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Promoting renewable electricity generation in imperfect markets: price vs. quantity policies

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Abstract

The search for economically efficient policy instruments designed to promote the diffusion of renewable energy technologies in liberalized markets has led to the introduction of quota-based tradable 'green' certificate (TGC) schemes for renewable electricity. However, there is a debate about the pros and cons of TGC, a quantity control policy, compared to guaranteed feed-in tariffs, a price control policy. In this paper we contrast these two alternatives in terms of social welfare, taking into account that electricity markets are not perfectly competitive, and show that the price control policy dominates the quantity control policy in terms of social welfare.

Key words: Green certificates, Renewable portfolio standard, Feed-in tariff

JEL classification: Q42, Q48

1 Introduction

Electricity generation from renewable energy sources is increasingly recognized to play an important role for the achievement of a variety of primary and secondary energy policy goals, such as improved diversity and security of energy supply, reduction of local pollutant and global greenhouse gas emissions, regional and rural development, and exploitation of opportunities for fostering social cohesion, value added and employment at the local and regional level.

The plan of the European Commission of the 1990s to issue an EU Directive on the promotion of electricity from renewables (CEC, 1998, 1999a,b), which eventually led to the issuance of Directive 2001/77/EC (CEC, 2001), has triggered an intensive political and intellectual debate over the pros and cons of guaranteed feed-in tariffs (FIT) versus tradable green certificate (TGC) schemes (e.g. Rader, 2000; Berry, 2002; Lauber, 2004; Palmer and Burtraw, 2005; Madlener and Stagl, 2005; Kildegaard, 2008). [1] Recently, a new and more comprehensive EU Draft Directive for renewable energy promotion has been published (CEC, 2008a), in which no clear preference for one or another instrument is indicated. According to an accompanying Commission staff working document (CEC, 2008b), however, and given the track record of the two instruments so far, the preference of the Commission seems to have shifted away from establishing a uniform European TGC scheme in favor of creating an investor-friendly climate and optimizing existing national systems. [2]

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[1] In the literature quota-based TGC schemes are sometimes also referred to as Renewable Portfolio Standards (RPS).

[2] This apparent shift has to be seen in light of the very ambitious and binding

Guaranteed FIT provide certainty about the achievable per-unit revenues from selling renewable electricity to the grid. While FIT have turned out to be very effective in countries such as Austria, Denmark, Germany and Spain, they cause market distortions to increase when electricity generation from renewables expands. In contrast, TGC are based on competitive market principles, typically featuring mandatory quota targets and certificate trading (e.g. Menanteau et al., 2003). Since TGC promise to enhance static and dynamic efficiency, they have attracted considerable attention. Over the years, they have been introduced in a number of countries with liberalized electricity markets (e.g. Berry and Jaccard, 2001; Dinica and Arentsen, 2003; Langniss and Wiser, 2003; Lorenzoni, 2003; Nielsen and Jeppesen, 2003; Verbruggen, 2004; Fan et al., 2005; Nishio and Asano, 2006; Sáenz de Miera et al., 2008). More recently, the debate has been revolving around the interplay between TGC markets and markets for tradable CO_2 permits (e.g. Morthorst, 2001; Jensen and Skytte, 2003; Söderholm, 2008), and between TGC markets and liberalized power markets (e.g. Amundsen and Mortensen, 2001, 2002; Jensen and Skytte, 2002; Morthorst, 2003; Amundsen and Bergman, 2004), respectively. Another active strand of research concerns financial risk of investors (Lemming, 2003; Dinica, 2006).

While FIT is similar to a subsidy for suppliers of renewables, TGC constitute

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policy target of achieving a 20% share of renewables in energy consumption by 2020. FIT, due to their relative simplicity in design, seem to find higher political acceptance and have become widespread in Europe and elsewhere in recent years. In CEC (2008a) it is reported that by 2007, of all 27 EU member countries, 18 had a FIT (or premium/bonus) system in place, seven a quota-based TGC system, and only two a tender system (Denmark for offshore wind, France for large projects).

an internalization mechanism in the Baumol-Oates standard-price tradition (Baumol and Oates, 1988). In fact, comparisons between taxes or subsidies and quota-based certificate schemes have so far been undertaken mainly in environmental economics, and in particular with regard to emission control. Denicolò (1999), for example, analyzes the effects of effluent charges and pollution permits when innovation is expected. Building on seminal work by Weitzman (1974, 1978), Pizer (1999a,b) studies the difference between a tax and quota policy under uncertainty, finding that uncertainty causes the optimal amount of emission reduction to increase, which justifies a preference for taxation over quantity control. In the context of renewable energy, Madlener et al. (2009) assess the impact of pre-commitment by government with respect to policy targets in the presence of cost-reducing innovation. In an empirical study, Palmer and Burtraw (2005) analyze the cost-effectiveness of two different renewable electricity policies (TGC vs. tax credits for renewable power production) in the U.S., and their impact on greenhouse gas emissions.

This paper is devoted to the issue of whether the diffusion of renewable power generating technologies can be better promoted by means of FIT or TGC, and in particular whether one of the schemes dominates the other in terms of cost-effectiveness and social welfare. We find that, given imperfectly competitive electricity markets, social welfare achieved under the optimal FIT policy is at least as high and likely to be strictly greater than social welfare under the optimal TGC policy, the latter importantly depending on the outcome of a strategic game in the market for tradable certificates. Our paper is organized as follows. Section 2 introduces the basic models used for contrasting effects of TGC and FIT in perfectly and imperfectly competitive markets for power. Under perfect competition, the equivalence of TGC and FIT is shown. This equivalence does not hold in a duopoly with quasi-symmetric costs, as demonstrated in section 3. Section 4 contains an evaluation of the two policies in terms of social welfare. Section 5 discusses policy implications, and section 6 concludes.

2 Promoting renewable electricity in a competitive market

We start our analysis with the simplest case, assuming that in a perfectly competitive electricity market there are N firms with equal electricity generation costs. Let there be only two options to produce electricity, either from fossil/nuclear or renewable resources (solar, wind, hydro, biomass etc.), with the second referred to as 'green electricity'. We assume that generation costs of fossil/nuclear power are generally lower than those of green electricity. However, green electricity cannot only help to avoid negative externalities from fossil/nuclear power generation, but also yield positive externalities in the form of different kinds of socio-economic benefits (e.g. creation of new employment, local value-added and infrastructure, spillovers from R&D in innovative energy technologies and systems). [3] The fact that these externalities are not sufficiently taken into account in decisions regarding the type and level of electricity production and consumption may motivate policy interventions such as the introduction of FIT and TGC.

[3] Note that the use of green electricity may also lead to non-negligible negative externalities (e.g. Abbasi and Abbasi, 2000; Tsoutsos et al., 2005), but we assume here that these are generally smaller than the positive ones.

2.1 FIT as a subsidy policy

The term ‘subsidy’ here refers to a transfer paid by the government or electricity consumers to the suppliers of green electricity. Thus, producers receive a surcharge s per unit of green electricity.[4] Given a competitive market, a representative generator of power faces the following optimization problem,

$$\max_{x_{\mathrm{b}},x_{\mathrm{g}}} \left[p x_{\mathrm{b}} + (p+s)x_{\mathrm{g}} - C_{\mathrm{b}}(x_{\mathrm{b}}) - C_{\mathrm{g}}(x_{\mathrm{g}})\right], \tag{1}$$

where x_{b} and x_{g} denote the amounts of electricity produced from fossil/nuclear (‘brown’) fuels and renewable (‘green’) energy sources, respectively, $C_{\mathrm{b}}(x_{\mathrm{b}})$ is the cost function for electricity produced from fossil/nuclear fuel, $C_{\mathrm{g}}(x_{\mathrm{g}})$ is the cost function for green electricity, and p denotes the average market price for electricity. For an interior solution, the f.o.c. are

$$p - C'_{\mathrm{b}}[x^*_{\mathrm{b}}] = 0 \tag{2}$$
$$p + s - C'_{\mathrm{g}}[x^*_{\mathrm{g}}] = 0. \tag{3}$$

Inserting (2) into (3), we find that in an optimum with $x_{\mathrm{b}} > 0$ and $x_{\mathrm{g}} > 0$, the government subsidy s (or negative tax) has to be equal to the (absolute) difference between the marginal costs of green and conventional electricity evaluated at the optimum, $C'_{\mathrm{g}}[x^*_{\mathrm{g}}]$ and $C'_{\mathrm{b}}[x^*_{\mathrm{b}}]$, with $C'_{\mathrm{g}}[x^*_{\mathrm{g}}] > C'_{\mathrm{b}}[x^*_{\mathrm{b}}]$. The economic intuition behind this result is that if $s > C'_{\mathrm{g}}[x^*_{\mathrm{g}}] - C'_{\mathrm{b}}[x^*_{\mathrm{b}}]$, all generators will supply green electricity only; in contrast, if $s < C'_{\mathrm{g}}[x^*_{\mathrm{g}}] - C'_{\mathrm{b}}[x^*_{\mathrm{b}}]$, then no green electricity at all will be provided.

