On the promotion of renewable sources in spot electricity markets. The role of feed-in-tariff systems

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Abstract

This paper addresses the question of how spot electricity markets are affected by the development of renewable energy source technologies within the new framework of electricity supply security and reduction of emissions of CO_2. In a spot electricity market two firms generate electricity by using renewable as well as non-renewable technologies. First, It is shown how wholesale prices tend to decline the larger the efficiency achieved by renewable tecnologies is. Second, the proportion of energy generated by renewables depends on the level of feed-in-tariff fixed by regulators but also on the efficiency achieved. However, a high subsidy can distort competition as technical maturity of renewables technologies is large enough. This call for attention that the intensity of feed-in tariffs systems should vary as efficiency conditions change.

Keywords: electricity technology mix, renewable energy sources, technical maturity, feed-in tariffs.

JEL Classification: L13, L51, L94.

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1 Introduction

There is a great worldwide concern on the need for an increase in the use of renewable energy sources (RES, hereafter). Technologies that use RES have the potential to displace fossil (and pollutant) sources in order to mitigate global climate change, preserve air quality, and improve energy security. In particular, the introduction of RES into the electricity generation sector has become an important energy issue at debate. However, demand increases make the development of RES technologies insuficient to meet demand requirements. Hence, the use and exploitation of non-renewable energy sources will continue to grow in the near future resulting in local and global negative externalities with short and long term effects.[1]

A sustainable energy policy has to design energy plans aimed to, (i) integrate both renewable and non-renewable technologies, and (ii) minimize the utilization of fossil sources by giving incentives to develop the use of RES. In the European Union (EU, hereafter) sphere, the liberalization of the electricity sector jointly with the reduction of greenhouse gas emissions are two main targets of energy policy. 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 2010 target for electricity was set at 22.1% as a share of electricity produced from RES. But increasing the share of RES in the electricity technology mix requires strong and efficient regulatory policy support.

The introduction of RES technologies as well as the liberalization of the electricity sector (Directive 96/92/EC on the common rules for the internal electricity market) are ongoing progressive processes in all EU member states. With respect to the use of RES, liberalization of the market implies both new opportunities and threats. First, in a competitive market, the green electricity may be less competitive than conventional electricity due to the failure of prices to account for all the costs of their associated environmental impact. As a result, an inefficient use of resources may occur. Therefore, efficiency requires that environmental costs have to be included on energy pricing. Unfortunately, this target is hindered by two serious difficulties: incomplete information on environmental costs, and limited experience in the application of internal regulation mechanisms. Second, within a competitive market, the price of electricity is expected to decrease. It may create a very difficult environment for RES to emerge on the market, since most green

[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.

electricity technologies still carry higher production costs than traditional electricity plants. Moreover, due to the local characteristics of the RES, the renewable generation plants are often decentralized and small.

In Spain and other EU Member States priority has been granted to pass electricity generated by RES through the grid (RD 661/2007), as it was specified in the European Directive 1996/92/EC. Later on, the Directive 2001/77/EC and its amendations state the promotion of electricity in the internal electricity market.[2]

The aim of the paper is to explore how feed-in tariffs and the minimum amount of RES requirements (over the total energy generated) determine the market outcome in spot electricity markets. In addition, we introduce technology improvements in the cost function in order to measure the effect of R&D with the above regulatory framework. We buid a multiplant oligopoly model where firms compete in supply functions in the way suggested by Klemperer and Meyer (1989). Firms are able to use two types of sources to produce electricity: RES and fossil fuels. Thus, cost functions are differerent for each plant and, in particular, the cost of energy form RES include the efect of R&D. Promotion of RES is tackled through feed-in tariffs and special requirements on amounts of green energy over the total energy produced.

