+\tau)$.The clearing market condition balances total supply and demand $\sum_{i=1,2} S_i(\beta_i) = D(\omega)$. The wholesale price ω is obtained endogenously,

$$\omega(\beta) = \frac{1}{1 + \sum_{i=1,2} \beta_i^F + \sum_{i=1,2} \beta_i^R (1+\tau)},$$

where $\beta = (\beta_1, \beta_2)$.

4.1 Oligopolistic competition

Under this environment each firm maximizes its profits. The supply schedule by each firm includes two supply functions, one for each type of technology.

Let us assume that $c_R = 1$ so that the divergence between c_F and $\phi(e)$ measures differences in the level of marginal costs (the relative differences between the price of fossil sources and the technical maturity of RES). Then, we define firms' profits $\pi_i(\beta_i, \beta_{-i})$ as a function of the supply schedules. The profit maximization programme for each firm i is

$$\underset{\beta_i}{MAX} \quad S_i(\beta_i)\omega(\beta) - C_i(S_i(\beta_i)).$$

The price-quantity equilibrium is obtained from the system of first order conditions,

$$\frac{\partial \pi_i(\beta_i,\beta_{-i})}{\partial \beta_i^F} = 0, \qquad \frac{\partial \pi_i(\beta_i,\beta_{-i})}{\partial \beta_i^R} = 0,$$

which yields optimal strategies,

$$\widehat{\beta}_i^F = \widehat{\beta}_i^R(1+\tau) - \frac{2\tau}{(\phi(e)+c_F)}, \qquad \widehat{\beta}_i^R = \frac{2\tau+\theta-c_F}{2(\phi(e)+c_F)(1+\tau)}, \tag{1}$$

where $\theta(\phi(e), c_F, \tau) = \frac{\sqrt{\phi(e)}\sqrt{4(\phi(e)-\tau^2)+c_F(4+\phi(e)+4\tau)}}{\sqrt{c_F}}$. Non-negative and rationale constraints impose that $\phi(e) > \tau^2$, and $c_F > 2\tau > 2\tau - \sqrt{c_F}\sqrt{4+c_F}$. Taking into account these constraints, the function $\theta(.)$ has the following properties: $\frac{\partial \theta}{\partial \phi(e)} > 0$, $\frac{\partial \theta}{\partial \tau} > 0$, and $\frac{\partial \theta}{\partial c_F} < 0$. Notice that also in the case of renewable sources are not utilized, firms have two asymmetric plants. We call it the benchmark case, in which firms have a fossil plant and another plant which consists of hydro and combined cycle. Under this benchmark case there is no feed-in tariff ($\tau = 0$) and the function $\phi(e)$ takes the value 1, yielding optimal strategies,

$$\left(\widehat{\beta}_i^F\right)^* = \frac{2}{c_F+\sqrt{c_F}+\sqrt{4+5c_F}}, \qquad \left(\widehat{\beta}_i^R\right)^* = \frac{2\sqrt{c_F}}{\sqrt{c_F}+\sqrt{4+5c_F}}. \tag{2}$$

Equilibrium magnitudes of the general model are,

$$\widehat{q}_i^F = \widehat{q}_i^R(1+\tau) - \frac{\phi(e)-4\tau-c_F}{4\theta}, \quad \widehat{q}_i^R = \frac{\theta+2\tau-c_F}{4\theta(1+\tau)}, \quad \widehat{\omega} = \frac{\phi(e)+c_F}{2\theta}, \tag{3}$$

yielding profits,

$$\widehat{\pi}_i = \frac{(\phi(e)+c_F)(2\theta-\phi(e)-c_F)}{8\theta^2} - \frac{c_F(\phi(e)+2\tau-\theta)^2}{32\theta^2} - \frac{\phi(e)(2\tau+\theta-c_F)^2}{32\theta^2(1+\tau)^2}.$$