[4] In reality it is usually the power fed into the grid that counts, which due to on-site electricity consumption and transmission losses may be considerably less than gross production. This difference is neglected here for simplicity.

2.2 TGC as a quota-based policy

Rather than subsidizing green electricity, the government can also impose a green power production quota on each generator.[5] If a generator falls short of the quota, it faces a fine that increases with the shortfall. For each unit of green electricity produced, the generator obtains a certificate, providing proof of partial satisfaction of the norm.

Initially, assume that certificates are non-tradable. This assumption is natural given the assumption of identical costs across generators (no opportunity for trading). In section 3 below, the non-tradability assumption will be relaxed and a market for certificates introduced. For the situation of non-tradable certificates, the objective function that applies to a generator can be stated as:

$$\max_{x_{\mathrm{b}},x_{\mathrm{g}}} \left[p \cdot (x_{\mathrm{b}} + x_{\mathrm{g}}) - f \cdot (\bar{x}_{\mathrm{g}} - x_{\mathrm{g}}) - C_{\mathrm{b}}(x_{\mathrm{b}}) - C_{\mathrm{g}}(x_{\mathrm{g}})\right], \tag{4}$$

where $\bar{x}_{\mathrm{g}}$ denotes the green electricity quota of the firm, f is the fine per unit of shortfall from the norm, and p, x_{b}, x_{g}, $C_{\mathrm{b}}(x_{\mathrm{b}})$, $C_{\mathrm{g}}(x_{\mathrm{g}})$ are the same as before. The f.o.c. with respect to x_{g} read

$$p - C'_{\mathrm{b}}[x^*_{\mathrm{b}}] = 0 \tag{5}$$
$$p + f - C'_{\mathrm{g}}[x^*_{\mathrm{g}}] = 0. \tag{6}$$

Note the similarity of (6) and (3). In fact the fine f plays the same role as the subsidy s, which therefore represents the shadow price of the quota. In an optimum, the unit price of the certificate should be equal to (slightly lower than) the value of the fine per unit.

[5] Note that in practice it is often the wholesalers or retailers, and sometimes even the final consumers of electricity, that are obliged to fulfil the quota.

2.3 Equivalence of FIT and TGC given identical costs

To show the equivalence of FIT and TGC, i.e. subsidy and quota-based policies, in terms of social welfare, we state the problem of a social planner as follows:[6]

$$W(Q, x_{\mathrm{g}}) = \max_{Q, x_{\mathrm{g}}} \int_0^Q p(\nu) d\nu - N \cdot C_{\mathrm{b}} \left(\frac{Q}{N} - x_{\mathrm{g}} \right) - N \cdot C_{\mathrm{g}}(x_{\mathrm{g}}) + E(N x_{\mathrm{g}}), \tag{7}$$

where $Q = N(x_{\mathrm{b}} + x_{\mathrm{g}})$ stands for total electricity output produced by N firms, $p(\nu)$ for the inverse demand function, and $E(Nx_{\mathrm{g}})$ for the monetary value of the avoided negative and achieved positive externalities associated with green electricity production. As f.o.c. one obtains

$$p[Q^*] - C'_{\mathrm{b}}[x^*_{\mathrm{b}}] = 0 \tag{8}$$

$$C'_{\mathrm{b}}[x^*_{\mathrm{b}}] = C'_{\mathrm{g}}[x^*_{\mathrm{g}}] - E'[N x^*_{\mathrm{g}}], \tag{9}$$

which determine the social optimum values of Q^*, x^*_{b} and x^*_{g}. Eq. (9) simply says that optimal aggregate output of green electricity must be such that the difference between the marginal cost and the marginal external benefit of green electricity is equal to the marginal cost of conventional power. If these quantities are known, the quota can be set as $\bar{x}_{\mathrm{g}} = x^*_{\mathrm{g}}$. The optimal subsidy level is given by $s^* = C'_{\mathrm{g}}[x^*_{\mathrm{g}}] - C'_{\mathrm{b}}[x^*_{\mathrm{b}}]$ from (3), and the optimal fine by $f^* = C'_{\mathrm{g}}[x^*_{\mathrm{g}}] - p$ from (6).

Obviously, subsidy and quota levels that are set according to the optimal values determined by maximizing social welfare will lead to the same level

[6] Seminal work on the equivalence of price and quantity control was provided by Bhagwati (1969) in the context of foreign trade (tariffs vs. quotas) and by Weitzman (1974) in the context of pollutant emission control (taxes vs. quotas), respectively.

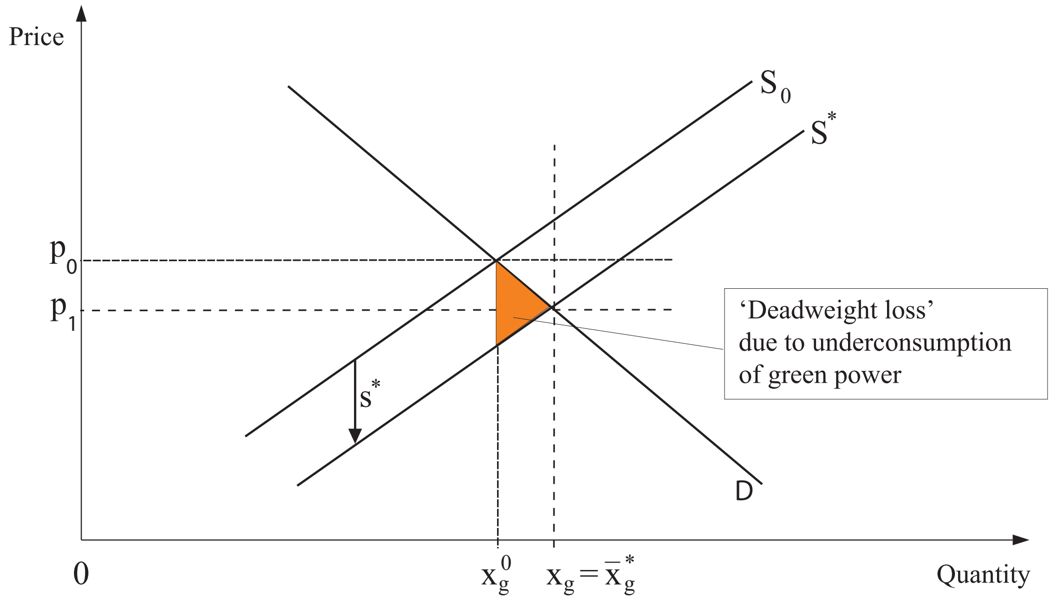

Fig. 1. Equivalence of subsidy and quota-based policy given equal costs.

of green electricity production, yielding the same welfare. In this sense, and given our assumptions, the subsidy system and quota system are equivalent. Figure 1 illustrates the basic intuition behind these results. Let S^* denote the supply schedule reflecting that green power creates an external benefit to society. Therefore, it should be used at a rate $x_\mathrm{g}^1 > x_\mathrm{g}^0$, with x_g^0 being the outcome of supply S_0 based on private (marginal) cost and demand D. Clearly, the efficient quantity of green power can be attained by paying the optimal subsidy s^*, or imposing the optimal quota $\bar{x}_\mathrm{g}^*$.

3 Duopoly market and quasi-symmetric costs

Studying the case of imperfectly competitive power markets as a duopoly game under quasi-symmetric costs can be justified on the following grounds. First, power markets are dominated by a few major players. For example, EdF still has a monopoly in France, PowerGen (now E.ON) has a market share of about 22 percent in the UK, and the four biggest suppliers in Germany, RWE, E.ON Energie, Vattenfall Europe and EnBW, together control more than two thirds of the market (cf. Bower et al., 2001; Matthes et al., 2005). Second, assuming the production costs of green power to be the same for all producers is not compatible with certificate trading. Therefore, we extend the basic model to the case of heterogeneous production costs in order to derive the potential for trade of green certificates.

Assume there are two generators in the market, firm 1 and 2, that have identical technology and hence cost functions in using fossil/nuclear fuel but different costs of generating renewable electricity. In this sense, the firms are 'quasi-symmetric'. The main reason to expect heterogeneous cost structures for green power is that it does not constitute yet a mature technology like that based on fossil or nuclear fuels, where competition presumably has forced operators to adopt the least-cost alternative. Therefore, producers of green power are assumed to employ different technologies, have more or less favorable siting of plants, use energy resources of different qualities, and employ different vintage mixes of a given technology.

