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Renewable Energy Policy Instruments and Market Power*

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Abstract

Markets for green certificates allow generators with market power to squeeze the margins of their competitors, as a generator that is vertically integrated into network activities might do. We analyze this issue in a stylized electricity industry in which a dominant producer of both conventional and renewable energy is facing a competitive fringe of renewable-energy producers. We demonstrate that whether or not a dominant firm is vertically integrated into network activities, it can disadvantage the fringe producers by distorting certificates prices, thereby inducing cost inefficiency in the generation of renewable energy. We compare green certificates to a system of feed-in tariffs, where a similar margin squeeze is not possible.

Keywords: Feed-in tariff; green certificates; market power; network regulation; renewable energy; vertical relations

JEL classification: *D*42; *L*11; *L*41; *L*42; *L*94

I. Introduction

Most electricity market reforms have included measures to increase competition and to undermine market power. Paradoxically, policies to further investment in renewable electricity may re-introduce opportunities for anti-competitive practices. In particular, when renewables are supported by tradable quotas, generators with market power might limit the profit margin for producers of renewable energy by acting simultaneously on electricity and quota markets. A similar opportunity for "margin squeeze" is not available when renewables are supported by a tax.

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Our interest in these issues is inspired by recent events in European energy policy. This policy aims at achieving competitiveness, sustainability, and security of supply. Measures to increase competitiveness include unbundling (i.e., the splitting up of vertically integrated incumbent power producers, so that market participants obtain network access on fair and non-discriminatory terms). However, concentration on the wholesale markets continues to persist, albeit at different degrees across countries.[1] Because of limited interconnection capacities, the European electricity industry is for the foreseeable future likely to continue as a series of essentially national or regional markets with a high degree of concentration.

To enhance sustainability and security of supply, the European Union has set a binding target of having 20 percent of final energy consumption met by renewable energy sources by 2020. At present, feed-in tariff schemes constitute the predominant support mechanism in Europe. In such a scheme, renewable electricity producers receive a fixed price (classical feed-in tariff) or, alternatively, a fixed premium on top of the electricity price (price premium). With progressing liberalization of the electricity sector, quota systems with tradable green certificates are receiving increased attention, as they leave price formation to markets. In such a scheme, the regulator stipulates a minimum percentage requirement of renewable energy sources (the quota) in total electricity consumption,[2] and electricity producers receive an amount of green certificates corresponding to the quantity of renewable energy they produce. The green certificates constitute a financial product that can be traded on a separate, purely financial market. Thus, eligible renewable electricity producers have two revenue streams: first, they obtain the conventional electricity price for selling electricity on the electricity market; second, they generate revenue by selling green certificates on the certificates market. Demand on the certificates market is created by means of the green quota imposed on end consumers and retailers.[3]

[1] For eleven Member States, the Herfindahl Hirschmann index indicates very high or high degrees of concentration for the electricity markets (European Commission, 2011). In Bulgaria, France, Ireland, Poland, Portugal, Slovakia, Spain, and the UK, market concentration has actually increased since 2008 (Commission of the European Communities, 2011).

[2] As an alternative to this downstream system, in the upstream system the obligation is put on the supply side (i.e., on electricity producers and importers). We concentrate attention on the downstream system, which is the more common; the analysis would be equivalent for an upstream system.

[3] Non-compliance with a certificates obligation is typically penalized with a fee. A fixed penalty payment in effect puts an upper bound on the price of green certificates, as there will be no demand for certificates sold at a price above the level of the fee. Some Member States allow for banking of certificates, which can reduce the volatility of certificates prices (see Amundsen *et al.*, 2006). We abstract from these issues in our analysis.

The establishment of a market for green certificates provides generators with a new means to exercise market power. In particular, by increasing the supply of renewable electricity and driving down the price of green certificates, a generator reduces the profitability of competitors in the renewables segment. In other words, by simultaneously playing on electricity and certificates markets – undersupplying conventional electricity and oversupplying renewable electricity – a generator can limit the market left for competing producers of renewables, and can shift output and profits towards itself. Such a strategy closely resembles "margin squeezing" or the strategy of a generator that controls access to infrastructure and prices access so as to discriminate against its competitors. Margin squeezing is not possible with a feed-in tariff, because here the premium for renewables is set by the regulator rather than the market.

We analyze these issues in a stylized model that is constructed so as to highlight the underlying mechanisms. In this model, a dominant firm supplying both conventional and renewable energy faces a fringe of price-takers that supply renewable energy only.[4] We think of the dominant firm as representing the typical market incumbent; their main interests are in conventional generation but they also partake in the renewables segment. A typical fringe firm would be involved in a single project of distributed generation. It would be straightforward to extend our analysis to a more general set-up, with more players with market power, supplying conventional and/or renewable energy. However, while this would considerably complicate the analysis, it would not alter the fundamental nature of our results. Moreover, our set-up highlights the parallel between the anti-competitive pricing of green certificates and network access.

In this model, we compare the outcome when renewables are regulated by green certificates and a feed-in tariff, respectively. In the first part, we show that with green certificates the dominant firm obtains an additional instrument to manipulate market outcomes because it makes the two electricity sources (conventional and renewables) complementary. As the dominant firm controls the supply of conventional electricity, it also determines the total demand for renewable electricity. By oversupplying renewable electricity, the dominant firm reduces the equilibrium premium on such electricity, allowing it to charge a higher price for the complementary good, conventional electricity; the dominant firm margin squeezes the fringe. The net effect is that the dominant firm acts as if it buys all electricity from the fringe and resells it to end-users, and, as in a monopsony,

[4] Strictly speaking, the two energy types are distinguished by how they are regulated rather than by differences in source or technology. Typically, regulation to support "green" energy is confined to new renewable energy sources, and so excludes existing plants even if they are based on renewable resources. For example, in the Nordic region, the category "conventional" would include large amounts of hydro-generation.

extracts rents from the fringe by setting a low price. Overall, this strategy reduces efficiency because the dominant firm generates too much – and the fringe too little – renewable electricity. We also show that if the dominant firm were to control a second complementary good (the transmission network), the outcome would not change, as control over one complementary good is sufficient to extract all rents from the fringe.

In the second part of the paper, we show that a feed-in premium reduces the possibility of the dominant firm to manipulate support for renewable electricity as long as it is financed by a general tax. However, when support is collected from final consumers as an electricity tax, the dominant firm will restrict renewable generation to limit the electricity tax.

Our analysis is related to three strands of literature, on instruments to promote renewables, leverage and foreclosure, and access pricing, respectively.[5] The early literature on green certificates concentrated on the interplay between perfectly competitive markets for certificates and electricity. Amundsen and Mortensen (2001, 2002) demonstrated that an increase in the percentage requirement of green certificates will increase the consumer price of electricity, although the effect on the certificates price, on the producer price of conventional electricity, and on the investment in renewables is inconclusive; in particular, it is not generally true that a higher quota induces a larger capacity of renewable electricity in the long run (see also Jensen and Skytte, 2002; Unger and Ahlgren, 2005; Böhringer and Rosendahl, 2010).[6] The more recent literature has introduced elements of imperfect competition; however, it has either assumed strategic behavior in the market for electricity only (as in Tamás *et al.*, 2010) or it has ignored the impact of conventional generation capacity on the price of certificates (as in Amundsen and Bergman, 2012). Thereby, the literature has circumvented the knife-edge problem identified by Amundsen and Nese (2004), that if green and conventional energy are supplied by Cournot quantity setters, there is no equilibrium unless one introduces exogenous upper and lower bounds on the certificates price.[7] We solve this problem by making the realistic assumption that there exists a segment of producers who adapt their behavior to market prices. This assumption allows us to study the behavior of strategic agents who take account of their impact on all relevant markets. Furthermore, we contrast the performance of green certificates to that of feed-in tariffs in an otherwise symmetrical setting with imperfect competition.

[5] It is also related to the literature on market power and permit trading, in particular the analysis of Liski and Montero (2006), who consider a dominant-firm framework.

[6] Amundsen and Nese (2009) consider similar issues for a green-certificate system that covers multiple jurisdictions.

[7] A similar knife-edge problem has been identified for access to transmission capacity; see, for instance, Oren (1997).

The literature on leverage and foreclosure has analyzed how a firm enjoying a dominant position in one market can extend that position into another market, thereby disadvantaging competitors; see Motta (2004) for an introduction to the literature. It has been demonstrated that, under certain circumstances, tying or bundling different products can constitute an element of such a strategy. In our setting, tying is not at the discretion of market participants but is a result of regulation: the green-certificates policy requires consumers to buy electricity and certificates in a certain proportion. However, the resulting relation between electricity and certificates markets allows the dominant firm to shift profitability from the segment where it faces competition to the segment where it does not. A similar bundling effect is not present when renewables are regulated by a feed-in tariff.

While tying is typically associated with horizontally related markets, leverage and foreclosure can also be undertaken in vertically related markets. The idea that a dominant firm can use its control over an essential input to raise rivals' costs is often associated with Salop and Scheffman (1983), but has been considered in a number of different settings, including network access (e.g., Armstrong *et al.*, 1996; Armstrong and Vickers, 1998) and market-based instruments for environmental regulation (e.g., von der Fehr, 1993). We demonstrate that there is a close parallel between discriminatory access pricing and anti-competitive behavior on the certificates market; indeed, in our setting they are equivalent.

The remainder of the paper is organized as follows. In Section II, we present our modeling framework. This is then used in Section III to examine the regime of green certificates, and in Section IV to examine the regime of a feed-in tariff. Finally, Section V contains our conclusions.

II. Electricity Industry Model

In this section, we present a stylized model of an electricity industry consisting of a dominant firm facing a competitive fringe. The fringe firms supply renewable electricity only, and we denote total output of the fringe by q_{F}. The dominant firm generates the amount q_{M} of conventional electricity, as well as an amount q_{R} of renewable electricity. At equilibrium, total electricity demand D is equal to total electricity supply, given by the sum of renewable generation from the fringe and conventional and renewable generation from the dominant firm:

$$D = q_{\mathrm{F}} + q_{\mathrm{M}} + q_{\mathrm{R}}. \quad (1)$$

Demand for electricity is a decreasing function of the price paid by consumers p (i.e., $D = D(p)$ with $D' < 0$).