Equlibrium magnitudes in the benchmark case are given by

$$\left(\widehat{q}_i^F\right)^* = \frac{2}{c_F+\sqrt{c_F}+\sqrt{4+5c_F}}, \quad \left(\widehat{q}_i^R\right)^* = \frac{2\sqrt{c_F}}{\sqrt{c_F}+\sqrt{4+5c_F}}, \quad \omega^* = \frac{\sqrt{c_F}}{\sqrt{4+5c_F}}, \tag{4}$$

yielding profits,

$$(\widehat{\pi}_i)^* = \frac{\sqrt{c_F}+\sqrt{4+5c_F}-c_F}{2(4+5c_F+\sqrt{c_F}+\sqrt{4+5c_F})}.$$

4.2 Technical maturity and regulation

We are interested now in the effects that different degrees of efficiency and the level of a feed-in tariff have on the equilibrium magnitudes that arise when RES are inputs. In particular, it is important to know whether for a sufficient level of technical maturity, the implementation of feed-in tariffs above a certain threshold, makes the market worse off in terms of output and price. Moreover, it is possible that the costs of fossil sources increase relatively more rapidly than technical maturity so there are different levels of e such that $\phi(e) \leq c_F$. Then, the following question arises: should the regulator subsidize RES? and, is it neccesary to maintain feed-in tariffs when a sufficient level of e is riched? The answer to these questions depend first, on the amount of energy that the system needs to avoid fallouts and, second, on the decision to pass through consumers the real level of the wholesale price or subsidize part of it by fixing a level of τ above zero.

4.2.1 Status quo

Consider first the current situation where $\phi(e) > c_F$. If the regulator avoids fixing a feed-in tariff above zero from expressions (1) and (3) we get the following ratio $\frac{\beta_i^F}{\beta_i^R}\rfloor_{\tau=0} = \frac{q_i^F}{q_i^R}\rfloor_{\tau=0} = \frac{\phi(e)}{c_F} > 1$, with total quantity and wholesale price,

$$\widehat{Q}\rfloor_{\tau=0} = 1 - \frac{\phi(e)+c_F}{2\theta\rfloor_{\tau=0}}, \quad \widehat{\omega}\rfloor_{\tau=0} = \frac{\phi(e)+c_F}{2\theta\rfloor_{\tau=0}},$$

To highlight what happens when the level of feed-in tariff is above zero we obtain the partial derivatives of $\frac{\widehat{q}_i^F}{\widehat{q}_i^R}$, $\widehat{Q}$ and $\widehat{\omega}$ with respect of τ and evaluate them for $\tau = 0$. We obtain that,

$$\frac{\partial(\frac{\widehat{q}_i^F}{\widehat{q}_i^R})}{\partial\tau}\rfloor_{\tau=0} < 0, \quad \frac{\partial(\widehat{Q})}{\partial\tau}\rfloor_{\tau=0} < 0 \quad \frac{\partial(\widehat{\omega})}{\partial\tau}\rfloor_{\tau=0} < 0$$

Then, despite the fact that the difference between fossil sources and RES is smaller, the total quantity and prices decrease. However, total profits increase. Then, a first conclusion is that when technical maturity is relatively low a feed-in tariff favours lower wholesale prices but does not enhance efficiency, given the decreasing total quantity. Let us illustrate the above conclusions by means of a numerical simmulation. Suppose that the technical maurity function is $\phi(e) = \frac{1}{1+e}$. In what follows we are going to give values to c_F, e, and τ. In particular, $c_F = 3/2$ and $\tau \in \{0, 0.25\}$. In this case, we are going to consider that techcnical maturity is $e = -1/2$, then

$\phi(-1/2) = 2$.

Table 1. Simulation for $e = -1/2$.