To keep our model simple and to avoid multiple equilibria, we assume the cost function in using fossil/nuclear fuel $C_{\mathrm{b}}(x_{\mathrm{b}}) = c_{\mathrm{b}}x_{\mathrm{b}}$ to be linear and the difference of marginal cost between firm 1 and firm 2, $C'_{1\mathrm{g}}(y) - C'_{2\mathrm{g}}(y)$, to be a positive constant. Without loss of generality, we assume $C_{1\mathrm{g}}(y) > C_{2\mathrm{g}}(y)$ for any $y > 0$. With some loss of generality, but considerable gain in simplicity, let the demand function take on the following form,

$$p(x_{1\mathrm{b}}, x_{1\mathrm{g}}, x_{2\mathrm{b}}, x_{2\mathrm{g}}) = a - x_{1\mathrm{b}} - x_{1\mathrm{g}} - x_{2\mathrm{b}} - x_{2\mathrm{g}}, \quad a > 0, \tag{10}$$

which implies that consumers' willingness to pay is the same for fossil/nuclear and green power.

We start with the subsidy policy, focussing on the Cournot solution because power markets have been characterized by an absence of the fierce price competition one would expect in a Bertrand world. Limited price competition may be the result of collusion (Newbery, 2002), a variant of which is to stick to Cournot strategies. Moreover, under certain circumstances (e.g., capacity constraints), Cournot strategies continue to be pursued even under Bertrand-type competition (Kreps and Scheinkman, 1983). In such a market set-up, firm 1 (the leader) believes that firm 2 (the follower) will react to firm 1's choice of green power produced. Thus in equilibrium firm 1 will have chosen a higher production level than in the case of a Cournot equilibrium and, consequently, firm 2 a lower level. [7]

3.1 Effect of subsidy on equilibrium

In this section, we assume that the subsidy is uniform, failing to take the difference in cost into account; the case of a non-uniform subsidy is discussed in section 3.2 below. Here, the two firms face the following decision problem,

$$\max_{x_{i\mathrm{b}},x_{i\mathrm{g}}} (a - x_{i\mathrm{b}} - x_{i\mathrm{g}} - x_{j\mathrm{b}} - x_{j\mathrm{g}})(x_{i\mathrm{b}} + x_{i\mathrm{g}}) + s x_{i\mathrm{g}} - c_{\mathrm{b}} x_{i\mathrm{b}} - C_{i\mathrm{g}}(x_{i\mathrm{g}}), \quad (11)$$

where $i, j = 1, 2$, and $i \neq j$.

We assume that the subsidy s is exogenous to and equal across firms. Generalizing condition (3), one can distinguish three different cases for the subsidy

[7] A Stackelberg variant of this model would be an interesting extension, which is beyond the scope of this paper, however.

level (denoted S1–S3).

3.1.1 *Case S1: $s \leq C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b} < C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_\mathrm{b}$*

If $s < C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b}$, it is obvious that no green electricity will be produced because the subsidy does not make up for the efficient producer's cost disadvantage. Accordingly, the standard Cournot solution to the game is (cf. Kreps, 1990, p. 326),

$$x^*_{1\mathrm{b}} = x^*_{2\mathrm{b}} = \frac{a - c_\mathrm{b}}{3}; \qquad x^*_{1\mathrm{g}} = x^*_{2\mathrm{g}} = 0. \tag{12}$$

If $s = C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b}$, then generator 2 is indifferent between producing green electricity and fossil/nuclear electricity.

3.1.2 *Case S2: $C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b} \leq s < C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_\mathrm{b}$*

In this case, the subsidy makes up for the cost disadvantage of green power for generator 2, but fails to do so for the less efficient generator 1, who therefore refrains from producing green electricity. The Cournot solution remains the same (in the sense that total electricity output of each firm remains unchanged), as compared to the case of a uniform quota.

So if $s > C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b}$, then generator 2 switches to green electricity, i.e.,

$$x^*_{1\mathrm{b}} = \frac{a - 2c_\mathrm{b} + C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - s}{3} \tag{13}$$

$$x^*_{2\mathrm{g}} = \frac{a - 2C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] + c_\mathrm{b} + 2s}{3} \tag{14}$$

$$x^*_{1\mathrm{g}} = x^*_{2\mathrm{b}} = 0. \tag{15}$$

Note that $x^*_{1\mathrm{b}}$ in (13) and $x^*_{2\mathrm{g}}$ in (14) are larger than in (12).

3.1.3 *Case S3:* $s \geq C'_{1g}[x^*_{1g}] - c_b$

If $s > C'_{1g}[x^*_{1g}] - c_b$, then the subsidy overcompensates the cost disadvantage of green power even for the less efficient generator 1. Therefore, both firms produce green electricity only. Accordingly, the optimal solutions are now

$$x^*_{1g} = \frac{a + C'_{2g}[x^*_{2g}] - 2C'_{1g}[x^*_{1g}] + s}{3} \tag{16}$$

$$x^*_{2g} = \frac{a + C'_{1g}[x^*_{1g}] - 2C'_{2g}[x^*_{2g}] + s}{3} \tag{17}$$

$$x^*_{1b} = x^*_{2b} = 0. \tag{18}$$

In the limiting case where $s = C'_{1g}[x^*_{1g}] - c_b$, generator 1 is indifferent between producing green and fossil/nuclear power, while generator 2, being efficient in the production of green power, supplies green electricity only.

3.1.4 *Optimal subsidy level*

The results derived in the previous subsection show that the equilibrium solutions to the Cournot game strongly depend upon the level of the subsidy. This raises the issue of determining the optimal subsidy level. In analogy to (7), let social welfare be given by

$$\begin{aligned} W^j(Q, x_{1g}, x_{2g}; s) = &\int_0^Q p(\nu)d\nu - c_b(Q - x_{1g} - x_{1g}) \\ &-C_{1g}(x_{1g}) - C_{2g}(x_{2g}) + E(x_g), \end{aligned} \tag{19}$$

with W^j denoting the social welfare gains associated with case j (j = 1, 2, and 3) of sections 3.1.1–3.1.3. We assume that in case 2, s is slightly greater than $C'_{2g}[x^*_{2g}] - c_b$, and in case 3 slightly greater than $C'_{1g}[x^*_{1g}] - c_b$, in order to avoid ambiguity.

To facilitate comparison between the cases, the externality function associated with green electricity takes the form $E(x_{\mathrm{g}}) = \beta x_{\mathrm{g}}$, $\beta > 0$. While it would certainly be interesting to elaborate on possible alternative functional forms of $E(x_{\mathrm{g}})$, and consequences for the outcome, such an analysis is beyond the scope of this paper and saved for future research.

The parameter β (called 'welfare parameter' henceforth) implies a constant marginal social benefit from producing green electricity. Using the equilibrium values given in (11) to (17), the welfare associated with the three cases can be written as follows:

$$W^1 = \left(a - \frac{Q}{2}\right) Q - c_{\mathrm{b}} Q \tag{20}$$

$$W^2 = \left(a - \frac{Q}{2}\right) Q + \beta x_{2\mathrm{g}} - c_{\mathrm{b}}(Q - x_{2\mathrm{g}}) - C_{2\mathrm{g}}(x_{2\mathrm{g}}) \tag{21}$$

$$W^3 = \left(a - \frac{Q}{2}\right) Q + \beta Q - C_{1\mathrm{g}}(x_{1\mathrm{g}}) - C_{2\mathrm{g}}(x_{2\mathrm{g}}). \tag{22}$$

As is to be expected, whether or not the welfare parameter β exceeds the marginal cost parameters is of crucial importance. For $\beta > C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_{\mathrm{b}}$, the welfare parameter is larger than the additional costs incurred by firm 1, so that it is optimal if both firms produce green electricity. Conversely, if the positive externality $\beta x_{2\mathrm{b}}$ exceeds the extra costs of producing green electricity for firm 2, it is optimal if firm 2 produces green instead of brown electricity.

More specifically, we can distinguish the following situations:

(A) if $\beta > C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_{\mathrm{b}}$, then $W^3 > W^2 > W^1$. Hence the optimal subsidy is the lower bound of the subsidy interval in case 3, i.e., $s^*_{\mathrm{A}} = C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_{\mathrm{b}}$.

(B) if $\beta = C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_{\mathrm{b}}$, then $W^3 = W^2 > W^1$. The welfare gains remain the same for $s^*_{\mathrm{B}} = C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_{\mathrm{b}}$ and $s^{**}_{\mathrm{B}} = C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_{\mathrm{b}}$, though the amounts of green electricity produced are different.