The dominant firm generates conventional electricity at increasing cost C_{M}, with $C'_{\mathrm{M}} \geq 0$, and renewable electricity at increasing and strictly convex cost C_R, with $C'_R \geq 0$ and $C''_R > 0$. The fringe produces renewable electricity at the same total cost C_R as the dominant firm. This latter assumption is purely for simplicity and does not affect the general nature of our results; in particular, it makes the analysis of renewables generation especially transparent as any difference between the dominant firm and the fringe arises from market power rather than technology or input prices.[8]

Electricity supply requires access to the (transmission and distribution) network, which is owned by an independent entity, and where access is granted on equal terms to the dominant firm and the fringe at a regulated network tariff a. This market structure will be referred to as unbundling or vertical separation. In our analysis of green certificates in the next section, we briefly compare it to a bundled or vertically integrated set-up where the network is owned and operated by the dominant firm (cf. Proposition 2). We let C_N denote network costs and assume that network costs are increasing in total generation (i.e., $C'_N \geq 0$).

For illustration, we sometimes refer to numerical solutions for a parametrized example with linear demand $D(p) = 1 - p$, constant unit cost of conventional electricity $C_M(q) = c_M q$, linear marginal cost of renewable electricity $C_R(q) = c_R q + (1/2)d_R q^2$, and constant unit network costs $C_N(q) = c_N q$. The numerical illustrations are based on the following parameter values: $c_M = 0$, $c_R = 0.5$, $d_R = 1$, and $a = 0.2$. For comparison purposes, we note that, without specific regulation (in which case the fringe would not want to enter the market), the monopoly price of electricity would equal $(1/2)(1 + c_M + a) = 0.6$, while the competitive price would be $c_M + a = 0.2$. Details of the example are given in Appendix B.

III. Green Certificates

In this section, we analyze the regime in which renewables are supported by green certificates. In particular, we assume that consumers of electricity are obliged to hold an amount of green certificates in proportion to their level of consumption. The imposition of this regulation creates a demand for green certificates kD, where $k \in [0, 1]$ denotes the proportionality factor or quota.[9] Electricity generators might sell an amount of green certificates

[8] However, this assumption does remove a potentially interesting comparison between the two subsidy regimes when firms differ in their efficiency in the generation of renewable electricity. In particular, with green certificates, inefficient generators would tend to be driven from the market by strategic behavior, whereas a feed-in tariff will shelter such inefficient generators.

[9] We assume complete fulfilment of the quota (i.e., there is no excess or undersupply of renewable energy and certificates, and no banking). These restrictions could be lifted at the cost of complicating the analysis, but without altering the main results; in particular, strategic behavior on the market for green certificates tends to reduce their price, making it less likely that a penalty for non-compliance would be binding, and hence affect the price.

equal to their output of renewable electricity, implying that the total supply of green certificates is given by $q_F + q_R$. At equilibrium, demand for certificates equals supply (i.e., $kD = q_F + q_R$). In other words, the supply of renewables is regulated so that, at equilibrium, it constitutes a fraction of total generation:

$$q_F + q_R = k(q_F + q_M + q_R). \tag{2}$$

It follows that the equilibrium supply of conventional electricity by the dominant firm can be expressed as a function of (the residual of) the quota and total demand:

$$q_M = (1 - k)D. \tag{3}$$

On the electricity market, electricity is traded at the price p_E, and on the green-certificates market, certificates are traded at the price p_C. Hence, while conventional electricity receives the electricity price only, renewable electricity is also paid the certificate price and so receives the total price $p_E + p_C$.

We assume that the consumer price of electricity p is given by the sum of the price of conventional electricity and the certificate price weighted by the quota:

$$p = p_E + kp_C. \tag{4}$$

This assumption would be satisfied if consumers operated directly on the electricity and green-certificates markets, implying that for a unit of electricity consumers effectively pay the electricity price p_E plus the price of green certificates p_C for a proportion k of their consumption. Alternatively, the assumption can be justified by appealing to a perfectly competitive retail segment with constant unit costs normalized to zero.

The profit of the fringe is composed of revenue from electricity and certificates sales and costs of generation and network services:

$$\pi_F = (p_C + p_E)q_F - C_R(q_F) - aq_F. \tag{5}$$

The fringe maximizes profits taking prices as given. The first-order condition for this problem implies that marginal costs equal the (net) price of renewable energy;[10] that is,

$$C_R' = p_C + p_E - a. \tag{6}$$

From this condition, we find (with slight abuse of notation) the supply function of the fringe,

$$q_F = q_F(p_C + p_E - a), \tag{7}$$

[10] We concentrate on the case in which there is an interior solution (i.e., the fringe supplies a positive amount of renewable electricity). There might also be cases with corner solutions (particularly for small quotas), where the dominant firm finds it optimal to set prices so as to drive the fringe out of the market.

where the function q_{F} is the inverse of the marginal cost function C'_{R}. It follows that the fringe supply function is strictly increasing (i.e., $q'_{\mathrm{F}} > 0$).

The revenue of the dominant firm is obtained from the sale of conventional and renewable electricity (and the corresponding amount of certificates), while it incurs generation costs as well as network costs:

$$\pi_{\mathrm{M}} = p_{\mathrm{E}}q_{\mathrm{M}} + (p_{\mathrm{C}} + p_{\mathrm{E}})q_{\mathrm{R}} - C_{\mathrm{M}}(q_{\mathrm{M}}) - C_{\mathrm{R}}(q_{\mathrm{R}}) - a(q_{\mathrm{M}} + q_{\mathrm{R}}). \tag{8}$$

The dominant firm's profit-maximization problem consists of maximizing equation (8) subject to equations (1), (2), (4), and (7).

Using equations (2), (3), and (4), we can rewrite the profit of the dominant firm as

$$\begin{aligned} \pi_{\mathrm{M}} = pD(p) - p_a q_{\mathrm{F}}(p_a) - C_{\mathrm{M}}((1-k)D(p)) \\ -C_{\mathrm{R}}(kD(p) - q_{\mathrm{F}}(p_a)) - aD(p), \end{aligned} \tag{9}$$

where $p_a = p_{\mathrm{C}} + p_{\mathrm{E}} - a$ is the (net) price of renewable energy obtained by the fringe. It is as if the dominant firm sells all electricity to final consumers at price p, buys electricity from the fringe at a price p_a, and generates the rest itself. The profit-maximization problem of the dominant firm can then alternatively be expressed as maximizing equation (9) by setting the monopoly output price p and the monopsony input price p_a.

We demonstrate the following result.

Proposition 1. *The dominant firm has an incentive to set a high consumer price in order to obtain high revenues from its energy sales, while keeping the price received by the fringe low so as to shift output from the fringe to itself – in effect exerting a margin squeeze on the fringe. As a result, at equilibrium, the dominant firm supplies more renewable electricity than the fringe (i.e., $q_{\mathrm{R}} > q_{\mathrm{F}}$), while the consumer price exceeds, and the certificates price falls below, competitive levels.*

The first-order conditions for the dominant firm's profit-maximizing problem can be written as[11]

$$p\left(1 - \frac{1}{\varepsilon_{\mathrm{D}}}\right) = (1-k)C'_{\mathrm{M}} + kC'_{\mathrm{R}} + a, \tag{10}$$

and

$$p_a\left(1 + \frac{1}{\varepsilon_{\mathrm{F}}}\right) = C'_{\mathrm{R}}. \tag{11}$$

Here, $\varepsilon_{\mathrm{D}} = -pD'/D > 0$ is (the absolute value of) the elasticity of demand with respect to the consumer price p, and $\varepsilon_{\mathrm{F}} = p_a q'_{\mathrm{F}}/q_{\mathrm{F}} > 0$ is the elasticity

[11] Throughout, we assume that the profit-maximization problem of the dominant firm is well behaved; in particular, we assume the relevant second-order conditions are satisfied.

of the supply of the fringe with respect to the (net) energy price received by the fringe. The left-hand side of equation (10) is the marginal revenue of supplying consumers with a unit of electricity, while the right-hand side is the corresponding marginal cost. The fact that electricity supplies must contain a fixed proportion of renewables is reflected in both price and marginal cost, where the latter is the weighted sum of the marginal cost of conventional and renewable generation, respectively, plus the incurred network cost. Similarly, equation (11) equates the marginal revenue and marginal cost of supplying a unit of renewable electricity, taking account of the supply response of the fringe; this corresponds to the trade-off of a monopsonist that can produce renewable electricity itself or buy such electricity from the fringe.

Compared to a perfectly competitive benchmark, there are two kinds of effects arising from the price-setting behavior of the dominant firm. First, there is the classic monopoly effect, whereby the dominant firm induces a gap between consumer price and marginal cost:

$$p > p\left(1 - \frac{1}{\varepsilon_{\mathrm{D}}}\right) = (1-k)C'_{\mathrm{M}} + kC'_{\mathrm{R}} + a. \tag{12}$$

Second, there is the monopsony effect that induces cost inefficiency in the production of renewable electricity. In particular, at equilibrium, the marginal cost of the dominant firm exceeds that of the fringe:

$$C'_{\mathrm{R}}(q_{\mathrm{R}}) = p_a\left(1 + \frac{1}{\varepsilon_{\mathrm{F}}}\right) > p_a = C'_{\mathrm{R}}(q_{\mathrm{F}}). \tag{13}$$

From equation (9), we see that for the dominant firm the (net) price of renewables p_a is relevant only because it affects the supply of the rival fringe. Moreover, the dominant firm has an incentive to reduce this price, which can be done by reducing the certificates price through supplying renewables and certificates to a point where marginal cost exceeds price (cf. equation (11)). It follows that while market power in the electricity market is exercised by undersupplying the relevant product, market power in the certificates market is exercised by oversupplying it.

We can compare this outcome with that of vertical integration, when the dominant firm owns and operates the network, and charges the fringe an access charge. In that case, the dominant firm could also exert a margin squeeze by means of the access charge, thereby raising the rival fringe's cost; in fact, the access charge and the certificates price are equivalent instruments in our setting – the dominant firm can extract the monopsony rents only once (see Appendix A for details). In other words, the certificates market enables the dominant firm to exercise market power as if it were vertically integrated. Although vertical separation hinders the dominant firm from inducing a margin squeeze by use of the network access charge, the certificates market provides it with the necessary means. Therefore, a margin squeeze on competitors in renewables generation occurs whether or not there is vertical integration.

Indeed, distortions might well be larger with vertical separation than with vertical integration. As we can see from equation (10), the marginal cost of the dominant firm of supplying consumers with electricity is increasing with the access charge. Moreover, it is easy to show that the consumer price of electricity is increasing with this charge.[12]

Therefore, we have the following result.