	$\tau = .0$	$\tau = 0.25$
π_i	.085	.089
q_i^F	.165	.140
q_i^R	.124	.125
Q	.578	.530
ω	.422	.405

4.2.2 A case with the same marginal cost

Suppose now that $\phi(e) = c_F$. If the regulator avoids fixing a feed-in tariff above zero, from expressions (1) and (3) we get the following ratio $\frac{\beta_i^F}{\beta_i^R}\rfloor_{\tau=0} = \frac{q_i^F}{q_i^R}\rfloor_{\tau=0} = 1$, with total quantity and wholesale price,

$$\widehat{Q}\rfloor_{\tau=0} = 1 - \frac{c_F}{\theta\rfloor_{\tau=0}}, \quad \widehat{\omega}\rfloor_{\tau=0} = \frac{c_F}{\theta\rfloor_{\tau=0}},$$

As in the previous section, we obtain partial derivatives of $\frac{\widehat{q}_i^F}{\widehat{q}_i^R}$, $\widehat{Q}$ and $\widehat{\omega}$ with respect of τ and evaluate them for $\tau = 0$. We obtain that,

$$\frac{\partial(\frac{\widehat{q}_i^F}{\widehat{q}_i^R})}{\partial\tau}\rfloor_{\tau=0} < 0, \quad \frac{\partial(\widehat{Q})}{\partial\tau}\rfloor_{\tau=0} < 0 \quad \frac{\partial(\widehat{\omega})}{\partial\tau}\rfloor_{\tau=0} < 0$$

In this case, we are going to consider that techcnical maturity is $e = \frac{1}{c_F} - 1 < 0$, then $\phi(\frac{1}{c_F} - 1) = 3/2$. Once again, despite to the fact that the difference between fossil sources and RES is lower, the total quantity and prices decrease. However, total profits increase. From table 2 it is shown that fixing τ above zero reduces both, the energy generated from fossil sources and from RES. Moreover, the wholesale price is reduced but firms' profits increase.

Table 2. Simulation for $e = \frac{1}{c_F} - 1$.

	0.0	0.25
π_i	.085	.089
q_i^F	.150	.123
q_i^R	.150	.149
Q	.600	.544
ω	.400	.381

4.2.3 Tecnical maturity above fossil prices

Finally, we consider that $\phi(e) < c_F$. If the regulator avoids fixing a feed-in tariff above zero from expressions (2) and (4) we get the following ratio

$\frac{\beta_i^F}{\beta_i^R}\rfloor_{\tau=0} = \frac{q_i^F}{q_i^R}\rfloor_{\tau=0} < 1$, with total quantity and wholesale price as especified in expressions (4). Taking the general model we explore what happens when the level of feed-in tariff is above zero. We obtain partial derivatives of $\frac{\widehat{q}_i^F}{\widehat{q}_i^R}$, $\widehat{Q}$ and $\widehat{\omega}$ with respect of τ and evaluate them for $\tau = 0$. We obtain that,

$$\frac{\partial(\frac{\widehat{q}_i^F}{\widehat{q}_i^R})}{\partial \tau}\rfloor_{\tau=0} < 0, \quad \frac{\partial(\widehat{Q})}{\partial \tau}\rfloor_{\tau=0} < 0 \quad \frac{\partial(\widehat{\omega})}{\partial \tau}\rfloor_{\tau=0} < 0$$

In this case, we are going to consider that techcnical maturity is $e \in \{0, 1/2\}$. Then $\phi(0) = 1$ and $\phi(1/2) = 2/3$. Now in both examples displayed in tbles 3 and 4. The differences between fossil sources and RES is larger, but the total quantity and prices decrease. However, total profits increase. From table 3 and 4 it is shown that fixing τ above zero may reduce both, the energy generated from fossil sources and from RES. Moreover, the wholesale price is reduced but firms' profits increase.

Table 3. Simulation for $e = 0$.

	0.0	0.25
π_i	.084	.088
q_i^F	.127	.097
q_i^R	.191	.185
Q	.636	.564
ω	.364	.342

Table 4. Simulation for $e = \frac{1}{2}$.