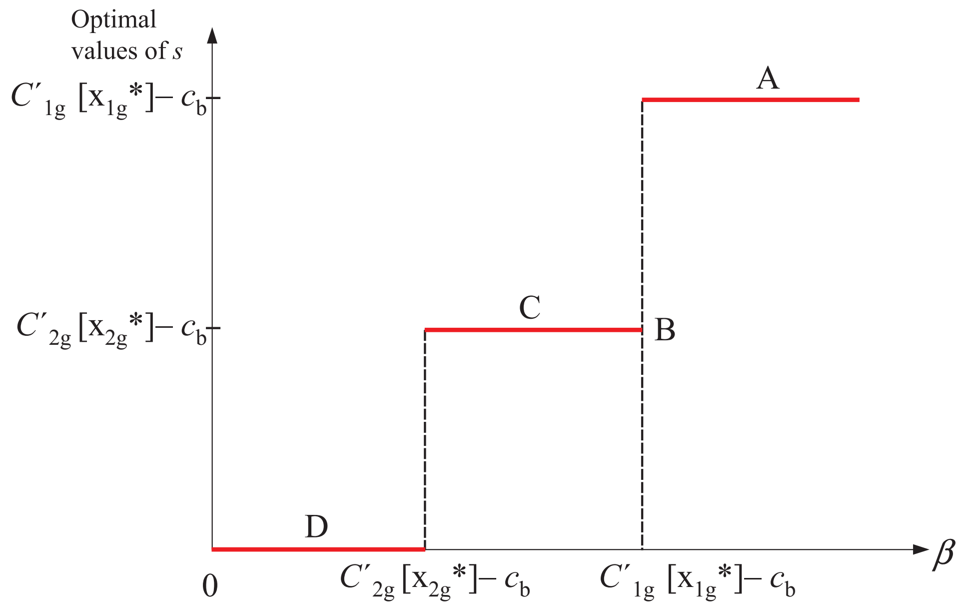

Fig. 2. Optimal subsidy levels vs welfare parameter β of green electricity, cases A through D.

(C) if $C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b} \leq \beta < C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_\mathrm{b}$, then $W^2 > W^3$ and $W^2 \geq W^1$. The optimal subsidy is thus equal to the lower bound of the subsidy interval in case 2, i.e., $s^*_\mathrm{C} = C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b}$.

(D) if $\beta < C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b}$, then $W^1 > W^2 > W^3$. Therefore, the optimal subsidy is zero, because none of the rates are effective in promoting green power.

Figure 2 summarizes the optimal subsidy schedule for different values of the welfare parameter β.

3.2 Quota-based policy

Building on (4) of section 2.2, the decision problem faced by the two firms in a duopoly market can be written as

$$\max_{x_{i\mathrm{b}},x_{i\mathrm{g}}} [(a - x_{i\mathrm{b}} - x_{i\mathrm{g}} - x_{j\mathrm{b}} - x_{j\mathrm{g}})(x_{i\mathrm{b}} + x_{i\mathrm{g}}) + z(\tilde{x}_{i\mathrm{g}} - \tilde{x}_{j\mathrm{g}})$$
$$- f(\bar{x}_{\mathrm{g}} - x_{i\mathrm{g}} - \tilde{x}_{i\mathrm{g}}) - c_{\mathrm{b}} x_{i\mathrm{b}} - C_{i\mathrm{g}}(x_{i\mathrm{g}})], \tag{23}$$
$$\text{s.t.} \quad x_{i\mathrm{g}} + x_{j\mathrm{g}} = 2\bar{x},$$

with $\tilde{x}_{i\mathrm{g}}$ ($\tilde{x}_{j\mathrm{g}}$) denoting the amount of certificates sold (purchased), respectively, $i, j = 1$ or 2, and $i \neq j$, f denoting the fine per unit as in (4), and z denoting the certificate price. Note that the constraint implies that the amount of green certificates produced by the two firms must not exceed the industry quota – i.e. we assume that once the quota is satisfied the certificate price drops to zero. Thus, there is no incentive to produce more green electricity than is required by the quota target.

In the above model, each firm has two choice variables. However, given the assumption that the difference $C'_{1\mathrm{g}}(y) - C'_{2\mathrm{g}}(y)$ is a positive constant for any $y > 0$, generator 1's choice of $x_{1\mathrm{g}}$ boils down to a choice between 0 and $\bar{x}_{\mathrm{g}}$, depending on the ordering of f, z, and the level of the difference in marginal costs of producing green and brown electricity (cf. figure 3). If it is in the interest of generator 1 to purchase green electricity certificates at all, it must also be (at least weakly) in its interest to go all the way. Therefore, we can find a Nash equilibrium by comparing the firms' payoffs for $x^*_{1\mathrm{g}} \in \{0, \bar{x}_{\mathrm{g}}\}$, which will be shown in the following section. Before turning to the Nash equilibrium, however, we briefly discuss the different possible cases, of which we will examine the two that are desirable from a social welfare point of view.

First, the fine could fall short of the difference in marginal costs for firms 1 and 2, in which both firms prefer to pay the fine and produce conventional electricity only.

Second, if the fine is larger than the cost difference for firm 2 but lower than the marginal cost difference for firm 1 of producing green instead of brown electricity, then we can distinguish two sub-cases: either the certificate price is larger or smaller than the fine. In the former case, firm 1 prefers to pay the fine, rather than buying certificates from firm 2, while in the latter case it would buy certificates from firm 2 up to its quota (provided, of course, that trading is possible).

Third, the fine is set at a higher level than the difference in the marginal costs of producing green instead of conventional electricity for both generators. In this case we can again distinguish two sub-cases, one where z is lower than the cost difference for firm 1 (so that it has an incentive to buy certificates up to $\bar{x}$ from generator 2) and a situation where it is higher (in which case generator 1 would self-generate green electricity up to its quota [8]).

In the following, we consider the two cases where certificate trading occurs (case I) and the case where firm 1 self-produces green certificates (case II).

3.3 Nash equilibrium under the quota-based policy

We now elaborate the Nash equilibrium for the quota-based policy, by comparing the firms' payoffs under the two socially desirable strategies stated at the end of the previous section 3.2. Hence, in the discussion that follows, we distinguish the two cases I and II.

[8] Note that in this situation generator 1 would possibly be forced at some point to leave the market, as its costs of producing green electricity are too high.

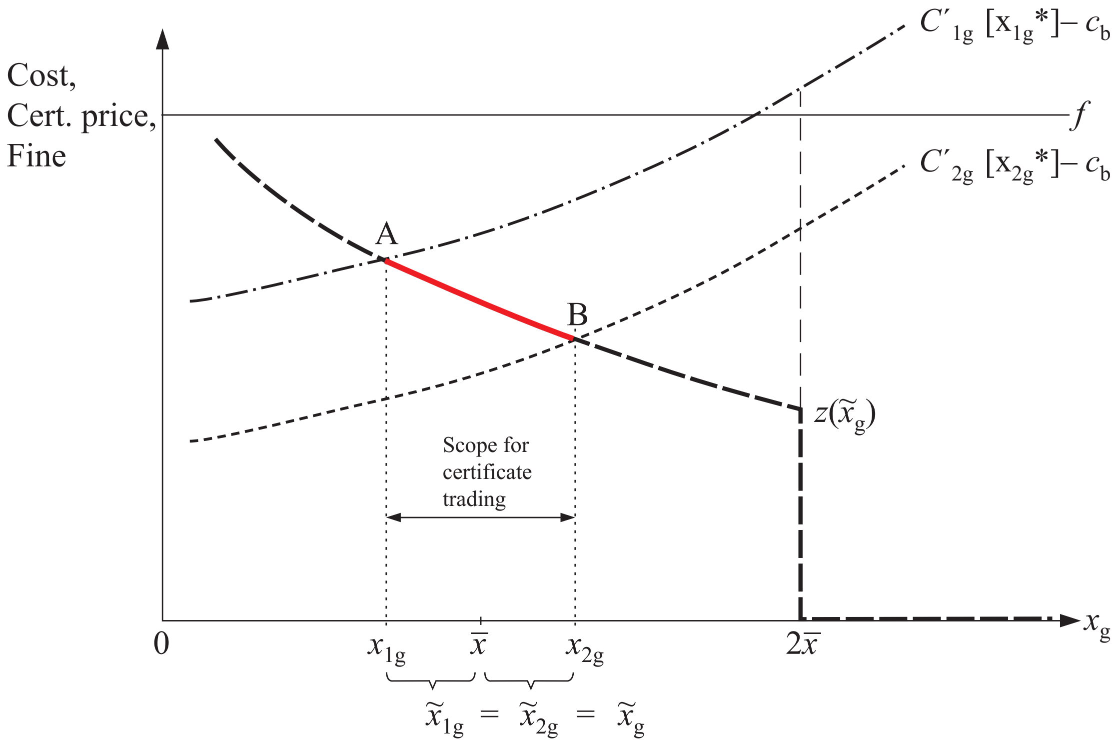

Fig. 3. Effects of the TGC policy in a duopoly game

3.3.1 Case I: $x^*_{1\mathrm{g}} = 0$

Case I refers to a situation where the cost difference for firm 1 of producing green instead of brown electricity is lower than the fine f but higher than the certificate price z. Therefore, it is cheaper for firm 1 to buy certificates from firm 2. Given that $x^*_{1\mathrm{g}} = 0$, generator 2 is required to produce at least $2\bar{x}_{\mathrm{g}}$ units of green electricity in order to satisfy the industry quota. This can be summarized as follows,

$$x^*_{1\mathrm{g}} = 0 \Leftrightarrow f > C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_{\mathrm{b}} > z > C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_{\mathrm{b}} \tag{24}$$

or as

$$C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_{\mathrm{b}} > f > z > C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_{\mathrm{b}}.$$