Proposition 2. *Unless regulation of network access is perfect (i.e., the access charge equals the marginal cost of network use), the consumer price of electricity is higher, and hence the output of conventional as well as renewable electricity is lower, with vertical separation than with vertical integration.*

While, with vertical integration, the monopolist faces the true cost of network use, with vertical separation, the monopolist faces a higher cost unless the access charge perfectly reflects the underlying cost of the network. Hence, the monopolist tends to set a higher price of electricity with vertical separation than with vertical integration. In other words, vertical separation involves a sort of double-marginalization problem in the absence of perfect regulation.

We conclude the analysis of green certificates by considering how equilibrium prices and quantities depend on renewable energy policy, as measured by the quota k.

It seems reasonable that an increase in the quota of green certificates raises the consumer price and the price of conventional electricity, and reduces total electricity supply and the supply of conventional electricity. Intuitively, as can be seen from equation (10), more stringent regulation of renewable energy deployment (i.e., a larger quota) raises the marginal cost of supplying consumers. As a consequence, the dominant firm responds by raising the price of electricity. This implies that demand will fall, and with it, the total supply and the supply of conventional electricity, giving room for a higher proportion of renewable electricity. This is shown in Figure 1, which provides an illustration of the relationship between market quantities and the quota.

Moreover, from the equilibrium condition $q_{\mathrm{F}} + q_{\mathrm{R}} = kD$, it is clear that an increase in the quota has two different and opposing effects on renewable energy supply. On the one hand, a higher quota means that, for a given

[12] The result is given by differentiating through the set of first-order conditions (10) and (11), using the fact that $\partial^2\pi_{\mathrm{M}}/\partial a\partial p = -D'$ and $\partial^2\pi_{\mathrm{M}}/\partial a\partial p_a = 0$, and assuming that the relevant second-order conditions are satisfied.

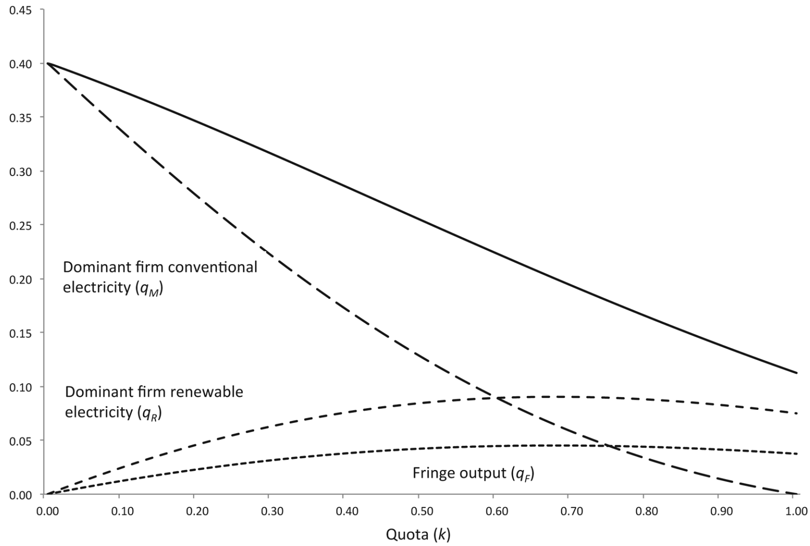

Fig. 1. Quantities as functions of the quota

level of the consumer price, and hence demand, renewable output increases; on the other hand, demand falls as the consumer price goes up. For low levels of the quota, we expect that the first effect will dominate, and hence that renewable output will increase with the quota, as shown in Figure 1. However, for sufficiently large levels of the quota, the second effect might dominate, in which case renewable output will decrease with the quota. In this case, although a higher quota induces a higher proportion of renewables in the total energy supply, the absolute level of renewable energy might be lowered by an increase in quota because of a contraction in demand.

Figure 2 depicts an example in which the fringe net price p_a has an inverse-U shape, mirroring fringe supply in Figure 1. Here, as the quota rises higher from its starting point at zero, the dominant firm engages in margin squeezing at a diminishing rate; that is, the dominant firm allows the fringe to obtain higher profits per unit of output, until the quota rises to a critical level where the fringe price has its maximum. After this level has been reached, the dominant firm successively increases the margin squeeze again. As explained above, the consumer price of electricity is nevertheless monotonically increasing with the quota over the whole range.

The behavior of the composite prices $p = p_{\mathrm{E}} + kp_{\mathrm{C}}$ and $p_a = p_{\mathrm{C}} + p_{\mathrm{E}} - a$ is reflected in the underlying prices of conventional electricity p_{E} and green certificates p_{C}. We expect the impact on the price of conventional electricity caused by an increase in the quota to be positive, as it responds to the increase in the cost of producing electricity. However,

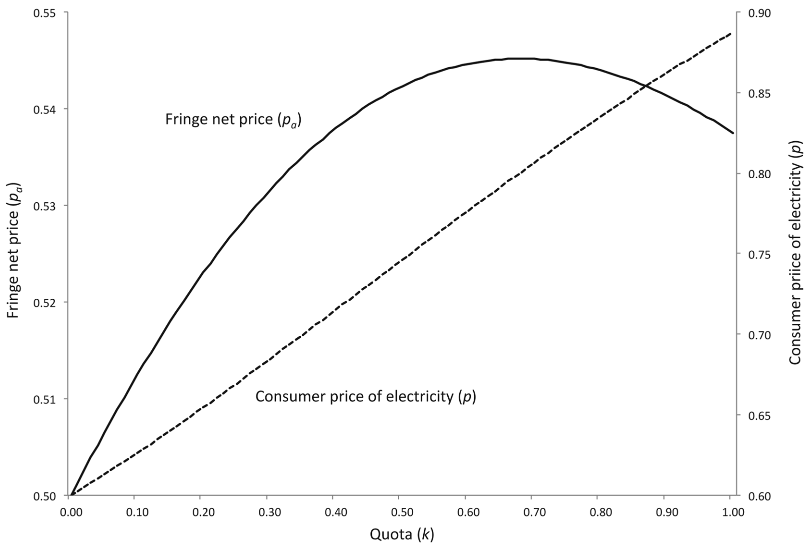

Fig. 2. Prices as functions of the quota

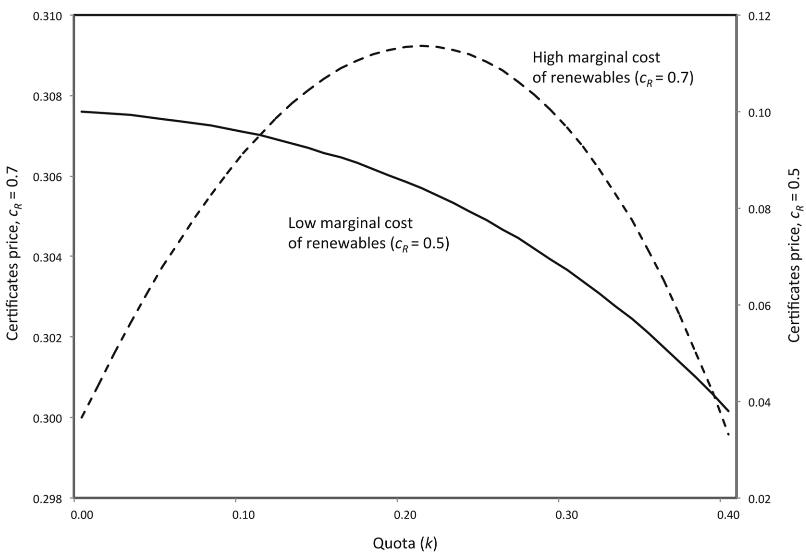

Fig. 3. Certificates price as a function of the quota

the relationship between the quota and the certificates price is more complicated, and the certificates price can be either increasing or decreasing in the quota, depending on the parameter values and the size of the quota. In Figure 3, we show two examples, with low and high marginal costs of renewables, respectively: one example where the relationship between the certificates price and the quota is monotonically decreasing, and one where it is non-monotonic.

IV. Feed-In Tariff

In this section, we consider a regime in which renewable electricity is subject to a feed-in tariff. We do so by disregarding the green-certificates market and assuming instead that renewable energy is paid a price τ per unit of output on top of the market price of electricity p_{E}. We could alternatively have assumed that renewable energy is paid a fixed price that is independent of the market price of electricity, but this would lead to essentially similar results. Indeed, Ropenus and Jensen (2009), who analyze cream-skimming effects in a dominant firm-fringe set-up, assume that producers of renewable energy obtain a fixed feed-in tariff; they show that a higher feed-in tariff leads to a lower electricity price.[13] We demonstrate that their results are also valid when the feed-in tariff constitutes a price premium, and we extend the analysis to the case when the feed-in tariff is financed by a tax on electricity consumers. For comparison with the regime in which renewable energy is regulated by means of green certificates, the formulation of a feed-in price premium is particularly convenient, as we demonstrate below.

The profit of the fringe now becomes

$$\pi_{\mathrm{F}} = (p_{\mathrm{E}} + \tau)q_{\mathrm{F}} - C_{\mathrm{R}}(q_{\mathrm{F}}) - aq_{\mathrm{F}}, \tag{14}$$

from which we derive its supply function

$$q_{\mathrm{F}} = q_{\mathrm{F}}(p_{\mathrm{E}} + \tau - a), \tag{15}$$

where, again, the function q_{F} is the inverse of the marginal cost function C'_{R}.

From equation (15), it is immediately clear that, because the feed-in tariff is exogenous, determined by the regulatory authority, the margin of the fringe can only be manipulated through the price of electricity.[14] In other words, while the reward for renewables is market-determined with green certificates, and hence open to manipulation, here it is exogenous and outside the reach of the dominant firm.

[13] They also show that if the dominant firm is vertically integrated, then a higher feed-in tariff induces the dominant firm to raise the access charge to skim part of the fringe's additional income and reduce the fringe's output.
[14] In the case of vertical integration, the fringe margin can also be manipulated through the access charge.

Proposition 3. *With a feed-in tariff, the dominant firm cannot induce a margin squeeze through the premium on renewables, as it can when renewables are regulated by green certificates. Hence, market power can only be exercised through the price of electricity.*

The profit of the dominant firm can be written as

$$\pi_{\mathrm{M}} = p_{\mathrm{E}} q_{\mathrm{M}} + (p_{\mathrm{E}} + \tau) q_{\mathrm{R}} - C_{\mathrm{M}}(q_{\mathrm{M}}) - C_{\mathrm{R}}(q_{\mathrm{R}}) - a(q_{\mathrm{M}} + q_{\mathrm{R}}). \qquad (16)$$

Note that, compared to equation (8) under the tradable green-certificates system, the only formal difference is that here the exogenous feed-in premium τ replaces the endogenous certificates price, p_{C}.