A number of papers have followed the supply function approach to modelize different issues in electricity markets. In Green (1996) and Green and Newbery (1992) some aspect of the liberalization within the England and Wales markets are addressed. In Baldick et al. (2004) an asymmetric model is used to explain some aspects of the liberalization of the British electricity market. For a general modelling approach of electricity markets and the effects that privatization and regulation rules have on such markets the reader can see Stoft (2000) and Newbery (1999). 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. However, rather than focusing on the competition model, they compare different regulatory regimes. More recently, Mátyás et al (2010) have explored feed-in tariff systems and tradable green certificates (TGC, hereinafter) schemes. They found that as long as markets become imperfect TGC should be implemented. Zhou and Mátyás (2010) investigate TGC and mergers between companies of conventional and renewable sources. Overall, it is found that TGC outcome is higher under

[2] The Directive follows up the RES-E White Paper which set a target of 12 percent of gross energy consumption from renewables for the EU-15 by 2010, of which electricity would represent 22.1 percent. With the 2004 enlargement, the EU's overall objective became 21 percent.

integration than under disintegration, reflecting efficiency gains from vertical integration. Finally, in Reichenbach and Requate (2012) an oligopoly model including learning by doing, spill-overs and two types of energy sources (green and black) is studied. They found that a first best policy requires a tax in the black energy sector and an optimum subsidy for RES technologies.

The rest of the paper is organized as follows. Section 2 describes policy mechanishms to promote green energy within the EU country memebers. Section 3 contains the model addressing the impact of RES on competitive electricity markets under the regulatory framework described. Section 5 concludes and gives some policy recommendations.

2 Policy mechanisms to promote RES

Regulatory framework attempts to internalize environmental costs by means of indirect mechanisms aimed at mitigating market imperfections. Since Directive 2001/77/EC each country member is free to choose their preferred support mechanism. Thus, many ways to support RES technologies have been implemented within EU member states. These instruments must be compatible with the liberalization of the energy market and thus, without negatively affecting competition. The major categories to support RES technologies are financial instruments and fiscal incentives. In this paper we take care of the former.[3]

Financial instruments are economic incentives that encourage technological transformation favouring activities with a smaller environmental impact. The most prominent ones are the schemes based on direct price support, investment aid or tax exemptions or reductions. Under direct price support schemes, generators that use RES 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 fixed by the government: the called quota obligations or renewable portfolio standards. They often are combined with a tradable green certificate (TGC) systems.[4] There are different variants of this fixed-price system but the primary support system used within EU country members are feed-in tariff systems. This system is 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

[3]Fiscal Incentives includes a given level of subsidy or tax deductions to promote the technological development of some expensive technologies.

[4]Another instrument based on quota requirements is a tender scheme.

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 but as RES technology increase it is not cost efficient since it does not aim at the lowest price per kWh.

In this paper we analyze the implementation of feed-in tariff systems and quota obligations because they are widely implemented in many EU countries. In particular, Spain, Germany, France, and Denmark implement feed-in tariffs as well as a quota requirement on RES over total energy traded.

3 The Model

We set up a duopoly model where firms generate electricity by using RES, R, and fossil sources, F. It yields a technology mix composed by two different production plants. The amounts of energy produced by RES and fossil sources are q_i^F and q_i^R ($i = 1, 2$), respectively, such that $\sum_{j=F,R} q_i^j = q_i$. Hence, total electricity generated is $\sum_{i=1,2} q_i = Q$. Production efficiency is reached by minimizing costs in each plant:

$$\begin{array}{c} \textit{Fossil} \\ \textit{plant} \end{array} \left\{ \begin{array}{l} \underset{F}{MIN}\ c_F \cdot F \\ s.t:\ F^{\alpha} = q_i^F, \end{array} \right. \qquad \begin{array}{c} \textit{Renewable} \\ \textit{plant} \end{array} \left\{ \begin{array}{l} \underset{R}{MIN}\ c_R \cdot R \\ s.t:\ [R/\phi(e)]^{\alpha} = q_i^R, \end{array} \right.$$

where $\alpha < 1$. Parameters c_F and c_R stand for unit costs of production. The function $\phi(e)$, which depends on the level of R&D e, specifies the degree of efficiency achieved by that plant that uses RES. We make two assumptions on the available technologies.