Firm 1 solves the problem

$$\max_{x_{1\mathrm{b}},x_{1\mathrm{g}}} \Pi_1 = (a - x_{1\mathrm{b}} - x_{2\mathrm{b}} - x_{2\mathrm{g}})x_{1\mathrm{b}} - c_\mathrm{b}x_{1\mathrm{b}} - z\tilde{x}_\mathrm{g} - \max\{0, f(\bar{x}_\mathrm{g} - \tilde{x}_{1\mathrm{g}})\}, \quad (25)$$

with f.o.c.:

$$\frac{\partial \Pi_1}{\partial x_{1\mathrm{b}}} = a - 2x^*_{1\mathrm{b}} - x^*_{2\mathrm{b}} - x^*_{2\mathrm{g}} - c_\mathrm{b} = 0. \quad (26)$$

Observing the constraint $x_{2\mathrm{g}} \geq 2\bar{x}_\mathrm{g}$, firm 2 solves

$$\begin{aligned}\max_{x_{2\mathrm{b}},x_{2\mathrm{g}}} L(x_{2\mathrm{b}}, x_{2\mathrm{g}}, \lambda) = {}&(a - x_{1\mathrm{b}} - x_{2\mathrm{b}} - x_{2\mathrm{g}})(x_{2\mathrm{b}} + x_{2\mathrm{g}}) - c_\mathrm{b}x_{2\mathrm{b}} + z\tilde{x}_\mathrm{g} \\ &- \max\{0, f(\bar{x}_\mathrm{g} - x_{2\mathrm{g}} + \tilde{x}_\mathrm{g})\} - C_{2\mathrm{g}}(x_{2\mathrm{g}}) + \lambda(2\bar{x}_\mathrm{g} - x_{2\mathrm{g}}),\end{aligned}$$

with $\lambda \geq 0$ denoting the Lagrange multiplier. The f.o.c. read,

$$\frac{\partial L}{\partial x_{2\mathrm{b}}} = a - x^*_{1\mathrm{b}} - 2x^*_{2\mathrm{b}} - 2x^*_{2\mathrm{g}} - c_\mathrm{b} = 0 \quad (27)$$

$$\frac{\partial L}{\partial x_{2\mathrm{g}}} = a - x^*_{1\mathrm{b}} - 2x^*_{2\mathrm{b}} - 2x^*_{2\mathrm{g}} - c_\mathrm{b} - C'_{2\mathrm{g}}(x^*_{2\mathrm{g}}) + f + \lambda = 0. \quad (28)$$

From (26) and (27) we get $x^*_{1\mathrm{b}} = (a - c_\mathrm{b})/3$, and from (27) and (28) we obtain $x^*_{2\mathrm{b}} + x^*_{2\mathrm{g}} = (a - c_\mathrm{b})/3$.

Given that firm 1 does not produce any green electricity, we need to distinguish two subcases. In the first subcase (Ia, Appendix A), firm 2 self-generates its own quota, while in the second subcase (Ib, Appendix A) it produces twice the individual firm's quota (and hence is able to sell the excess certificates to firm 1, which faces higher production costs).

Eqs. (A.1) and (A.2) say that the two firms will produce the same total quantity of electricity, determined by the maximum possible market demand and the cost of producing electricity from fossil/nuclear fuel. From (27) and (28) we obtain

$$\lambda = C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b} - f. \quad (29)$$

Eq. (29) indicates that if $C'_{2g}[x^*_{2g}] - c_b > f$, such that $\lambda > 0$, generator 2 will only produce green electricity up to the industry quota as required by our assumptions, due to the Kuhn–Tucker condition. Note that trading of certificates is also possible as long as $C'_{1g}[x^*_{1g}] - c_b \geq f$. However, if $C'_{2g}[x^*_{2g}] - c_b = f$ (and hence $\lambda = 0$), generator 2 has an incentive to produce at least the quota required from the industry. Also note that different values of $f \in [C'_{2g}[x^*_{2g}] - c_b, C'_{1g}[x^*_{1g}] - c_b]$ only affect the distribution of profits between the two firms, with no impact on the amount of certificate trading and social welfare. Therefore, we first focus on the case $C'_{2g}[x^*_{2g}] - c_b = f$ as a benchmark.

The optimal quota continues to be determined as in eqs. (7)–(9), except that $C'_b[x^*_b] = c_b$. Hence $\bar{x}_g = x^*_g/2$ still holds. As long as $2\bar{x}_g \leq (a - c_b)/3$ [see eq. (A.2)], generator 2 produces $(a - c_b)/3 - 2\bar{x}_g$ units of electricity using fossil/nuclear fuel and $2\bar{x}_g$ units of green electricity. As to $2\bar{x}_g > (a - c_b)/3$, recall that a denotes the willingness to pay for the first kWh of electricity, while c_b symbolizes the (constant) marginal cost of fossil/nuclear power, which makes $a - c_b$ a very large number. It is unlikely for $\bar{x}_g$ to exceed one sixth of that number, justifying that this case is neglected.

So far, we have assumed that generator 1 is the only buyer of generator 2's extra certificates. However, there may be another agent willing to purchase the certificates at the market price, for example, an environmental protection agency or a foundation promoting renewable energy. Since the equilibrium price of certificates is determined in such a manner that generator 2 is indifferent between producing green or fossil/nuclear fuel electricity, the presence of an additional bidder might cause generator 2 to produce green electricity in excess of the quota. However, this would make the system a combination of quantity and price policies. The reason is that these extra purchases, resulting in an increase of the value of the certificates, can be viewed as a subsidy. It is possible that such a policy mix is more effective in promoting green power than either one of the two policy instruments individually. However, a detailed analysis of such a mixed policy is beyond the scope of this paper.

3.3.2 Case II: $x^*_{1g} = \bar{x}_g$

We now turn to the case of generator 1 producing green electricity to satisfy the quota. This is possible if the difference in the marginal cost of producing green and brown electricity is strictly lower than the certificate price (and the fine), or formally,

$$x^*_{1g} = \bar{x}_g \Leftrightarrow f > z > C'_{1g}[x_{1g}] - c_b. \tag{30}$$

With no external agent purchasing, the condition $x_{1g} = \bar{x}_g$ or $x_{2g} = \bar{x}_g$ continues to hold. Firm 1's optimization problem now reads,

$$\max_{x_{1b}, x_{1g}} \Pi_1 = (a - x_{1b} - x_{2b} - \bar{x}_g - x_{2g})(x_{1b} + \bar{x}_g) - c_b x_{1b} - C_{1g}(\bar{x}_g),$$

with f.o.c.,

$$\frac{\partial \Pi_1}{\partial x_{1b}} = a - 2x^*_{1b} - 2\bar{x}_g - x^*_{2b} - x_{2g} - c_b = 0; \tag{31}$$

while firm 2 solves the problem

$$\begin{aligned} \max_{x_{2b}, x_{2g}} \Pi_2 = & (a - x_{1b} - x_{2b} - \bar{x}_g - x_{2g})(x_{2b} + x_{2g}) - c_b x_{2b} - C_{2g}(x_{2g}) \\ & - \max\{0, f(\bar{x}_g - x_{2g})\}. \end{aligned} \tag{32}$$

Since x^*_{2g} can only take on $\bar{x}_g$ or $2\bar{x}_g$ as optimal values, we concentrate on $x^*_{2g} \geq \bar{x}_g$ and only consider the first-order condition concerning variable x_{2b}, which reads:

$$\frac{\partial \Pi_2}{\partial x_{2b}} = a - 2x^*_{2b} - 2x_{2g} - x^*_{1b} - \bar{x}_g - c_b = 0. \tag{33}$$

From (31) and (33) we get $x^*_{1\mathrm{b}} = (a - c)/3 - \bar{x}_{\mathrm{g}}$ and $x^*_{2\mathrm{b}} = (a - c)/3 - x_{2\mathrm{g}}$.

As before, we have to distinguish two subcases (IIa and IIb in Appendix A), in both of which firm 1 self-generates green electricity up to its individual quota, while firm 2 either produces $\bar{x}_{\mathrm{g}}$ or twice $\bar{x}_{\mathrm{g}}$.