We first consider the case in which the feed-in tariff is financed in a way that is exogenous to activity in the electricity industry (i.e., by a general tax). Then, the price paid by consumers is simply equal to that received by producers, exclusive of any feed-in tariff, that is,

$$p = p_{\mathrm{E}}. \qquad (17)$$

The profit of the dominant firm can be rewritten as

$$\pi_{\mathrm{M}} = (p - a)(D - q_{\mathrm{F}}) + \tau q_{\mathrm{R}} - C_{\mathrm{M}}(D - q_{\mathrm{F}} - q_{\mathrm{R}}) - C_{\mathrm{R}}(q_{\mathrm{R}}), \qquad (18)$$

where q_{F} is given by equation (15). We can think of the dominant firm's problem as setting the price of electricity p (taking account of how price affects the demand as well as the supply of the fringe) and determining the amount of renewable energy to be produced by itself q_{R}.

We demonstrate the following proposition.

Proposition 4. *When the feed-in tariff is financed by a tax that is exogenous to activity in the electricity market, the dominant firm exercises market power by undersupplying electricity; in particular, it supplies less renewable energy than the fringe (i.e., $q_{\mathrm{R}} < q_{\mathrm{F}}$), but chooses a cost-efficient output mix: $C'_{\mathrm{R}}(q_{\mathrm{R}}) - \tau = C'_{\mathrm{M}}(q_{\mathrm{M}})$. Supply of renewables and total supply of electricity are increasing with the tariff.*

The first-order conditions for the dominant firm's profit-maximization problem can be written as[15]

$$p\left(1 - \frac{1}{\varepsilon_{DF}}\right) = C'_{\mathrm{M}} + a = C'_{\mathrm{R}} + a - \tau, \qquad (19)$$

where $\varepsilon_{DF} = -p(D' - q'_{\mathrm{F}})/(D - q_{\mathrm{F}}) > 0$ is (the absolute value of) the elasticity of the residual demand curve facing the dominant firm. The first

[15] When presenting first-order conditions, we implicitly assume that the solution is interior. Below, we consider examples where corner solutions occur; these are further discussed in Appendix B.

equality equates marginal revenue – evaluated with respect to the residual demand curve – with the marginal cost of supplying electricity. Note that, unlike in the case with green certificates where the dominant firm effectively controls the output of the fringe by manipulating the net price paid for renewables, here the dominant firm must take into account the response of the fringe when setting the price of electricity. Note also that a more generous policy towards renewables (i.e., a higher feed-in tariff) tends to reduce the consumer price of electricity and to increase demand.[16] A decrease in the consumer price of electricity would also occur in the case of a fixed feed-in tariff system, as shown by Ropenus and Jensen (2009). In other words, feed-in systems, in the form of either a premium or a fixed tariff, have the opposite effect of green certificates on total energy consumption. As we shall see below, this result depends crucially on the assumption that the feed-in tariff is not financed by revenues raised in the electricity industry itself.

The second equality in equation (19) equates the marginal costs of supplying electricity from conventional and renewable sources. Irrespective of source, costs include production costs and the access charge; however, for renewables, costs are taken net of the feed-in tariff, which effectively subsidizes the generation of renewable electricity. In other words, taking the subsidy to renewable electricity into account, the dominant firm balances renewable and non-renewable output so as to minimize costs.

Figure 4 shows demand and supply for different values of the feed-in tariff. For the lowest levels of the tariff ($\tau \leq 0.10$), the dominant firm sets the unconstrained monopoly price and only supplies conventional electricity. For higher values ($0.10 < \tau \leq 0.23$), the dominant firm limits prices so as not to make it profitable for the fringe to enter. Note that for this range, although there is no supply of renewable electricity, conventional electricity supply actually increases because of the imposition of the feed-in tariff, countering the market power of the dominant firm and benefitting consumers. For yet higher values ($\tau > 0.23$), the fringe supplies, while the dominant firm only produces from renewable sources when net costs are sufficiently low compared to the cost of conventional electricity ($\tau > 0.5$). While the total demand and supply of renewable electricity are increasing in the feed-in tariff, the supply of conventional electricity is decreasing and eventually ceases for sufficiently high levels of the tariff ($\tau > 0.77$).

While, with green certificates, the fringe generates less renewable electricity than the dominant firm, here the fringe's output of renewable electricity is greater (as illustrated in Figure 4). There are two reasons for this.

[16] Comparative statics on the first-order conditions (19) demonstrates that a sufficient condition for $dp/d\tau < 0$ is that the cost of renewable electricity is increasing at a faster rate than the cost of conventional electricity over the relevant ranges (i.e., $C''_{\mathrm{R}} \geq C''_{\mathrm{M}}$). The same condition ensures $dq_{\mathrm{R}}/d\tau > 0$.

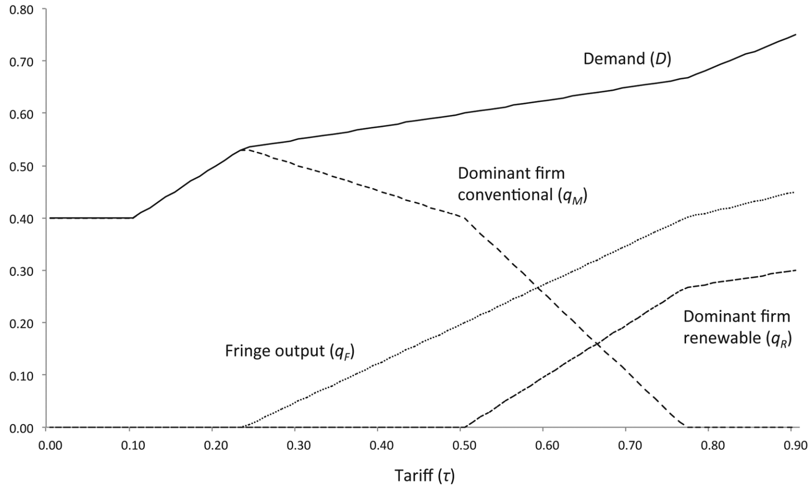

Fig. 4. Quantities as functions of tariff: exogenous tax

First, the dominant firm has a higher effective (opportunity) cost of renewable electricity than the fringe, as it balances the cost of renewables against the cost of conventional electricity. Second, being sensitive to its ability to influence the market price, *ceteris paribus* the dominant firm supplies less than the fringe.

So far, we have assumed that the feed-in tariff is financed in a way that is exogenous to activity in the electricity industry. One could argue that, because with green certificates electricity consumers finance the cost of the subsidy for renewables, a more relevant comparison with this regime would be when the feed-in tariff is financed in a similar manner. We now turn to this case.

Suppose the feed-in tariff is financed by a tax on electricity consumption

$$p = p_{\mathrm{E}} + t, \tag{20}$$

where t is the tax rate. We assume that the tax rate is set so as to exactly cover the cost of the feed-in tariff, that is

$$\tau(q_{\mathrm{F}} + q_{\mathrm{R}}) = tD(p). \tag{21}$$

Note that, while the feed-in tariff τ corresponds to the price of green certificates p_{C}, the tax rate t corresponds to the premium paid by consumers to cover the costs of green certificates kp_{C}. We return to this correspondence in the comparison of the two regimes below.

The dominant firm's profit can now be written as

$$\pi_{\mathrm{M}} = (p - t - a)(D - q_{\mathrm{F}}) + \tau q_{\mathrm{R}} - C_{\mathrm{M}}(D - q_{\mathrm{R}} - q_{\mathrm{F}}) - C_{\mathrm{R}}(q_{\mathrm{R}}), \tag{22}$$

where $D = D(p)$ and $q_F = q_F(p - t + \tau - a)$.

Again, the problem of the dominant firm can be viewed as setting the price of electricity and the amount of renewable output, that is, maximizing equation (22) with respect to p and q_R given equation (21). So, now the dominant firm must not only take account of the supply of the fringe but also the fact that the consumer tax will be set so as to cover the cost of the feed-in tariff. We have the following.

Proposition 5. *When the feed-in tariff is financed by a tax on electricity consumption, under reasonable assumptions the dominant firm exercises market power by both undersupplying electricity (i.e., $p_E > C'_M + a$) and oversupplying conventional electricity relative to renewable electricity (i.e., $C'_M(q_M) > C'_R(q_R) - \tau$). For a sufficiently high tariff, the total supply of electricity is decreasing with the tariff.*

From equation (21), we find the following partial relationships:

$$\frac{dt}{dp} = \frac{\tau q'_F - tD'}{\tau q'_F + D} > 0; \tag{23}$$

$$\frac{dt}{dq_R} = \frac{\tau}{\tau q'_F + D} > 0. \tag{24}$$

The first relationship is derived by holding the dominant firm's supply of renewables fixed; then, a higher price of electricity reduces demand and increases the fringe's supply of renewables, necessitating a rise in the tax to finance the cost of the feed-in tariff. The second relationship is derived by holding the price of electricity fixed; then, a larger supply of renewables by the dominant firm necessitates an increase in the tax to cover the feed-in tariff.

Using the above partial relationships, we find that the first-order conditions for the dominant firm's problem can be written as

$$(p - t)\left(1 - \frac{\varepsilon_{P_E}}{\varepsilon_{DFt}}\right) = C'_M + a, \tag{25}$$

and

$$C'_M = C'_R - \tau\left(1 - \frac{q_M + q_R}{D}\right)\left(1 + \frac{p_a - C'_R}{p_a}\varepsilon_F\right). \tag{26}$$

Here,

$$\varepsilon_{DFt} = -p\frac{D' - q'_F(dp_a/dp)}{D - q_F} > 0$$

is (the absolute value of) the elasticity of the residual demand curve facing the dominant firm with respect to the consumer price, $\varepsilon_{P_E} =$

$(dp_{\mathrm{E}}/dp)/(p/p_{\mathrm{E}})$ is the elasticity of the producer price with respect to the consumer price, $\varepsilon_{\mathrm{F}} = p_a q_{\mathrm{F}}'/q_{\mathrm{F}} > 0$ is the elasticity of fringe supply, and $p_a = p - t + \tau - a$ is the (net) price of renewable electricity.