	0.0	0.25
π_i	.082	.085
q_i^F	.103	.071
q_i^R	.235	.221
Q	.676	.584
ω	.324	.301

From the tables (3, 4), it is shown that feed-in tariffs are useful especially when technical maturity is such that $\phi(e) < c_F$. This occurs when $e < e^* = 1/c_F - 1$. However, an increase in τ never leads to larger renewable quantities causing always the total quantity to decrease. This calls for a carefully consideration of the levels of τ and its application in the different stages of technical maturity. Another open dabate is whether wholesale market should be lower when RES are included in the technology mix or the use of RES implies a trade off between green energy and energy prices.

5 Data and Market Structure

We use data from the Spanish electricity market during the period 2002 to 2008. There are six large generators: *Endesa Generación* (ENG), *Iberdrola Generación* (IBG), *Unión Fenosa Generación* (UFG), *Hidrocantábrico Generación* (HCG), *Viesgo Generación* (VIG) and *Gas Natural* (GN). On the demand side, distributors provide the bulk of electricity to final consumers at a regulated price.[5] For instance, we call *Endesa Demand* (END), the share of total demand covered by distributor and end-supplier. The rest of demand-side market operators are: *Iberdrola Demand* (IBD), *Unión Fenosa Demand* (UFD), *Hidrocantábrico Demand* (HCD), *Viesgo Demand* (VID). Notice that there are five vertically integrated firms[6]; *Endesa* (EN), *Iberdrola* (IB), *Unión Fenosa* (UF), *Hidrocantabrico* (HC) and *Viesgo* (VI). Table 5 summarizes generation and distribution market shares of the largest firms.

Table 5. Market Shares

Demand

	END	IBD	UFD	HCD	VID	GN	OTh
2002	0.39	0.39	0.11	0.06	0.01	0.01	0.03
2003	0.39	0.38	0.14	0.06	0.01	0.01	0.01
2004	0.40	0.37	0.12	0.06	0.01	0.01	0.03
2005	0.37	0.38	0.12	0.06	0.01	0.01	0.05
2006	0.37	0.38	0.14	0.05	0.02	0.01	0.03
2007	0.44	0.33	0.12	0.04	0.01	0.01	0.05
2008	0.32	0.28	0.18	0.04	0.01	0.02	0.15

Supply

	ENG	IBG	UFG	HCG	VIG	GN	OTh
2002	0.43	0.30	0.12	0.07	0.04	0.01	0.03
2003	0.43	0.29	0.12	0.07	0.02	0.01	0.06
2004	0.43	0.26	0.11	0.07	0.01	0.02	0.10
2005	0.36	0.24	0.12	0.07	0.02	0.02	0.17
2006	0.31	0.25	0.11	0.05	0.03	0.05	0.20
2007	0.30	0.25	0.12	0.06	0.03	0.05	0.19
2008	0.25	0.20	0.13	0.06	0.03	0.05	0.28

Source: OMEL and own calculations

Table 5 shows that market shares of generators remain quite stable between 2002 and 2004. This was because there had been a significant increase in installed capacity by the incumbents whereas entry of new firms had not been significant. However, since 2005 there has been entry by new small scale firms. We observe a significant loss in market share for ENG, while market shares of competitors remain stable. Moreover, for the whole period

[5] There have also been end-demand suppliers in some periods. Difference between distributors and end-demand suppliers is that the later cannot provide electricity directly to consumers. They must serve electricity thorugh the distributor network.

[6] Ciarreta et al. (2007) investigate experimentally the effects of vertical integration on the functioning of the Spanish electricity market.

considered, there is a dominant position for EN and IB. Finally, demand does not play a strategic role in the market since 62% of the total demand goes to regulated distributors.