Assumption 1: $\phi(e)$ depends negatively on e; that is $\frac{\partial \phi(e)}{\partial e} < 0$, Thus, the larger the efficiency, the higher the R&D measured by the parameter e is (and a high cost reduction is achieved). Formally,

$$\phi(e) \left\{ \begin{array}{ll} > 1 & \text{if } e \in (-\infty, 0) \\ = 1 & \text{if } \widehat{e} = 0 \\ < 1 & \text{if } e \in (0, \infty) \end{array} \right.$$

where $\widehat{e}$ is the R&D value that makes both plants symmetric in terms of efficiency.

Assumption 2: Technologies exhibit decreasing returns of scale, $0 < \alpha < 1$.

In order to keep tractability of the model we take $c_R = 1$. Moreover, we assume $\alpha = \frac{1}{2}$. The first normalization is without loss of generality and the later provides the quadratic-cost especification that allows us to introduce capacity restrictions in a smooth way. Thus, this cost function depends on RES technical efficiency and unit fossil costs 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). [5]

Lemma 1 *Given the above minimizing programs the efficient generation rule between RES and fossil sources is*

$$q_i^R = \frac{c_F}{c_F + \phi(e)} q_i \text{ and } q_i^F = \frac{\phi(e)}{c_F + \phi(e)} q_i$$

Proof. *Under the assumptions of the model, cost minimization implies that marginal cost of generation from each plant must be equal so that* $c_F q_i^F = \phi(e) q_i^R$. *Then,*

$$\frac{q_i^F}{q_i^R} = \frac{\phi(e)}{c_F}.$$

Thus, given that $q_i^F + q_i^R = q_i$, *it holds that*

$$q_i^R = \frac{c_F}{c_F + \phi(e)} q_i,$$

and q_i^F *the remaining.* ■

Taking the above lemma, the total cost function for each firm is

$$C_i(q_i) = \frac{c_F \phi(e)}{c_F + \phi(e)} q_i^2,\ i = 1, 2.$$

We assume that the regulator incentives each kilowatt generated by RES with a feed-in-tariff $\tau > 0$. This subsidy remunerates each unit of energy (measured in kilowatts) generated by RES.

Following Klemperer and Meyer (1989) we assume firms compete in supply functions with stochastic demand $D(\omega) = \theta(\mu) - \omega$. We take an additive

[5] Despite the fact that RES are still less efficient than fossil fuels they are experimenting a growing efficiency in the recent years. Research plans have provided improvements both in the amount of megawatts produced by unit of source and the modularity (complementarity) between different renewable sources.

demand variability $\theta(\mu) = (\alpha - \mu, \alpha + \mu)$ with $\mu \in (0, 1)$, so that demand is either low $\underline{\theta}(\mu)$ or high $\overline{\theta}(\mu)$ with probability p and $1 - p$, respectively.

Each firm submits a supply function for each plant under its ownership. By Lemma 1 the problem reduces to one of each firm choosing its optimal supply function. We focus on affine supply functions $S_i(\varphi_i, \omega) = \varphi_i \omega$, where ω is the wholesale market price and $\varphi_i = (\gamma_i, \beta_i)$. Thus, ω is obtained endogenously by the market clearing condtion $\sum_{i=1,2} S_i(\varphi_i, \omega) = D(\omega)$,

$$\omega(\mu, \varphi) = \frac{\theta(\mu) - \sum_{i=1,2} \gamma_i}{1 + \sum_{i=1,2} \beta_i},$$

where $\varphi = (\varphi_i, \varphi_j)$.