Condition (25) equates the marginal revenue of increasing the supply of conventional energy with the corresponding marginal cost. Comparing equation (25) with equation (19), we find three differences.

First, the producer price of electricity is different from, and smaller than, the consumer price of electricity (i.e., $p_{\mathrm{E}} = p - t < p$) when the feed-in tariff is financed by a tax on electricity consumption.

Second, a change in the consumer price affects the producer price directly as well as indirectly through the the tax rate; this effect is captured by the elasticity of the producer price with respect to the consumer price $\varepsilon_{P_{\mathrm{E}}}$. Note that

$$\varepsilon_{P_{\mathrm{E}}} = \frac{1 - (dt/dp)}{1 - (t/p)},$$

where dt/dp is the derivate of the consumer tax with respect to the consumer price of electricity. It follows that $\varepsilon_{P_{\mathrm{E}}} > 1$ if $dt/dp < t/p$ – or $(dt/dp)/(p/t) < 1$ (i.e., the elasticity of the tax with respect to the consumer price is greater than one) – and so an increase in the consumer price reduces the producer price. Taken in isolation, this effect tends to increase the incentive to exercise market power when $\varepsilon_{P_{\mathrm{E}}} > 1$ or $dt/dp < t/p$, and vice versa.

Third, the induced change in the tax rate affects the supply of the fringe; this effect is captured by the elasticity of the residual demand curve facing the dominant firm with respect to the consumer price ε_{DFt}, and, in particular, the element dp_a/dp, the derivative of the price received by the fringe with respect to the consumer price. We have $dp_a/dp = 1 - dt/dp$. Therefore, because an increase in the consumer price increases the tax rate (i.e., $dt/dp > 0$), $dp_a/dp = 1 - dt/dp < 1$, and so the response of the fringe is smaller than if the tax was exogenous. Taken in isolation, this effect tends to increase the incentive to exercise market power.

Overall, we find that the endogeneity of the tax rate has potentially conflicting effects on the incentive to exercise market power in the electricity market. If the elasticity of consumer demand is sufficiently small, then it follows from equation (23) that $dt/dp < t/p$; in this case, the endogeneity of the tax rate tends to increase the incentive to exercise market power.

Condition (26) equates the marginal cost of conventional and renewable energy, respectively. Comparing equations (26) and (19), we find two differences. The first, captured by the term $(q_{\mathrm{M}} + q_{\mathrm{R}})/D$ (i.e., the share of the dominant firm in overall supply), reflects the fact that an increase in the supply of renewable energy raises the cost of the feed-in tariff, inducing an increase in the tax rate and a corresponding reduction in the producer

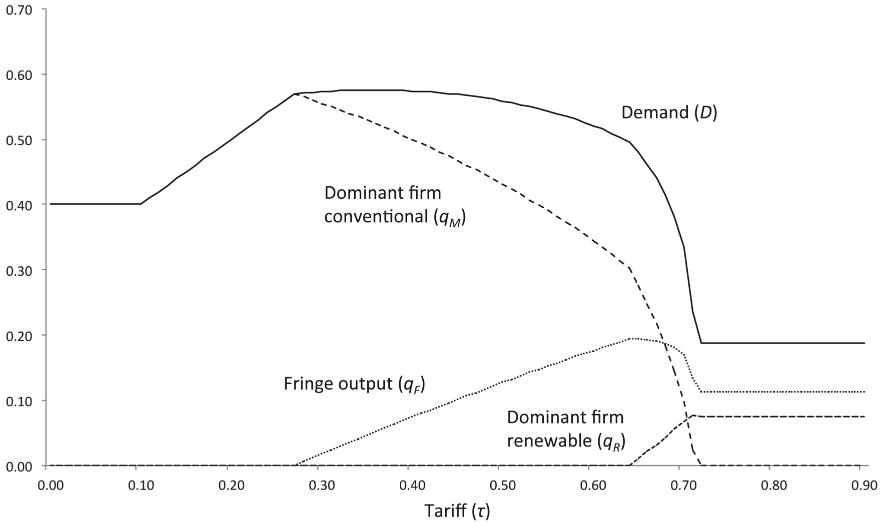

Fig. 5. Quantities as functions of tariff: endogenous tax

price of electricity. This effect, which tends to reduce the profitability of increasing the supply of renewable energy, depends on the market share of the dominant firm.

The second difference, captured by the term $[(p_a - C'_{\mathrm{R}})/p_a]\varepsilon_{\mathrm{F}}$, reflects the fact that the induced increase in the tax rate reduces fringe supply. This effect, which tends to increase the profitability of increasing supply of renewable electricity, depends on the profit margin for renewable electricity, $(p_a - C'_{\mathrm{R}})/p_a$, as well as the elasticity of fringe supply, ε_{F}.

Overall, we find again that the endogeneity of the tax rate has conflicting effects; the smaller the market share of the fringe, the dominant firm's profit margin for renewables, and the elasticity of fringe supply are, the more likely it is that the dominant firm's incentive to supply renewables is smaller when the tax rate is endogenous than when it is exogenous.

Figure 5 shows demand and supply quantities for different values of the feed-in tariff, as in Figure 4. Qualitatively, we have the same picture. For the lowest levels of the tariff, the dominant firm operates as an unconstrained monopolist. Then, there is a region where the dominant firm limits prices; for yet higher tariff levels, the higher the tariff, the more the fringe enters and supplies, while the dominant firm reduces the output of conventional electricity, then starts supplying renewable electricity, and finally concentrates on renewables only.

An obvious difference from the case when subsidies for renewables are financed by a general tax is that here the renewables tax on electricity consumers tends to reduce demand for electricity. This effect is small for low levels of the feed-in tariff where the boost to the supply of renewables drives down the electricity price and increases demand. However, for higher levels of the tariff, the cost of financing increases with the penetration of renewables and reduces overall demand. When the tariff becomes so high that conventional electricity is driven out entirely, tax and tariff become identical and outweigh each other, so that demand and supply of electricity become independent of the level of the tariff. Because of the downward pressure on demand from the tax on consumption, the point at which conventional electricity is driven out occurs earlier than when the feed-in tariff is externally financed (at $\tau = 0.72$ instead of at $\tau = 0.77$).

The endogenous tax strengthens the incentive of the dominant firm to exercise market power. The region where the dominant firm limits prices increases (from $0.10 < \tau \leq 0.23$ to $0.10 < \tau \leq 0.27$). Also, the dominant firm requires a higher tariff level to supply any renewables at all ($\tau > 0.64$ as opposed to $\tau > 0.5$) and supplies less for any level of the tariff; supplying renewables tends to increase the tax on consumption and hence to reduce demand, while supplying conventional electricity has the opposite effect.

We end by comparing the feed-in tariff and green-certificates regimes when both are financed in the electricity market. It is easy to demonstrate that in the absence of market power, market performance would be identical; in particular, with price-taking behavior by all participants, setting $\tau = p_C$ and $t = kp_C$ (where p_C refers to the equilibrium value of the quota price for a quota equal to k) would implement the same outcome in both cases.

Based on the analysis in this and the previous sections, we would expect market power to increase consumer price more, and hence reduce demand and overall supply more, in the green-certificates regime, as there the dominant firm is able to contain the response of the fringe by manipulating the premium on renewable electricity. For the same reason, we would expect the dominant firm to have both a larger market share and a larger share of the supply of renewable electricity with green certificates than with a feed-in tariff.

We have not been able to prove these conjectures analytically, but they do hold in our parametrized example, as illustrated in Figure 6. This figure builds on Figure 5, where we have restricted attention to the region in which the renewables policy is effective (i.e., $0.27 \leq \tau \leq 0.72$). For each value of the feed-in tariff, we have calculated the share of renewables in total supply, $(q_F + q_R)/(q_F + q_R + q_M)$, and we have presented the corresponding variables for the green-certificates regime for this value of k (accordingly, the horizontal axis measures the value of $k = (q_F + q_R)/(q_F + q_R + q_M)$). In other words, we compare outcomes across the two regimes for identical shares of renewables in total electricity output. This seems a natural comparison given that goals for renewables are often stated in terms

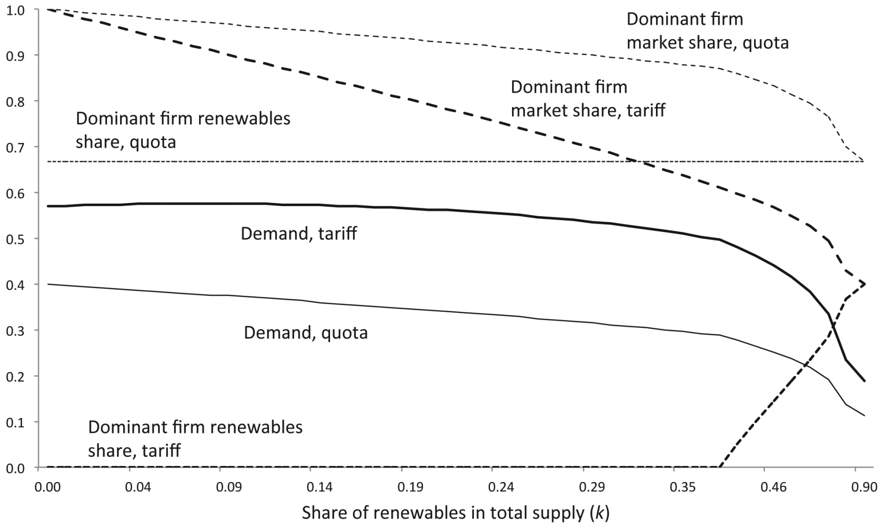

Fig. 6. Comparison of tariff and quota: endogenous tax

of their share in total output (see the 20–20–20 goals of the European Union).

The two solid lines in Figure 6 show that total demand (and supply) is greater in the feed-in tariff regime. This reflects the weaker market power of the dominant firm in the tariff regime; whereas, with green certificates, the dominant firm is able to influence the margin for renewables separately, with a feed-in tariff the firm is only able to exercise market power through the price of electricity. Consequently, the dominant firm supplies more, or sets a lower price on electricity, in the tariff regime than in the green-certificates regime.

The two dashed lines show that, although total supply is smaller, the market share of the dominant firm is higher with green certificates than with a feed-in tariff. In the green-certificates regime, by simultaneously withholding supply and squeezing the margin for renewables, the dominant firm is able both to raise prices and to shift supply towards itself; in the tariff regime, withholding supply and raising the electricity price encourage the fringe to supply more.