Table 6 in the Appendix 2 shows capacity of generation by type of technology since 2002 to 2008. Non-renewable sources include fossil fuels such as combined cycle, oil-fired, nuclear and coal-burning plants. Other renewables include mostly aeolic power, biomass and solar power plants. One can see that there has not been further entry of non-renewable plants.[7] Note that EN is the largest firm in terms of thermal capacity, closely followed by IB. IB is clearly the leader in terms of capacity installed in renewable sources. Thus, IB's capacity investments have been directed more towards non-renewable sources as compared to EN's investments. There is a remarkable assymmetry in costs as a result of differences in technology generation.

Table 7 in the Appendix 3 summarizes the percentage of total hours in which either EN or IB alone set the system marginal price. Within each year, we compute the percentage that comes from renewables.[8] We observe that there is a large number of hours in which hydroelectric renewables set the SMP, which means that generators may use these plants strategically. This is more likely during peak demand hours, because it is when margins are higher. This means that generators that own renewable as well as non-renewable sources can bid strategically to push prices upwards and then obtain positive price-cost margins.

Finally, we use load duration curves to classify hours into peak demand hours, load above 26000 MWh, and off-peak demand hours, load below 16000 MWh. Appendix 4 plot load duration curves since 2002 to 2008.

6 Data analysis

Investment in the electricity sector is a long-term decision because sunk costs are high. Thus, profit-maximizing firms' decision to invest is affected by the regulatory framework and the availability of inputs. In the case of renewables, we have already to discuss regulatory policies. The choice of technology is

[7]New combined cycle plants have been built after 2003. However, most of them started operating in the mid-2005.

[8]The Spanish pool is a Day-ahead uniform-price auction in which buyers and sellers' offers for each of the units they own are matched to keep the market balanced. For each hour of any given day the market clearing price, called System Marginal Price (SMP), is determined by a generation unit under the ownership of a generator. For example, in 2005 out of 8760 observations, *Duero* (DUER), a hydroelectric unit under the ownership of IB, set the SMP 339 times. However, it may happen that more than one unit of different generators set the SMP, in which case there is a rationing mechanism.

based on the specific market conditions. We focus on the short-term decision, concerning the strategic use of already existing units aimed at profits maximization. We analyze this feature by estimating a regression model that considers how assymmetries in the technology mix result in differencies in bidding behavior in the day ahead market. Table 8 summarizes the explanatory variables used in the regression model.

Table 8. Summary statistics of variables				
	Mean	Std. dev.	min	max
Dep. Variable				
SMP	38.4	18.6	0	158.4
Indep. Variables				
Available Nuclear	7113	758	4587	7735
Available Coal-burning	9517	577	7431	10273
Available Oil-Fired	6092	450	4327	7011
Available Combined-cycle	4879	2904	8	11898
Available Hydroelectric	15622	345	14627	16386
Available Windmills	–	–	–	–
Available Other	–	–	–	–
Source: OMEL, CNE and own calculations.Data: jan.2002 to dec. 2008.				

The average SMP is 38.4 €/MWh. As a first approach, we consider a regression model in which the SMP is a function of the fraction of fossil fuel plants (nuclear, D^N, coal-burning, D^{C-B}, oil-fired, D^{O-F},and combined cycle, D^{C-C}) available for the following day (which is announced the day before, that is in $t-1$), expected weather conditions for eah hour, W_{th}^{N-H}, and water reserves, W_{th}^{H}.

$$SMP_{th} = \alpha + \beta_1 D_{t-1}^{N} + \beta_2 D_{t-1}^{C-B} + \beta_3 D_{t-1}^{O-F} + \beta_4 D_{t-1}^{C-C} + \gamma_1 W_{th}^{H} + \gamma_2 W_{th}^{N-H} + \varepsilon_t, \quad [1]$$

$$SMP_{th} = \alpha + \beta_1 D_{t-1}^{N} + \beta_2 D_{t-1}^{C-B} + \beta_3 D_{t-1}^{O-F} + \beta_4 D_{t-1}^{C-C} + \gamma_1 W_{th}^{H} + \gamma_2 W_{th}^{N-H} + T_{th} + \varepsilon_t, \quad [2]$$

where $h = 1, ..., 24$. The error term includes unexpected breakouts, errors in demand forecast etc. In competitve markets we would expect prices to reflect opportunity costs of generation.