		Firm 2	
		$\bar{x}_{\mathrm{g}}$	$2\bar{x}_{\mathrm{g}}$
Firm 1	0	$-f\bar{x}_{\mathrm{g}},\ -c_{\mathrm{b}}\bar{x}_{\mathrm{g}} - C_{2\mathrm{g}}(\bar{x}_{\mathrm{g}})$	$-z\bar{x}_{\mathrm{g}},\ (z - 2c_{\mathrm{b}})\bar{x}_{\mathrm{g}} - C_{2\mathrm{g}}(2\bar{x}_{\mathrm{g}})$
	$\bar{x}_{\mathrm{g}}$	$c_{\mathrm{b}}\bar{x}_{\mathrm{g}} - C_{1\mathrm{g}}(\bar{x}_{\mathrm{g}}),\ c_{\mathrm{b}}\bar{x}_g - C_{2\mathrm{g}}(\bar{x}_g)$	$c_{\mathrm{b}}\bar{x}_{\mathrm{g}} - C_{1\mathrm{g}}(\bar{x}_{\mathrm{g}}),\ 2c_{\mathrm{b}}\bar{x}_{\mathrm{g}} - C_{2\mathrm{g}}(2\bar{x}_{\mathrm{g}})$

Fig. 4. Payoffs to producers of green electricity under the TGC policy

If firm 2's strategy is to produce the minimal quota, then firm 1's best response is $x_{1\mathrm{g}} = \bar{x}_{\mathrm{g}}$ if $C_{1\mathrm{g}}(\bar{x}_{\mathrm{g}}) - c_{\mathrm{b}}\bar{x}_{\mathrm{g}} \leq f\bar{x}_{\mathrm{g}}$. However, if firm 2's strategy is to produce twice the quota, then firm 1's best response is $x_{1\mathrm{g}} = 0$ if $C_{1\mathrm{g}}(\bar{x}_{\mathrm{g}}) - c_{\mathrm{b}}\bar{x}_{\mathrm{g}} \geq z\bar{x}_{\mathrm{g}}$. If firm 1's strategy is to produce 0, then firm 2's best response is $2\bar{x}_{\mathrm{g}}$, provided the following condition holds: $C_{2\mathrm{g}}(2\bar{x}_{\mathrm{g}}) - C_{2\mathrm{g}}(\bar{x}_{\mathrm{g}}) \leq (z - c_{\mathrm{b}})\bar{x}_{\mathrm{g}}$. This condition holds due to the assumptions made in this paper. If firm 1's strategy is to produce the minimal quota, then firm 2's best response is $\bar{x}_{\mathrm{g}}$, provided that the following condition is satisfied: $C_{2\mathrm{g}}(2\bar{x}_{\mathrm{g}}) - C_{2\mathrm{g}}(\bar{x}_{\mathrm{g}}) \geq c_{\mathrm{b}}\bar{x}_{\mathrm{g}}$. This condition again holds due to the assumptions made. Therefore, if the condition $z\bar{x}_{\mathrm{g}} \leq C_{1\mathrm{g}}(\bar{x}_{\mathrm{g}}) - c_{\mathrm{b}}\bar{x}_{\mathrm{g}} \leq f\bar{x}_{\mathrm{g}}$ is satisfied, this game has two Nash equilibria in pure strategies: $(0, 2\bar{x}_{\mathrm{g}})$ and $(\bar{x}_{\mathrm{g}}, \bar{x}_{\mathrm{g}})$.

4 Welfare comparison between subsidy and quota-based policies

In spite of the simplifying assumptions made, a welfare comparison between a price-subsidy and a quota policy may be worthwhile because it promises to provide some guidance to policy-makers regarding the choice of instruments for promoting renewable energy use.

4.1 Welfare gains under the subsidy policy

Since our main interest is to discuss how to efficiently promote green power, case S1 (section 3.1.1) can be disregarded since it is fossil/nuclear only. In addition, case S3 (section 3.1.3) is not realistic because it predicts that all firms exclusively produce green power, which would presuppose extremely high green electricity quota. Therefore, we only examine the case associated with condition $C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b} \leq \beta < C'_{1\mathrm{g}}[x^*_{1\mathrm{g}}] - c_\mathrm{b}$, i.e. case S2 of section 3.1.2. The pertinent welfare function is repeated from (21) for convenience,

$$W^s = \left(a - \frac{Q}{2}\right) Q - c_\mathrm{b}(Q - x_{2\mathrm{g}}) - C_{2\mathrm{g}}(x_{2\mathrm{g}}) + \beta x_{2\mathrm{g}}, \tag{34}$$

where Q continues to be total production of both types of electricity. Remember that in case S2 we have $x^*_{1\mathrm{g}} = x^*_{2\mathrm{b}} = 0$ and the optimal subsidy is given by $s^*_C = C'_{2\mathrm{g}}[x^*_{2\mathrm{g}}] - c_\mathrm{b}$, thus the total production given the optimal subsidy scheme can be determined as $Q^s = x^s_{1\mathrm{b}} + x^s_{2\mathrm{g}} = 2(a - c_\mathrm{b})/3$, with $x^s_{2\mathrm{g}} = (a - c_\mathrm{b})/3$ denoting the amount of green energy produced by firm 2. Therefore, social welfare achieved by the optimal subsidy scheme is

$$W^s = (Q^s)^2 - C_{2\mathrm{g}}\left(\frac{Q^s}{2}\right) + (c_\mathrm{b} + \beta)\,\frac{Q^s}{2}. \tag{35}$$

4.2 Welfare gains under the quota-based policy

If marginal costs of green power are increasing, the optimal quota cannot be determined directly. To match the production of green electricity in the subsidy case, we simply assume that $\bar{x}_{\mathrm{g}}$ is equal to $(a - c_{\mathrm{b}})/6$, which may constitute a rather frequent solution [see the discussion after eq. (29) in section 3.3.1]. The welfare function for the quota-based certificate system can then be specified as

$$W^q = \left(a - \frac{Q}{2}\right) Q - c_{\mathrm{b}}(Q - x_{2\mathrm{g}}) - C_{2\mathrm{g}}(x_{2\mathrm{g}}) + \beta x_{2\mathrm{g}}. \tag{36}$$

The total amount of energy $Q^q = 2(a - c_{\mathrm{b}})/3$ produced given the quota-based policy is identical with Q^s. However, w.r.t. to $x_{2\mathrm{g}}$, we have to distinguish the following two possible pure Nash equilibrium outcomes of the game described in section 3.3.2:

(i) Welfare achieved in the Nash equilibrium $(x_{1\mathrm{g}}^{q1}, x_{2\mathrm{g}}^{q1}) = (0, 2\bar{x}_{\mathrm{g}})$,

$$W^{q1} = (Q^q)^2 - C_{2\mathrm{g}}\left(\frac{Q^q}{2}\right) + (c_{\mathrm{b}} + \beta)\,\frac{Q^q}{2}. \tag{37}$$

Since $Q^q = Q^s$, the welfare under the quota-based policy realized in this Nash equilibrium is equal to the welfare under the optimal subsidy policy.

(ii) Welfare achieved in the Nash equilibrium $(x_{1\mathrm{g}}^{q2}, x_{2\mathrm{g}}^{q2}) = (\bar{x}_{\mathrm{g}}, \bar{x}_{\mathrm{g}})$,

$$W^{q2} = (Q^q)^2 - C_{2\mathrm{g}}\left(\frac{Q^q}{4}\right) + (c_{\mathrm{b}} + \beta)\,\frac{Q^q}{4}. \tag{38}$$

Note that the welfare level W^{q2} is lower than $W^{q1} = W^s$ if

$$C_{2\mathrm{g}}(2\bar{x}_{\mathrm{g}}) - C_{2\mathrm{g}}(\bar{x}_{\mathrm{g}}) < (c_b + \beta)\bar{x}_{\mathrm{g}}.$$

This condition is satisfied if the level of marginal social benefit of green electricity β is sufficiently high. Hence, the subsidy policy guarantees a welfare level which might not be achieved with the quota policy if the Nash equilibrium $(\bar{x}_g, \bar{x}_g)$ is played. A comparison of both firms' profits as well as of their sum shows that only firm 1 is better off in the socially efficient equilibrium $(0, 2\bar{x}_g)$. Under our assumptions, both firm 2's profit and total producer surplus are likely to be higher in the socially less desirable equilibrium $(\bar{x}_g, \bar{x}_g)$. Therefore, even if the Cournot game were repeated an infinite number of times, no cooperative equilibrium would occur with both firms choosing the socially desirable strategies.

4.3 Welfare of subsidy and quota-based policies in a quasi-symmetric duopoly

Comparing welfare levels given in (35), (37), and (38), one sees that, for sufficiently high marginal social benefits of green energy, $W^s = W^{q1} > W^{q2}$. This result implies that even with imperfect competition and quasi-heterogeneous costs, subsidies should be preferred to tradable certificates. This is intuitive, since outcomes in a duopoly crucially depend on whether firms pursue price- or quantity-oriented strategies and FIT could be said to be price-oriented whereas TGC is quantity-oriented. However, the results established above given imperfectly competitive markets seem to hinge on two crucial assumptions. The first is that TGC are tradable. This means that price is the signal to competitors, precisely as the subsidy under FIT. And since the quota and the subsidy are set as to optimally internalize the externalities present, the information content of price is the same under both regimes. Second, competitors pursue optimal duopoly strategies regardless of the choice of internalization policy adopted by the government.