Finally, the dotted lines show that the dominant firm's share of renewables is greater in the green-certificates regime than in the feed-in tariff regime. With green certificates, the dominant firm oversupplies renewable electricity to drive down the price received by the fringe. By contrast, with a feed-in tariff the dominant firm undersupplies renewable electricity to limit the tax on consumers, and hence the price they pay and their demand for electricity.

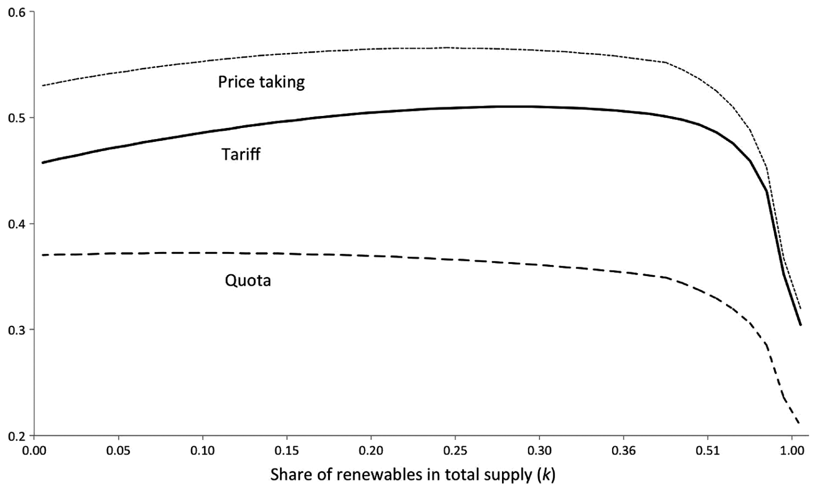

Fig. 7. Net surplus

The fact that, for a given share of renewables, the total supply is lower with green certificates than with a feed-in tariff – and so, of course, is the supply of both conventional and renewable generation – indicates that market power has a greater impact on overall supply with a certificates regime than with a tariff regime. In other words, the deviation from the outcome without market power is greater with green certificates than with a feed-in tariff. Taken in isolation, this result would tend to favor green certificates over a feed-in tariff, if, for other reasons, negative externalities from conventional generation are relatively important (e.g., because of carbon emissions that are not properly accounted for by other policies). However, if positive externalities from renewables are relatively important (e.g., due to innovation spillovers), a feed-in tariff regime would tend to be better than a green-certificates regime as the former leads to a larger output of renewables. Specifically, if negative externalities from conventional generation are properly accounted for (so that c_M reflects true, economy-wide costs), then a feed-in tariff is preferable because it does not allow the dominant firm to manipulate the premium on renewables and it tends to undermine the dominant firm's market power in the electricity market.

The latter point is illustrated in Figure 7, which shows net surplus for different shares of renewables in total supply for the two regulatory regimes, as well as for a model in which all firms act as price takers. Net surplus is given by total willingness to pay less total costs plus the positive externality of renewables, which is assumed to be proportional to the volume of renewables with a proportionality factor equal to 1 (i.e., we model the externality as $\delta(q_F + q_R)$ and set $\delta = 1$ in the numerical example). In this case (which is exactly when a subsidy for renewables is the economically relevant policy), the tariff regime dominates the quota regime for all renewable shares because of the higher levels of supply. The surplus-maximizing policy is $\tau = 0.55$ in the feed-in tariff regime – which corresponds to a share of renewables equal to 0.28 – and $k = 0.09$ in the green-certificates regime; by comparison, the optimal policy with price-taking behavior is $\tau = 0.51$ or $k = 0.24$.[17]

In other words, the optimal policy is stronger in the tariff regime (a higher tariff), but weaker in the quota regime (a lower quota), compared to the case with no market power.[18]

V. Conclusion

In this paper, we have considered a set-up in which a dominant electricity producer that operates in both the conventional and renewables segments faces a fringe of price-taking producers of renewable energy. The analysis leads to a number of insights.

First, we have found that when renewable energy is regulated by green certificates, the dominant firm will find it optimal to impose a margin squeeze on its rivals by oversupplying renewable energy in order to drive down the price of certificates. This demonstrates that the establishment of a market for green certificates introduces a new opportunity for strategic price manipulation by agents with market power, which might not only distort the certificates market but might also affect the performance of the electricity market and the efficiency in generation.

Second, we have seen that the market outcome is the same whether or not the dominant firm is vertically integrated into the network business, as long as the network access price is perfectly regulated in the case of vertical separation; if regulation is imperfect, distortions are smaller under vertical integration than under vertical separation.[19] The main insight from this result is not that vertical separation or unbundling is a bad idea (our simple model does not account for a number of important aspects of this issue), but rather that the establishment of a green-certificates market might undermine the pro-competitive effects of unbundling by re-introducing means for predation and foreclosure. In particular, the margin squeeze that can

[17] Because the subsidy for renewables is paid for by electricity consumers – and hence introduces a distortion in the electricity market – the optimal tariff is smaller than the marginal value of the externality even with price-taking behavior.

[18] These results are robust for alternative values of the externality δ.

[19] We are not the first to point to the possibility of such double marginalization when regulation is imperfect; see, for instance, Cremer *et al.* (2007), who also provide a more general discussion of the merits of vertical separation.

be imposed through the certificates market parallels that which can be imposed through the pricing of access to networks or other essential facilities; in fact, in our set-up, the two sets of strategies are equivalent.

Third, we have found that feed-in tariffs do not provide a similar opportunity for manipulating the support for renewable energy. The difference between feed-in tariffs and green certificates is especially pronounced when the tariff is financed by a general tax, as the whole support system is then essentially exogenous to participants in the electricity industry.[20] However, if the tariff is financed by a tax on electricity consumers, the tax affects the dominant firm's incentive to exercise market power on the electricity market, as well as the incentive to balance conventional and renewable energy. Under reasonable assumptions, the dominant firm has a stronger incentive to exercise market power and to produce conventional energy when the tax is financed by the industry itself than when it is not. However, the incentive and ability to exercise market power is nevertheless smaller in the feed-in tariff regime than in the green-certificates regime.

Admittedly, our set-up is simple and abstracts from a number of real-world characteristics of electricity markets and renewables policies. In particular, market structures are more heterogeneous than our extreme dominant firm–fringe dichotomy suggests, and green-certificates markets often contain additional elements such as penalties for non-compliance and opportunities for banking. While it would be interesting to extend the analysis to such more realistic settings, we believe the fundamental insights of our analysis are robust.

Appendix A: Green Certificates with Vertical Integration

In this appendix, we briefly outline the analysis of green certificates in a market structure with vertical integration, where the dominant firm owns the network. Irrespective of its empirical relevance, this market structure allows us to highlight the parallel between dominant-firm strategies that might be pursued when controlling access to infrastructure and those made possible by the presence of a green-certificates market. As we shall see, in our setting, these strategic opportunities are, in fact, equivalent; hence, only one is necessary for the firm to achieve its preferred outcome.

For the competitive fringe, the analysis is exactly as with vertical separation; profits are given by equation (5), which, when maximized, results in fringe supply as described in equation (7), where a now denotes the per unit access fee a for transmission services charged by the dominant firm.

[20] Ropenus and Jensen (2009) show that the tariff can affect the incentive of a vertically integrated dominant firm to distort the access charge.

The revenue of the vertically integrated dominant firm is obtained from the sale of conventional and renewable energy (and the corresponding amount of certificates) and network services. The dominant firm incurs generation costs as well as network costs. Hence, the profit of the dominant firm is

$$\pi_{\mathrm{M}} = p_{\mathrm{E}} q_{\mathrm{M}} + (p_{\mathrm{C}} + p_{\mathrm{E}}) q_{\mathrm{R}} + a q_{\mathrm{F}} - C_{\mathrm{M}}(q_{\mathrm{M}}) - C_{\mathrm{R}}(q_{\mathrm{R}}) \\ - C_{\mathrm{N}}(q_{\mathrm{F}} + q_{\mathrm{M}} + q_{\mathrm{R}}). \quad \text{(A1)}$$

Comparing equation (A1) with equation (8), we note that here the dominant firm earns revenues from access payments by the fringe. Furthermore, rather than incurring the network tariff contribution for transmission of its own electricity, here the dominant firm pays the full cost for the transmission of electricity.

Analogous to the case of vertical separation, we can express the dominant firm's profit in terms of the consumer price and the fringe price:

$$\pi_{\mathrm{M}} = (p_{\mathrm{E}} + k p_{\mathrm{C}})(q_{\mathrm{F}} + q_{\mathrm{M}} + q_{\mathrm{R}}) - (p_{\mathrm{C}} + p_{\mathrm{E}} - a) q_{\mathrm{F}} \\ - C_{\mathrm{M}}(\cdot) - C_{\mathrm{R}}(\cdot) - C_{\mathrm{N}}(\cdot) \quad \text{(A2)}$$

or, alternatively,

$$\pi_{\mathrm{M}} = p D(p) - p_a q_{\mathrm{F}}(p_a) - C_{\mathrm{M}}((1-k) D(p)) \\ - C_{\mathrm{R}}(k D(p) - q_{\mathrm{F}}(p_a)) - C_{\mathrm{N}}(D(p)). \quad \text{(A3)}$$

Formally, the difference between the cases of vertical separation and vertical integration is that here the term $C_{\mathrm{N}}(D)$ takes the place of aD in the case of vertical separation. It follows that if network regulation is perfect (i.e., $aD \equiv C_{\mathrm{N}}(D)$), then profit expressions, and hence market outcomes, would be equivalent.

We see from this last expression that the dominant firm's profit depends on the composite prices p and p_a only. This implies that the original problem of maximizing equation (A1) subject to equations (1), (2), (4), and (7) is indeterminate. In other words, as long as the three component prices p_{C}, p_{E}, and a satisfy the relations $p = p_{\mathrm{E}} + k p_{\mathrm{C}}$ and $p_a = p_{\mathrm{C}} + p_{\mathrm{E}} - a$, the dominant firm can implement its optimal solution in an infinity of different ways. In particular, for any given value of one of the component prices, the dominant firm can always find values for the two other components that implement the profit-maximizing solution.

The result is general, in the sense that it does not depend on functional forms or any other technical assumption. It is related to the fact that profits of the dominant firm are influenced by two endogenous entities – total demand for electricity and renewables supply from the fringe –

and only two instruments are required to control these entities: the consumer price of electricity and the price of electricity obtained by the fringe. Because the dominant firm has three instruments at its disposal, but requires only two, it has one degree of freedom in how it implements the solution.