As a first approach, we use univariate time-series models because we would expect that the behavior of the SMP depends on past values, as the correlogram suggests. The variance of the current error term is a function of the variances of the previous time period's error terms. Arch relates the error variance to the square of a previous period's error. It is employed commonly in modeling financial time series that exhibit time-varying volatility clustering, i.e. periods of swings followed by periods of relative calm. In electricy markets volatility of the variance is also dependent on previous periods variance volatility. Therefore, we estimate a Arch model under two different specifications: Equation [1] does not include explicitly time effects, whereas Equation [2] includes time dummies, T_{th}, to account for time-specific effects such as peak demand and off-peak demand hours, and differences between patterns of consumption during the week. Table 9 reports estimation results for the two specifications of the Arch model.

Table 9. Estimation from two alternative models

	[1]	[2]
Nuclear	-0.019^{***}	-0.016^{***}
Coal	-0.025^{***}	0.003
Oil faired	0.008^{***}	0.021^{***}
Combined cicle	-0.010^{***}	0.007^{***}
Hydro	0.005	0.032^{***}
Time dummies	NO	YES
Log likelihood	-7714	-8059

***Significant at 1%.

Estimation results are not conclusive and call for futher research. But we can still conclude that hours during which there was a higher proportion of hydroelectric resources available ex-post prices were higher. It is clear that availability of more nuclear resources lowers prices whereas the evidence for the other sources is mixed. In general, oil-fired plants amd hydro are used during peak demand hours, this coukd explain the persistent positive estimation result. However, coal-burning plants availability is highly dependent on the regulatory framework that favours national coal producers.

7 Conclusions

Fossil resources are scarce, produced at high prices, and cause environmental problems that make the actual electric technology mix unsustainable. Besides, IEA predictions over renewable energy increments are ambigous, and depend on country-specific policies. The use of renewable energy will grow in different ways depending on the area of the world: It could increase inequality and energy dependence. The OECD area is expected to lead the 'renewable sources revolution' by means of policy suggestions to the member states.

Liberalization in the Spanish electricity market is still incomplete because firms try to maintain their market power. The special regime must encourage trading renewable energy at the pool in order to increase efficiency. Increasing the share of renewable sources could mitigate collusion and increase efficiency. Preliminary estimation results for the period 2002-2005 when the availability of non-hydro renewable sources was limited, show how market prices are higher when the share of hydroelectricity is higher. However, given the cost of generation of these units, it provides generators with incentives to increase price-cost margins.

Our results suggest that changes in the regulatory regime could affect bidding behavior of generators in any direction. We explore how these changes towards promotion of renewable sources have affected prices in the Day-ahead market. Based on data from the period 2005 until May 2008. The period is characterized by significant changes in electricity market rules and regulation and some of the effects of these changes have been identified.

Appendix 1. RES regulatory policy in the Spanish Electricity Market: the Special regime.

The Special regime establishes the framework to promote the electricity generation from RES. It has been regulated in Spain since 1980 when Law 80/1980 on Energy Conservation came into force. It established energy efficiency improvement objectives for the industry and reductions in external dependence. As a result, self-generation of electricity and the hydroelectric production in small power stations was encouraged.

Later, within the process of liberalization of the electricity market started with the General Electricity Law 54/1997, Spain made an effort to promote generation of electricity by RES to cope with Kyoto's targets on emissions of CO2. Competition was introduced in generation and end-supply whereas transmission and distribution remained regulated. The Law aimed to reconcile the liberalization of the electricity system with the objective of guaranteeing supply of appropriate quality, at the lowest possible price and minimizing the environmental impact. Installations under the Special regime may leave any surplus energy to the network, offer it on the Day-ahead market, or establish physical bi-lateral contracts. The economical framework was developed by the RD 2818/1998, on electric energy production by installations using renewable resources, waste and co-generation.