3.1 Oligopolistic competition

This subsection is devoted to obtain the supply function equilibrium under the assumptions and environment described above. It is useful to define each firm's profit function as $\pi_i(\mu,\varphi)$. Definition 1 characterizes the supply function Nash equilibrium (SNE hereafter)

Definition 1 *$(\varphi_i^*,\ \varphi_j^*)$ is a SNE equilibrium such that each choose $\varphi_i^* \in \arg\max_{\varphi_i} \pi_i(\varphi_i, \varphi_j)$, where*

$$\pi_i(\varphi_i, \varphi_j) = S_i(\varphi_i, \omega(\mu, \varphi))\omega(\mu, \varphi) + \frac{c_F\ \tau}{c_F + \phi(e)} S_i(\varphi_i, \omega(\mu, \varphi)) - C_i\left(\varphi_i, \omega(\mu, \varphi)\right) \tag{1}$$

for $i, j = 1, 2., i \neq j$.

The supply schedule by each firm includes both technologies.[6] The SNE equilibrium is obtained from the system of first order conditions $\partial \pi_i(\varphi_i, \varphi_j)/\partial \varphi_i = 0$, which yields optimal strategies,

$$\varphi_i^* = (\gamma_i^*, \beta_i^*) = \left(\frac{c_F\ \tau}{c_F \phi(e) + \Omega(c_F, \phi(e))}, \frac{\Omega(c_F, \phi(e))}{2 c_F \phi(e)} - \frac{1}{2}\right) \tag{2}$$

where $\Omega(c_F, \phi(e)) = \sqrt{c_F \phi(e)(2\phi(e) + c_F(2 + \phi(e)))}$. Notice that as long as $\beta_i^* > 0$ we obtain that $\gamma_i^* < \tau/2\phi(e)$ always.

The environmental policy requires that the quota of RES production must be no less than σ $(0 < \sigma < 1)$,

$$\sum_{i=1,2} q_i^R \geq \sigma Q$$

[6] First order conditions for profit-maximizing programs throughout the paper are relegated to appendix 1.

The resulting amount of electricity produced by fossil sources and RES is obtained from $q_i^* = \gamma_i^* + \beta_i^* \omega$ and Lemma 1,

$$\left(q_i^F\right)^* = \frac{\phi(e)[(c_F+\phi(e))\theta(\mu)+c_F\tau]}{(c_F+\phi(e))[2(c_F+\phi(e))+c_F\phi(e)+\Omega(c_F,\phi(e))]}, \qquad (q_i^R)^* = \frac{c_F}{\phi(e)}\left(q_i^F\right)^*, \qquad (3)$$

with total quantity and price,

$$Q(\mu)^* = \frac{(c_F+\phi(e))}{\phi(e)}\left(q_i^F\right)^*,\ \omega(\mu)^* = \frac{(c_F+\phi(e))\theta(\mu) - 2c_F\tau}{2(c_F+\phi(e)) + c_F\phi(e) + \Omega(c_F,\phi(e))}$$

yielding profits,

$$\begin{aligned}\pi_i^*(\mu,p) = &\frac{[2(c_F+\phi(e))+c_F\phi(e)][c_F\phi(e)+\Omega(c_F,\phi(e))]}{(c_F+\phi(e))[2(c_F+\phi(e))+c_F\phi(e)+\Omega(c_F,\phi(e))]^3}\times \\ &\times [c_F\tau + (c_F+\phi(e))m_1(p,\mu)]^2\end{aligned} \qquad (4)$$

where $m_1(p,\mu)$ is the first moment with respect the mean of μ. We call the case with $\tau = 0$ it the benchmark case. By replacing $\tau = 0$ in (2) we obtain,

$$\widehat{\varphi}_i(\widehat{\gamma}_i, \widehat{\beta}_i) = (0, \beta_i^*) \qquad (5)$$

In the next section we investigate some alternative scenarios concerning different levels of technical maturity and subsidies.