In addition to these two basic premises, there are simplifying assumptions that should be kept in mind. Specifically, the cost of administering subsidies and/or quota are neglected and therefore assumed equal. However, when it comes to start-up costs, a certificate system may require more resources than a subsidy system, especially for establishing appropriate regulation and regulatory control. Also, information regarding cost and marginal revenues on the part of competitors as well as marginal positive externalities of green power on the part of government was assumed perfect. Yet due to cost heterogeneity, the amount of information required for calculating the optimal subsidy typically increases with a growing number of firms. Although the setting of the optimal quota requires similar information, the heterogeneity of firms does not enter their determination, causing it to be relatively straightforward and hence probably less costly than a subsidy system. These considerations also suggest that a generalization from duopoly to oligopoly would be straightforward.

Further, we found that subsidies provide more incentives for green power precisely when its marginal social benefits are high (as in case S3 of section 3.1.3). A pure quota-based TGC system lacks this feature.

5 Policy implications

Based on several models incorporating imperfect competitiveness of markets for power for added realism, we find that the subsidy (FIT) approach, when implemented at its socially optimal value, leads to a welfare gain, which is not necessarily achieved with the quota-based (TGC) policy. Furthermore, the subsidy policy is generally preferred by utilities, likely because it does not call into question their right to cause a certain amount of pollution when using fossil/nuclear fuel input. At the same time, subsidies do provide stronger incentives for pollution-abating innovation than quotas by directly favoring production of green electricity. Since the future of green electricity importantly depends on future technological progress for lowering its cost of production, subsidies are also more efficient dynamically.

On the other hand, the financing of subsidies requires tax revenue. When the (economic or political) cost of additional taxation is high, like in the United States (but also in Scandinavian countries e.g.), the quota-based approach may provide a viable alternative. As found in the present analysis, tradable green certificates are more efficient than non-tradable ones regardless of market structure. Trade in certificates is likely to develop because green power does not yet rely on a mature cost-minimizing technology, contrary to fossil/nuclear generation. Moreover, since the cost of running a market for certificates is lower once the market is established, the disadvantage of the quota-based policy will gradually wane, without however reaching the dynamic efficiency of the subsidy approach.

6 Conclusions

This paper starts from the suspicion that the conventional wisdom, claiming a tax/subsidy (FIT) and a quota/certificate (TGC) policy scheme to be equivalent in terms of static efficiency, might not hold if markets for power are imperfectly competitive. Based on a duopoly model in which the two competitors differ in terms of their marginal cost of producing 'green' power, we show that, if both schemes are implemented at their respective socially optimal values, the subsidy policy is at least equivalent, but can be superior to the quota policy depending on the outcome of the game in the market for green certificates. The subsidy and the tradable certificate contain the same (correct) price information entering competitors' strategy choices, which are of the Cournot type regardless of the scheme considered. Interestingly, however, only one of two pure-strategy Nash equilibria under the quota-based policy corresponds to the unique equilibrium outcome under the subsidy policy whereas the other Nash equilibrium (in which both firms produce green energy) leads to a lower welfare level. In view of the technological heterogeneity of green power generation, it is important that certificates are tradable. Also, the possible equivalence breaks down as soon as incentives for pollution-abating innovation are considered as well. Thus, the subsidy is the preferable approach; on the other hand, its financing may meet with a high marginal cost of taxation.

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References

Abbasi, S. A. and Abbasi, N. (2000). The likely adverse environmental impacts of renewable energy sources. *Applied Energy*, 65(1–4):121–144.

Amundsen, E. and Bergman, L. (2004). Green certificates and market power on the Nordic power market. Expert Report for the SESSA Conference "Addressing Market Power and Industry Restructuring for Consumer Benefits", Stockholm, Sweden, 7–8 October 2004.

Amundsen, E. S. and Mortensen, J. B. (2001). The Danish Green Certificate System: some simple analytical results. *Energy Economics*, 23(5):489–509.

Amundsen, E. S. and Mortensen, J. B. (2002). Erratum to "The Danish Green Certificate System: some simple analytical results". *Energy Economics*, 24(5):523–524.

Baumol, W. J. and Oates, W. E. (1988). *The Theory of Environmental Policy.* Cambridge University Press, Cambridge.

Berry, D. (2002). The market for tradable renewable energy credits. *Ecological Economics*, 42(3):369–379.

Berry, T. and Jaccard, M. (2001). The renewable portfolio standard: design considerations and an implementation survey. *Energy Policy*, 29(4):263–277.

Bhagwati, J. N. (1969). *Trade, Tariffs, and Growth.* MIT Press, Cambridge, Mass.

Bower, J., Bunn, D. W., and Wattendrup, C. (2001). A model-based analysis of strategic consolidation in the German electricity market. *Energy Policy*, 29(12):987–1005.

CEC (1998). Draft Proposal for a Directive of the European Parliament and of the Council on access of electricity from renewable energy sources to the internal market in electricity. 13 October 1998, Commission of the European Communities, Brussels.

CEC (1999a). Proposal for a Directive of the European Parliament and of the Council on the promotion of electricity from renewable energy sources in the internal electricity market. 23 November 1999, Commission of the European Communities, Brussels.

CEC (1999b). Working Paper of the European Commission. Electricity from renewable sources and the internal electricity market. March, Commission of the European Communities, Brussels.

CEC (2001). Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity from renewable energy sources in the internal electricity market. Official Journal of the European Commission, L283: 33–40, Commission of the European Communities, Brussels.

CEC (2008a). Proposal for a directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. COM(2008) 19 final, 23 Jan 2008, Commission of the European Communities, Brussels.

CEC (2008b). The support of electricity from renewable energy sources. Accompanying document to the Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. Commission Staff Working Document, SEC(2008) 57, 23 Jan 2008, Commission of the European Communities, Brussels.

Denicolò, V. (1999). Pollution–reducing innovations under taxes or permits. *Oxford Economic Papers*, 51(1):184–199.

Dinica, V. (2006). Support systems for the diffusion of renewable energy technologies—an investor perspective. *Energy Policy*, 34(4):461–480.

Dinica, V. and Arentsen, M. J. (2003). Green certificate trading in the Netherlands in the prospect of the European electricity market. *Energy Policy*, 31(7):609–620.

Fan, J., Sun, W., and Ren, D. (2005). Renewables portfolio standard and regional energy structure optimisation in China. *Energy Policy*, 33(3):279–287.

Jensen, S. G. and Skytte, K. (2002). Interactions between the power and green certificate markets. *Energy Policy*, 30(5):425–435.

Jensen, S. G. and Skytte, K. (2003). Simultaneous attainment of energy goals by means of green certificates and emission permits. *Energy Policy*, 31(1):63–71.

Kildegaard, A. (2008). Green certificate markets, the risk of over-investment, and the role of long-term contracts. *Energy Policy*, 36:3413–3421.

Kreps, D. and Scheinkman, J. (1983). Quantity precommitment and Bertrand competition yield Cournot outcome. *Bell Journal of Economics*, 14(2):326–337.

Kreps, D. M. (1990). *A Course in Microeconomic Theory.* Prentice Hall, Upper Saddle River/NJ.

Langniss, O. and Wiser, R. (2003). The renewables portfolio standard in Texas: an early assessment. *Energy Policy*, 31(6):527–535.

Lauber, V. (2004). REFIT and RPS: options for a harmonised Community framework. *Energy Policy*, 32(12):1405–1414.

Lemming, J. (2003). Financial risks for green electricity investors and producers in a tradable green certificate market. *Energy Policy*, 31(1):21–32.

Lorenzoni, A. (2003). The Italian Green Certificates market between uncertainty and opportunities. *Energy Policy*, 31(1):33–42.

Madlener, R., Neustadt, I., and Gao, W. (2009). Renewable energy policy in the presence of innovation: does government pre-commitment matter? FCN Working Paper, Institute for Future Energy Consumer Needs and Behavior (FCN), Faculty of Business and Economics / E.ON Energy Research Center, RWTH Aachen University, Germany. (forthcoming).

Madlener, R. and Stagl, S. (2005). Sustainability-guided promotion of renewable electricity generation. *Ecological Economics*, 53(2):147–167.

Matthes, F. C., Poetzsch, S., and Grashoff, K. (2005). Power generation market concentration in Europe 1996-2004. An empirical analysis. Report No. 2005-012-en, Öko-Institut e.V., Berlin.

Menanteau, P., Finon, D., and Lamy, M.-L. (2003). Prices versus quantities: choosing policies for promoting the development of renewable policy. *Energy Policy*, 31(8):799–812.

Morthorst, P. E. (2001). Interactions of a tradable green certificate market with a tradable permits market. *Energy Policy*, 29(5):345–353.