The White Paper of 1997 started a program to promote the use of renewable sources implementing different policy instruments. The most relevant one was the modified Aid for Electricity Generated from Renewable and Combined Heat and Power Sources, which provides incentives for new installed capacity of RES, and requires evaluation of costs and impacts as RES gain in popularity and stringency.

The National Energy Plan 1991-2000 established an incentive scheme for production by co-generation and RES to meet 10% of national electricity production in 2000 (from 4.5% in 1990). Within this period, Law 40/1994 consolidated the Special regime concept as such, and the RD 2366/1994 defined the principles established there in. It was concerned with hydroelectric energy production, co-generation and other installations supplied by RES.

In 1999, and in conformity with EU directives, the Government approved a Plan for the Promotion of Renewable Energies which included the necessary relevant strategies so that the growth of energy produced from RES covers at least 12 % of primary energy consumption by the year 2010. To meet this target, it is necessary to double production of renewable energies, as the demand for energy rapidly grows. The core of the current contribution of these energies comes from hydroelectric generation and from biomass generation (95% together).

The Royal Decree 436/2004 went beyond in the scope of the Special regime. Distributors were obliged to purchase all the electricity generated by RES at a fixed price. As the amount of energy generated became more important, a fraction of the total had to be traded trough the pool at the system marginal price. The way the fixed price was set followed an estimation of the fixed cost of production by the regulatory board.

Currently, the regulation that sets the legal framework for the Special regime is RD 661/2007 which repeals RD 436/2004. The latter maintains the basic principles of the former regulation with minor changes. Spanish regulation aims to cope with the main target of Directive 2001/77/EC by 2010: at least 29.4% of total electricity consumption should come from renewable sources. There are two possibilities to sell electricity generated by RES in the Spanish electricity market:

- Generators can put electricity directly into the grid, without passing across the Day-ahead market, and obtaining a single regulated tariff for each hour of the day. Sells are done through the market operator although offers are at zero prices in the Day-ahead market, unlike offers from other technologies.
- Generators can make offers of electricity at the price resulting from the uniform-price auction of the Day-ahead market or at the price set through bilateral contracting, with a subsidy to compensate for the higher cost of generation as compared to the market price.

The National Energy Commission settles the payment of the Special Regime and publishes a report on energy purchases which includes the most relevant information on the aforementioned activity. In December 1999, and in agreement with the EU, the Government approved a Plan for the Promotion of Renewable Energies which included the necessary relevant strategies so that the growth of each of the areas of renewable energies may cover, all together, at least 12 % of primary energy consumption by the year 2010.

Appendix 2: Capacity of generation by type of technology

Table 6. Generators' Capacity in 2002 and 2008 (MW)

	Firm												TOTAL		
	EN			IB			UF			Others (HC, VI,GN)					
Technology	2002	2005	2008	2002	2005	2008	2002	2005	2008	2002	2005	2008	2002	2005	2008
Hydroelectric	5211	5247	5247	8542	8578	8578	1766	1766	1766	1066	1066	1066	16586	16657	16657
Other renewable	20	1931	–	121	3810	–	0	924	–	0	2772	–	6373	12497	28127
Total Renewable	5231	7178	–	8663	12388	–	1766	2690	–	1066	3838	–	22959	29154	44784
Nuclear	3611	3611	3611	3306	3306	3306	735	735	735	164	164	164	7816	7816	7716
Coal	5759	5759	5759	1249	1249	1249	2047	2047	2047	2521	2521	2521	11565	11565	11359
Oil-fired	1529	1529	1315	2024	2024	2024	820	820	820	528	528	528	4632	4632	4418
Combined Cycle	1364	1364	1779	3152	3468	5939	2150	2150	4962	2420	2420	4678	6376	6692	21667
Total Non-renewable	12263	12263	12464	9731	10047	12518	5752	5752	8564	3633	3633	5891	33379	36140	61817
TOTAL	17494	19441	-	18394	22435	-	7518	8442	-	4699	7471	-	56338	65294	89944

Sources: Firms' web pages, Red Eléctrica Española (REE), and OMEL. Islands not included. Provisional values for 2008.