3.2 Technical maturity vs feed-in tariff levels.

We are interested in the effects that different degrees of efficiency (which depends on the RES technical maturity) and the level of feed-in tariff have on the equilibrium magnitudes. In particular, it is interesting to know whether for a sufficient level of technical maturity, the implementation of feed-in tariffs above a certain threshold, makes market equilibrium worse off in terms of output and price. As the possibility that costs of fossil sources increase relatively more rapidly than technical maturity decreases there are different levels of e such that $\phi(e) \leq c_F$. Then, the following questions 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 wholesale price or subsidize part of it (by fixing a level of τ above zero).

From equilibrium magnitudes found in the previous section we can state the folowing

Proposition 1 *The amount of energy traded Q always increase as technical maturity and the level of feed-in tariff increase, $\frac{\partial Q}{\partial \phi(e)} < 0$, $\frac{\partial Q}{\partial \tau} > 0$; moreover, the amount of energy produced from RES and fossil sources also increase, $\frac{\partial q_i^j}{\partial \phi(e)} < 0$, $\frac{\partial q_i^j}{\partial \tau} > 0$, $i = 1, 2$, and $j = F, R$. Finally, A or equivalently the ratio $\frac{q_i^F}{q_i^R}$ always decrease in $\phi(e)$, regardless the level of the feed-in tariff.*
Proof. *Available upon request.* ■

Proposition 1 states an important result: from an environmental point of view is always postive to subsidize RES whatever the level of the technical maturity is. Indeed, A does not depend on τ, so what is relevant is the ratio $\frac{\phi(e)}{c_F}$. However, firms do not take care of environmental concerns. Hence, in order to achieve any increment in RES technology regulatory authorities should subsidize RES. The model internalize this fact which is stated in the following

Proposition 2 *Firms maximize profits for a certain value of $\phi(e)$ which also decrease as long as τ decrease. That is $\frac{\partial \pi_i(\phi(e),\tau)}{\partial \phi(e)} < 0$, $\frac{\partial^2 \pi_i(\phi(e),\tau)}{\partial \phi(e) \partial \tau} > 0$.*

Proof. Available upon request. ■

The above discussion has an important implication from a policy maker point of view: there is a trade off between environmental concerns and profit-maximizing behaviour: Moreover, it suggest that a welfare analysis should be done in order to highlight to what extend consumer surplus and firms' profits are affected by model parameters.[7]

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.

4 Conclusions

Renewable energy technologies are becoming popular because of source availability, fossil fuel independence, modularity, and their environmental characteristics.[8] Modularity may help to relax market power exerted by large firms

[7] A detailed analysis of welfare and environmental issues is now in progress. A further draft of this document will incorporate a more complete model and results.

[8] Modularity is used here as complementarity. That is, we want to note that different renewable technologies enter the market as long as they are available and that the failure of one of them is covered succesfully by other ones.

as long as ownership does not remain under the dominant firms. Therefore, environmental issues jointly with market considerations make to increase the share of RES in the electricity technology mix interesting.

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.

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. In particular, feed-in tariffs should decrease as RES technologies increase. Moereover, RES quotas requirements imply a trade-off between feed-in tariffs and tehnical maturity. Finally, the above results have to be complemented with taxes on fossil sources in order to internalize environmental effects. This issue exceeds the aim of this paper but it should be studied.

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Appendix 1

First order conditions,

$$\frac{\partial \pi_i(\varphi_i, \varphi_j)}{\partial \gamma_i} = \frac{(\tau - B\gamma_i) - C(A - B\gamma_i)}{A} = 0;$$

$$\frac{\partial \pi_i(\varphi_i, \varphi_j)}{\partial \beta_i} = \frac{C(\tau - B\gamma_i) - ((1-p)\omega_{-\mu}^2 - p\omega_{\mu}^2)(A - B\beta_i)}{A} = 0;$$

where $B = 2(1 + c_R)\phi(e)$, and $C = (1-p)\omega_{-\mu} + p\omega_{\mu}$.