Morthorst, P. E. (2003). A green certificate market combined with a liberalised power market. *Energy Policy*, 31(13):1393–1402.

Newbery, D. M. (2002). *Privatization, Restructuring, and Regulation of Network Utilities*. MIT Press, Cambridge.

Nielsen, L. and Jeppesen, T. (2003). Tradable green certificates in selected European countries—overview and assessment. *Energy Policy*, 31(1):3–14.

Nishio, K. and Asano, H. (2006). Supply amount and marginal price of renewable electricity under the renewables portfolio standard in Japan. *Energy Policy*, 34(15):2373–2387.

Palmer, K. and Burtraw, D. (2005). Cost-effectiveness of renewable electricity policies. *Energy Economics*, 27(6):873–894.

Pizer, W. (1999a). Choosing price or quantity controls for greenhouse gases. Climate Issues Brief No. 17, Resources for the Future, Washington D.C.

Pizer, W. A. (1999b). The optimal choice of climate change policy in the presence of uncertainty. *Resource and Energy Economics*, 21(3–4):255–287.

Rader, N. (2000). The hazards of implementing renewable portfolio standards. *Energy & Environment*, 11(4):391–405.

Sáenz de Miera, G., del Rio González, P., and Vizcaíno, I. (2008). Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. *Energy Policy*, 36(9):3345–3359.

Söderholm, P. (2008). The political economy of international green certificate markets. *Energy Policy*, 36(6):2051–2062.

Tsoutsos, T., Frantzeskaki, N., and Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy Policy*, 33(3):289–296.

Verbruggen, A. (2004). Tradable green certificates in Flanders (Belgium). *Energy Policy*, 32(2):165–176.

Weitzman, M. L. (1974). Prices vs. quantities. *Review of Economic Studies*, 41(4):477–491.

Weitzman, M. L. (1978). Optimal rewards for economic regulation. *The American Economic Review*, 68(4):683–691.

A Appendix

Subcase Ia: $x_{1\mathrm{b}}^* = \dfrac{a - c_\mathrm{b}}{3}$; $x_{1\mathrm{g}}^* = 0$; $x_{2\mathrm{b}}^* = \dfrac{a - c_\mathrm{b}}{3} - \bar{x}_\mathrm{g}$; $x_{2\mathrm{g}}^* = \bar{x}_\mathrm{g}$

Market demand:

$$a - x_{1\mathrm{b}} - x_{2\mathrm{b}} - x_{2\mathrm{g}} = \frac{a + 2c_\mathrm{b}}{3} \tag{A.1}$$

Firms' profits:

$$\Pi_1 = \frac{a + 2c_\mathrm{b}}{3}\,\frac{a - c_\mathrm{b}}{3} - c_\mathrm{b} \cdot \frac{a - c_\mathrm{b}}{3} - f\bar{x}_\mathrm{g} \;=\; \frac{(a - c_\mathrm{b})^2}{9} - f\bar{x}_\mathrm{g};$$

$$\begin{aligned}\Pi_2 &= \frac{a + 2c_\mathrm{b}}{3}\,\frac{a - c_\mathrm{b}}{3} - c_\mathrm{b} \cdot \left(\frac{a - c_\mathrm{b}}{3} - \bar{x}_\mathrm{g}\right) + z\bar{x}_\mathrm{g} - C_{2\mathrm{g}}(\bar{x}_\mathrm{g}) - f\bar{x}_\mathrm{g} \\ &= \frac{(a - c_\mathrm{b})^2}{9} - c_\mathrm{b}\bar{x}_\mathrm{g} - C_{2\mathrm{g}}(\bar{x}_\mathrm{g})\end{aligned}$$

Subcase Ib: $x_{1\mathrm{b}}^* = \dfrac{a - c_\mathrm{b}}{3}$; $x_{1\mathrm{g}}^* = 0$; $x_{2\mathrm{b}}^* = \dfrac{a - c_\mathrm{b}}{3} - 2\bar{x}_\mathrm{g}$; $x_{2\mathrm{g}}^* = 2\bar{x}_\mathrm{g}$

Market demand:

$$a - x_{1\mathrm{b}} - x_{2\mathrm{b}} - x_{2\mathrm{g}} = \frac{a + 2c_\mathrm{b}}{3} \tag{A.2}$$

Firms' profits:

$$\Pi_1 = \frac{a + 2c_\mathrm{b}}{3}\,\frac{a - c_\mathrm{b}}{3} - c_\mathrm{b}\frac{a - c_\mathrm{b}}{3} - z\bar{x}_\mathrm{g} \;=\; \frac{(a - c_\mathrm{b})^2}{9} - z\bar{x}_\mathrm{g};$$

$$\begin{aligned}\Pi_2 &= \frac{a + 2c_\mathrm{b}}{3}\,\frac{a - c_\mathrm{b}}{3} - c_\mathrm{b}\left(\frac{a - c_\mathrm{b}}{3} - 2\bar{x}_\mathrm{g}\right) + z\bar{x}_\mathrm{g} - C_{2\mathrm{g}}(2\bar{x}_\mathrm{g}) - f\bar{x}_\mathrm{g}\\ &= \frac{(a - c_\mathrm{b})^2}{9} + (z - 2c_\mathrm{b})\bar{x}_\mathrm{g} - C_{2\mathrm{g}}(2\bar{x}_\mathrm{g})\end{aligned}$$

Subcase IIa (symmetry): $x^*_{1\mathrm{b}} = x^*_{2\mathrm{b}} = \dfrac{a - c_\mathrm{b}}{3} - \bar{x}_\mathrm{g}$; $x^*_{1\mathrm{g}} = x^*_{2\mathrm{g}} = \bar{x}_\mathrm{g}$

Market demand:

$$a - x_{1\mathrm{b}} - x_{1\mathrm{g}} - x_{2\mathrm{b}} - x_{2\mathrm{g}} = \frac{a + 2c_\mathrm{b}}{3} \tag{A.3}$$

Firms' profits:

$$\Pi_1 = \frac{a + 2c_\mathrm{b}}{3}\,\frac{a - c_\mathrm{b}}{3} - c_\mathrm{b}\left(\frac{a - c_\mathrm{b}}{3} - \bar{x}_g\right) - C_{1\mathrm{g}}(\bar{x}_\mathrm{g}) \;=\; \frac{(a - c_\mathrm{b})^2}{9} + c_\mathrm{b}\bar{x}_\mathrm{g} - C_{1\mathrm{g}}(\bar{x}_\mathrm{g});$$

$$\Pi_2 = \frac{a + 2c_\mathrm{b}}{3}\,\frac{a - c_\mathrm{b}}{3} - c_\mathrm{b}\left(\frac{a - c_\mathrm{b}}{3} - \bar{x}_\mathrm{g}\right) - C_{2\mathrm{g}}(\bar{x}_\mathrm{g}) \;=\; \frac{(a - c_\mathrm{b})^2}{9} + c_\mathrm{b}\bar{x}_\mathrm{g} - C_{2\mathrm{g}}(\bar{x}_\mathrm{g})$$

Subcase IIb: $x^*_{1\mathrm{b}} = \dfrac{a - c_\mathrm{b}}{3} - \bar{x}_\mathrm{g}$; $x^*_{1\mathrm{g}} = \bar{x}_\mathrm{g}$; $x^*_{2\mathrm{b}} = \dfrac{a - c_\mathrm{b}}{3} - 2\bar{x}_\mathrm{g}$; $x^*_{2\mathrm{g}} = 2\bar{x}_\mathrm{g}$

Market demand:

$$a - x_{1\mathrm{b}} - x_{1\mathrm{g}} - x_{2\mathrm{b}} - x_{2\mathrm{g}} = \frac{a + 2c_\mathrm{b}}{3} \tag{A.4}$$

Firms' profits:

$$\Pi_1 = \frac{a + 2c_\mathrm{b}}{3}\,\frac{a - c_\mathrm{b}}{3} - c_\mathrm{b}\left(\frac{a - c_\mathrm{b}}{3} - \bar{x}_\mathrm{g}\right) - C_{1\mathrm{g}}(\bar{x}_\mathrm{g}) \;=\; \frac{(a - c_\mathrm{b})^2}{9} + c_\mathrm{b}\bar{x}_\mathrm{g} - C_{1\mathrm{g}}(\bar{x}_\mathrm{g});$$

$$\Pi_2 = \frac{a + 2c_\mathrm{b}}{3}\,\frac{a - c_\mathrm{b}}{3} - c_\mathrm{b}\left(\frac{a - c_\mathrm{b}}{3} - 2\bar{x}_\mathrm{g}\right) - C_{2\mathrm{g}}(2\bar{x}_\mathrm{g}) \;=\; \frac{(a - c_\mathrm{b})^2}{9} + 2c_\mathrm{b}\bar{x}_\mathrm{g} - C_{2\mathrm{g}}(2\bar{x}_\mathrm{g})$$

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