Note that this result implies that as long as the dominant firm owns the network, it does not matter whether it is free to set the access charge or not. More specifically, for any given access charge, the dominant firm will be able to implement its preferred market outcome. It follows that if the access charge were regulated, the market power of the dominant firm would not be affected.

The profit-maximization problem of the dominant firm can alternatively be expressed as maximizing equation (A3) with respect to p and p_a. The first-order conditions for this problem are

$$p\left(1-\frac{1}{\varepsilon_{\mathrm{D}}}\right)=(1-k)C'_{\mathrm{M}}+kC'_{\mathrm{R}}+C'_{\mathrm{N}}, \tag{A4}$$

and

$$p_a\left(1+\frac{1}{\varepsilon_{\mathrm{F}}}\right)=C'_{\mathrm{R}}. \tag{A5}$$

The margin squeeze can be obtained by different combinations of the three component prices that constitute the composite price, $p_a = p_{\mathrm{C}} + p_{\mathrm{E}} - a$. As pointed out above, whereas the composite prices p and p_a are determined by profit-maximization of the dominant firm, the component prices a, p_{C}, and p_{E} are not. However, given the composite prices, a particular relationship exists between the component prices. For example, we can write the profit-maximizing values of the price of conventional electricity p_{E} and the certificate price p_{C} as functions of the access charge:

$$p_{\mathrm{E}}=\frac{1}{1-k}(p-kp_a-ka); \tag{A6}$$

$$p_{\mathrm{C}}=\frac{1}{1-k}(p_a-p+a). \tag{A7}$$

We observe that while the equilibrium price of conventional electricity is decreasing, the equilibrium certificate price is increasing with the access charge. It follows that there is a negative relation between the equilibrium values of the price of conventional electricity and the certificate price.

Appendix B: A Parametrized Example

In this appendix, we consider the parametrized example of the general model that forms the basis for the illustrations in the main text. We also derive closed-form solutions and further characterize results.

In this example, demand is linear with coefficients normalized to 1:

$$D(p) = 1 - p. \tag{B1}$$

The renewable generation costs are quadratic in output,

$$C_{\mathrm{R}}(q) = c_{\mathrm{R}}q + \frac{1}{2}d_{\mathrm{R}}q^2, \tag{B2}$$

while conventional generation costs are linear,

$$C_{\mathrm{M}}(q) = c_{\mathrm{M}}q, \tag{B3}$$

and so are network costs,

$$C_{\mathrm{N}}(q) = c_{\mathrm{N}}q, \tag{B4}$$

where c_{M}, c_{N}, and c_{R} are non-negative constants, and d_{R} is strictly positive.

In order to ensure that supply of conventional and renewable electricity are non-negative at market equilibrium, we require that for both technologies marginal cost at zero output falls below the maximum price, or

$$1 - c_{\mathrm{M}} - c_{\mathrm{N}} > 0 \tag{B5}$$

and

$$1 - c_{\mathrm{R}} - c_{\mathrm{N}} > 0. \tag{B6}$$

We further assume that, disregarding costs of emissions, conventional energy is always cheaper than renewable energy, that is,

$$c_{\mathrm{M}} \leq c_{\mathrm{R}}. \tag{B7}$$

Moreover, we assume that the fringe would not want to enter the renewables business in the absence of specific regulations; in particular, we assume that when the dominant firm maximizes profits supplying conventional electricity only, the price does not exceed the marginal cost of the fringe at zero output:

$$\frac{1}{2}(1 + c_{\mathrm{M}} + a) \leq c_{\mathrm{R}} + a.$$

Here, the left-hand side is the price that maximizes total industry revenue minus the costs of supplying conventional electricity (including the network access fee), and the right-hand side is the marginal cost of supplying renewables at zero output.

Green Certificates

The consumer price and the fringe price are given by

$$p = 1 - \frac{3}{2(3 + k^2 d_{\mathrm{R}})}[1 - c_{\mathrm{M}} - a - k(c_{\mathrm{R}} - c_{\mathrm{M}})] \tag{B8}$$

and

$$p_a = c_{\mathrm{R}} + \frac{k d_{\mathrm{R}}}{2(3 + k^2 d_{\mathrm{R}})}[1 - c_{\mathrm{M}} - a - k(c_{\mathrm{R}} - c_{\mathrm{M}})]. \tag{B9}$$

From the assumptions that $1 - c_{\mathrm{N}} - c_{\mathrm{R}} > 0$ and $c_{\mathrm{R}} \geq c_{\mathrm{M}}$, and because $k \leq 1$, we have

$$1 - c_{\mathrm{M}} - c_{\mathrm{N}} - k(c_{\mathrm{R}} - c_{\mathrm{M}}) > 1 - c_{\mathrm{M}} - c_{\mathrm{N}} - c_{\mathrm{R}} + c_{\mathrm{M}} = 1 - c_{\mathrm{N}} - c_{\mathrm{R}} > 0,$$

from which it follows that $p < 1$ and $p_a > c_{\mathrm{R}}$ at $a = c_{\mathrm{N}}$.

Outputs are given by

$$q_{\mathrm{F}} = \frac{k}{2(3 + k^2 d_{\mathrm{R}})}[1 - c_{\mathrm{M}} - a - k(c_{\mathrm{R}} - c_{\mathrm{M}})], \tag{B10}$$

$$q_{\mathrm{M}} = \frac{3(1-k)}{2(3 + k^2 d_{\mathrm{R}})}[1 - c_{\mathrm{M}} - a - k(c_{\mathrm{R}} - c_{\mathrm{M}})], \tag{B11}$$

and

$$q_{\mathrm{R}} = \frac{k}{3 + k^2 d_{\mathrm{R}}}[1 - c_{\mathrm{M}} - a - k(c_{\mathrm{R}} - c_{\mathrm{M}})], \tag{B12}$$

where we note that the equilibrium supply of renewable electricity by the dominant firm is twice that of the fringe:

$$q_{\mathrm{R}} = 2q_{\mathrm{F}}. \tag{B13}$$

We conclude the analysis of green certificates by considering how equilibrium prices and quantities depend on renewable energy policy, as measured by the quota k, assuming that the access charge is set equal to marginal network costs (i.e., $a = c_{\mathrm{N}}$).[21]

For the electricity price paid by consumers, we obtain

$$\frac{dp}{dk} = \frac{3(c_{\mathrm{R}} - c_{\mathrm{M}}) + 3kd_{\mathrm{R}}[2(1 - c_{\mathrm{M}} - a) - k(c_{\mathrm{R}} - c_{\mathrm{M}})]}{2(3 + k^2 d_{\mathrm{R}})}. \tag{B14}$$

Because $c_{\mathrm{R}} \geq c_{\mathrm{M}}$ and $1 - c_{\mathrm{M}} - c_{\mathrm{N}} - k(c_{\mathrm{R}} - c_{\mathrm{M}}) > 0$, we find

$$\frac{dp}{dk} > \frac{3(c_{\mathrm{R}} - c_{\mathrm{M}})}{2(3 + k^2 d_{\mathrm{R}})} > 0. \tag{B15}$$

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[21] All arguments go through so long as a is sufficiently close to c_{N}.

Furthermore, we find

$$\frac{dp_a}{dk} = \frac{3d_R(1 - c_M - a) - kd_R[kd_R(1 - c_M - a) + 6(c_R - c_M)]}{2(3 + k^2 d_R)}. \quad \text{(B16)}$$

As is easily seen, dp_a/dk is decreasing in k; that is, the fringe price is concave in the quota. Furthermore, at $k = 0$, $dp_a/dk > 0$. This means that the fringe price is increasing at no (or, by continuity, small) quota. By contrast, at $k = (1 - c_M - a)/(c_R - c_M)$, we have $dp_a/dk < 0$. It follows that there exists some $\hat{k} \in [0, (1 - c_M - a)/(c_R - c_M)]$, for which $dp_a/dk = 0$.

Because $(1 - c_M - c_N)/(c_R - c_M) > 1$, it is not clear that $\hat{k} < 1$ (the maximum quota); indeed, depending on parameter values, we can have either $\hat{k} > 1$ or $\hat{k} < 1$. In the former case, the fringe price is always increasing in the quota, whereas in the latter case, the fringe price is first increasing and subsequently decreasing in the quota.

The behavior of the composite prices is reflected in the underlying prices of conventional electricity and green certificates. The marginal impact on the price of conventional electricity by an increase in the quota is unambiguously positive:

$$\frac{dp_E}{dk} = \frac{1 - c_R - a}{2(1 - k)^2} > 0. \quad \text{(B17)}$$

However, the relation between the quota and the certificates price is more complicated, and the certificates price can be both increasing or decreasing in the quota, depending on parameter values and the size of the quota.

In order to shed some further light on the relationship between prices and the quota, let us now investigate the impact of the quota on outputs. From the first-order condition for the profit maximization of the fringe (7), we have

$$q_F = \frac{1}{d_R}(p_a - c_R). \quad \text{(B18)}$$

It follows that the relationship between q_F and k has the same shape as that between p_a and k; more specifically, q_F is increasing in k whenever p_a is, and vice versa. Moreover, because the renewables supply of the dominant firm is proportional to that of the fringe, the same is true for the dominant firm's renewable supply.