Appendix 3: Marginal plants

Table 7: Marginal Plants

	2002			2005			2007			2008		
Firm	% hours	From RES		% hours	From RES		% hours	From RES		% hours	From RES	
		Hy	Non-hy		Hy	Non-hy		Hy	Non-hy		Hy	Non-hy
IB	42.5	40.1	0	30.3	15.5	0	22.55	36.41	0.55	14.55	40.47	1.23
Peak IB	72.5	71.8	0	39.6	52.8	0	25.02	31.40	0.94	26.39	45.49	2.03
Off-Peak IB	10.9	6.5	0	4.4	2.5	0	15.72	37.66	0.05	8.20	34.95	0.36
EN	23.4	7.2	0.01	27.1	10.2	0	15.93	14.84	0	17.58	15.84	0
Peak EN	12.3	11.6	0	23	31.6	0	11.01	29.76	0	12.25	19.67	0
Off-Peak EN	36.4	0	0	36.2	0	0	13.94	8.35	0	20.58	11.96	0

Appendix 4: Load duration curves

Load duration curves measure the number of hours per year at which the total load is at or above a given level of demand. The curve is constructed sorting the load from the smallest amount to the highest in a given year. Figure 10 plots load duration curves for each year in Spain. On the vertical axes we have load and on the horizontal axes the fraction of hours. We see that load is a monotonically decreasing description of the profile of consumption.

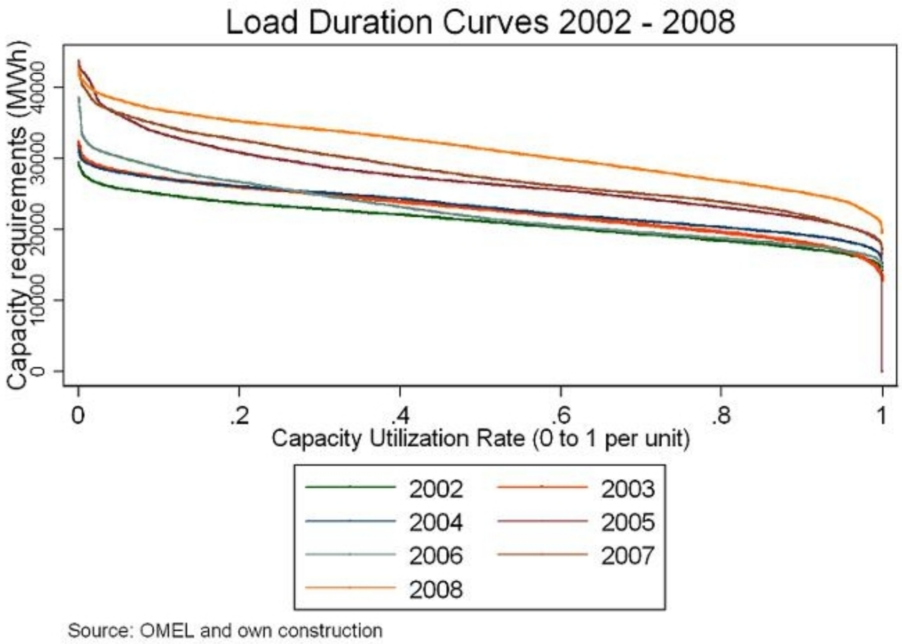

Figure 10. Load duration curves for each year in Spain.

Peak demand hours mostly correspond to the concave part of the load duration curve. Off-peak demand hours mostly correspond to the convex part of the load duration curve close to one. This classification is done ex-post, that is, using equilibrium quantities from the current year. OMEL classifies demand hours using a classification of hours. The correlation between both classifications is high.

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