Using equation (2), we can alternatively state the supplies of renewable electricity as

$$q_F = \frac{k}{3}(1 - p) \quad \text{(B19)}$$

and

$$q_{\mathrm{R}} = \frac{2k}{3}(1-p). \tag{B20}$$

Moreover, from equation (3), we find that

$$q_{\mathrm{M}} = (1-k)(1-p). \tag{B21}$$

Feed-In Tariff: Exogenous Tax

Under the assumption that parameters are such that the fringe would produce nothing without a specific renewables policy, it follows that the dominant firm, for sufficiently low values of the feed-in tariff, is unconstrained and can act as a monopolist, supplying only conventional electricity. The dominant firm's problem is then to maximize

$$\pi_{\mathrm{M}} = (p-a)D + C_{\mathrm{M}}(D), \tag{B22}$$

which, in the example, has the solution

$$p = \frac{1}{2}(1 + c_{\mathrm{M}} + a). \tag{B23}$$

The dominant firm is unconstrained so long as the monopoly price is at or below the net marginal cost of the fringe at zero output (i.e., $p \leq c_{\mathrm{R}} + a - \tau$), which yields the first critical value for the feed-in tariff:

$$\tau_1 = c_{\mathrm{R}} - c_{\mathrm{M}} - \frac{1}{2}(1 - c_{\mathrm{M}} - a). \tag{B24}$$

For higher values of the feed-in tariff, the unconstrained monopoly price will be sufficiently attractive to induce entry by the fringe; however, it might then be in the interest of the dominant firm to supply more in order to drive down the electricity price to the limit price $p = c_{\mathrm{R}} + a - \tau$ and forestall entry. A necessary condition for it to be optimal for the dominant firm to hold the price at this level is that the marginal profit from raising the price, taking account of the response of the fringe, is non-positive. Taking the derivative of equation (18) with respect to p, substituting the limit price for p, setting the result equal to zero and solving, yields the next critical value for feed-in tariff:

$$\tau_2 = c_{\mathrm{R}} - c_{\mathrm{M}} - \frac{d_{\mathrm{R}}}{2d_{\mathrm{R}}+1}(1 - c_{\mathrm{M}} - a). \tag{B25}$$

For still higher values of the feed-in tariff, it is optimal for the dominant firm to set a price so high that the fringe supplies renewable electricity.

Here, we find from equation (19) the following solutions for the electricity price:

$$p = 1 - \frac{1}{2(1 + d_R)}[(2 + d_R)(1 - c_M - a) + c_M - c_R + \tau], \qquad \text{(B26)}$$

However, it is only when the tariff is high enough so that the net cost of renewable electricity falls below the cost of conventional electricity that the dominant firm, which chooses the cost-minimizing combination of renewable and conventional electricity, itself produces renewable electricity. The third critical value for the feed-in tariff therefore becomes

$$\tau_3 = c_R - c_M. \qquad \text{(B27)}$$

Here, we find from equation (19) the following solutions for the dominant firm's output of renewable electricity

$$q_R = \frac{1}{d_R}(c_M - c_R + \tau). \qquad \text{(B28)}$$

Finally, for sufficiently high values of the feed-in tariff, the dominant firm will find it most profitable not to produce any conventional electricity, in which case the dominant firm maximizes the following expression:

$$\pi_M = (p - a + \tau)(D - q_F) - C_R(D - q_F), \qquad \text{(B29)}$$

which has the solution

$$p = \frac{1}{(3 + d_R)(1 + d_R)}[(2 + d_R)d_R - (3 + 2d_R)(\tau - c_R - a)]. \qquad \text{(B30)}$$

Using this and the condition that, at optimum, net marginal cost of renewable electricity is lower than the marginal cost of conventional electricity, which in the example can be written as $c_R + d_R(D - q_F) - \tau \leq c_M$, we find the fourth and final critical value for the feed-in tariff:

$$\tau_4 = c_R - c_M + \frac{d_R}{3}(1 - c_M - a). \qquad \text{(B31)}$$

In order to compare the policies of feed-in tariffs and green certificates with respect to the composition of electricity generation, we consider the case when the respective policies are set such that the share of renewables in total electricity output is the same; that is, such that

$$\frac{q_F + q_R}{q_F + q_M + q_R} = k. \qquad \text{(B32)}$$

From equations (B28)–(B32), we find the feed-in tariff that corresponds to a particular share of renewables:

$$\tau = \frac{d_R[k(2 + d_R) - 1]}{3 + (4 - k)d_R}(1 - c_M - a) + c_R - c_M. \qquad \text{(B33)}$$

Substituting equation (B33) in equations (15) and (B28), we find

$$\frac{q_F}{q_R} = \frac{2(1+d_R)[k(1+2d_R)-1] + (2-k)(2+d_R) + d_R}{2(1+d_R)[k(1+2d_R)-1]} > 1. \qquad \text{(B34)}$$

Feed-In Tariff: Endogenous Tax

The characterization of equilibrium for the endogenous-tax case follows the same line as for the case of an exogenous tax. In particular, the range for which the dominant firm is unconstrained is the same in both cases, and so the first critical value for the feed-in tariff is again

$$\tau_1 = c_R - c_M - \frac{1}{2}(1 - c_M - a). \qquad \text{(B35)}$$

The limit price is also the same and equals $p = c_R + a - \tau$ (note that $t = 0$ when there is no supply of renewable electricity), but the second critical value for the feed-in tariff differs, because the impact on the price received by the fringe, and hence its response, is different when the tax rate is endogenous. Taking the derivative of equation (18) with respect to p, substituting the limit price for p, setting the result equal to zero and solving, yields the next critical value for the feed-in tariff

$$\tau_2 = \frac{1}{4(1+d_R)}\left\{(2+d_R)(c_R - c_M) - (1+3d_R)(1-c_R-a) + \sqrt{\begin{array}{c}[(2+d_R)(c_R-c_M) + (1-d_R)(1-c_R-a)]^2 \\ +4d_R(1+d_R)(c_R-c_M)(1-c_R-a)\end{array}}\right\}. \qquad \text{(B36)}$$

For yet higher values of the feed-in tariff, it is optimal for the dominant firm to set a price so high that the fringe supplies renewable electricity. For this range, we have not been able to find closed-form solutions, but we have had to rely on numerical simulations. The first-order condition (26) can be written as

$$q_R = \frac{1}{d_R(1+2A^2)} \times \{2(1-A)A + [1 + (1-2A)A](\tau + c_M - c_R) - d_R A(1-p)\}, \qquad \text{(B37)}$$

where $A = \tau/[\tau + d_R(1-p)]$, and we have used the following expressions derived from equations (21) and (15):

$$t = A(p + \tau - a - c_R + d_R q_R); \qquad \text{(B38)}$$

$$q_F = \frac{1}{d_R}(1 - A)(p + \tau - a - c_R) - Aq_R. \tag{B39}$$

This gives us a recursive system with q_R, q_F, and t as functions of p that allows us to find the p that maximizes profits for any given τ.

The critical value of the feed-in tariff, τ_3, at which the dominant firm starts to produce not only conventional but also renewable electricity, is found where the solution to equation (B37) equals exactly 0 for the optimal value of p (at lower tariff levels, the solution to equation (B37) is negative and so we set $q_R = 0$).

Similarly, the critical value of the feed-in tariff, τ_4, at which the dominant firm stops producing conventional electricity, is found where the solution to equation (B37) equals exactly $D - q_F$ (and so the supply of renewable electricity equals total demand). For higher levels of the tariff, when the dominant firm finds it most profitable not to produce any conventional electricity, it follows from equation (21) that $t = \tau$. We find the profit-maximizing price in the same manner as in the case of an exogenous tax:

$$p = \frac{1}{(3 + d_R)(1 + d_R)}[(2 + d_R)d_R + (3 + 2d_R)(c_R + a)]. \tag{B40}$$

Note that, for $\tau \geq \tau_4$, the market outcome is independent of the level of the feed-in tariff; a higher tariff requires a correspondingly higher tax, but as the producer price, $p_E + \tau$, and the consumer price, $p_E + t$, remain identical, the market price of electricity, p_E, simply adjusts accordingly.

References

Amundsen, E. S. and Bergman, L. (2012), Green Certificates and Market Power on the Nordic Power Market, *Energy Journal 33*, 101–117.

Amundsen, E. S. and Mortensen, J. B. (2001), The Danish Green Certificate System: Some Simple Analytical Results, *Energy Economics 23*, 489–509.

Amundsen, E. S. and Mortensen, J. B. (2002), Erratum to "The Danish Green Certificate System: Some Simple Analytical Results", *Energy Economics 24*, 523–524.

Amundsen, E. S. and Nese, G. (2004), Market Power in Interactive Environmental and Energy Markets: The Case of Green Certificates, Working Paper, University of Bergen (MPRA Paper No. 10559).

Amundsen, E. S. and Nese, G. (2009), Integration of Tradable Green Certificate Markets: What Can Be Expected?, *Journal of Policy Modeling 31*, 903–922.

Amundsen, E. S., Baldursson, F. M., and Mortensen, J. B. (2006), Price Volatility and Banking in Green Certificate Markets, *Environmental and Resource Economics 35*, 259–287.

Armstrong, M. and Vickers, J. S. (1998), The Access Pricing Problem with Deregulation: A Note, *Journal of Industrial Economics 46*, 115–121.

Armstrong, M., Doyle, C., and Vickers, J. S. (1996), The Access Pricing Problem: A Synthesis, *Journal of Industrial Economics 44*, 131–150.

Böhringer, C. and Rosendahl, K. E. (2010), Green Serves the Dirtiest – On The Interaction Between Black and Green Quotas, *Journal of Regulatory Economics 37*, 316–325.

Commission of the European Communities (2011), 2009–2010 Report on Progress in Creating the Internal Gas and Electricity Market, Commission Staff Working Document, Commission of the European Communities, Brussels.

Cremer, H., Crémer, J., and De Donder, P. (2007), Costs and Benefits of Vertical Divestiture, *Communications and Strategies 68*, 41–56.

European Commission (2011), 2009–2010 Report on Progress in Creating the Internal Gas and Electricity Market – Technical Annex, European Commission, Brussels.

Fehr, N.-H. M. von der (1993), Tradable Emission Rights and Strategic Interaction, *Environmental and Resource Economics 3*, 129–151.

Jensen, S. G. and Skytte, K. (2002), Interactions Between the Power and Green Certificate Markets, *Energy Policy 30*, 425–435.

Liski, M. and Montero, J.-P. (2006), Forward Trading and Collusion in Oligopoly, *Journal of Economic Theory 131*, 212–230.

Motta, M. (2004), *Competition Policy: Theory and Practice*, Cambridge University Press, Cambridge.

Oren, S. (1997), Economic Inefficiency of Passive Transmission Rights in Congested Electricity Systems with Competitive Generation, *Energy Journal 18*, 63–83.

Ropenus, S. and Jensen, S. G. (2009), Support Schemes and Vertical Integration – Who Skims the Cream?, *Energy Policy 37*, 1104–1115.

Salop, S. C. and Scheffman, D. T. (1983), Raising Rivals' Costs, *American Economic Review 73*(2), 267–271.

Tamás, M. M., Shrestha, S. O. B., and Zhou, H. (2010), Feed-in Tariff and Tradable Green Certificates in Oligopoly, *Energy Policy 38*, 4040–4047.

Unger, T. and Ahlgren, E. O. (2005), Impacts of a Common Green Certificate Market on Electricity and CO_2-Emission Markets in the Nordic Countries, *Energy Policy 33*, 2152–2163.

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