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Some implications of design element choice when combining a green quota with a system of feed-in tariffs

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Abstract

Concerns about carbon emissions from fossil fuel-based electricity generation have led to interest in the promotion of "renewable energy." Around the world, many countries now employ "renewable portfolio standards" or "green quotas," which stipulate a minimum percentage of total electricity generation that must be derived from renewable sources. Among the many support mechanisms, Feed-In Tariffs (FITs) — which provide direct technology-specific subsidies for generation from renewable sources — are widely believed to be the most effective. In this paper, we study an electricity market operated under a mandated green quota combined with a system of differentiated FITs financed by an end-user tax on electricity. We provide a full characterization of the set of FIT equilibria and demonstrate that the FIT subsidies and the green quota cannot be employed simultaneously as exogenously specified policy instruments. We also examine the implications of this design element restriction on an important policy objective — investor security/risk reduction. We show that employing the FIT subsidies as the exogenously specified policy instruments when attempting to enforce the green quota is likely to lead to greater investor security than the alternative of employing the level of the green quota and the end-user tax as the exogenously specified policy instruments.

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1. Introduction

Around the world, electricity generation is a major source of carbon emissions. Many nations have begun employing policy instruments capable of stimulating and supporting deployment of renewable (“green”) energy sources (RES) with a primary objective of lowering greenhouse gas (GHG) emissions (Tsao *et al*., 2011; Nielsen and Jeppesen, 2003; Currier, 2014). In addition to conferring environmental benefits, such measures are believed to contribute to energy security by permitting renewable producers to compete with conventional energy technologies (fossil fuel, or “black,” technologies) (Held *et al*., 2006). As an example of such an initiative, the European Union Climate and Energy Package of 2007 calls for a 20% reduction in GHG emissions, increasing the share of energy obtained from RES to 20%, and a 20% improvement in energy efficiency by the year 2020 (the “20-20-20 plan”).

Feed-In Tariffs (FITs) are known to be an effective method of stimulating the development and deployment of RES (Couture and Gagnon, 2010). A system of FITs operates by offering subsidies (or guaranteed prices) for fixed periods of time for electricity generated via RES. Under such a scheme, network operators are required to connect electricity generated from RES. FITs are offered to green producers for every kWh of electricity produced, thereby compensating for the higher costs of the renewable generation. FITs are widely applied around the world, including 19 countries in the European Union (del Río and Cerdá, 2014).

While the structural details of FIT schemes vary widely across applications, FIT design elements broadly consist of possible linkages to other policy targets (e.g., renewable portfolio standards (RPS)), technology eligibility requirements, tariff rate setting and differentiation, tariff duration and “degression,” and funding/cost recovery methods. There is a general consensus among policy analysts that FIT subsidies should in general be (i) differentiated across installations (i.e., be project specific) so as to ensure a “normal” return to a wide array of RE project sizes, locations and technology types and (ii) be ratepayer funded (as opposed to taxpayer/ government funded) so as to ensure cost recovery and reduce the risk that funding be withdrawn etc[1]. Policy considerations typically involve investor confidence (i.e., risk reduction), energy access (particularly in developing countries), grid stability, policy costs, energy price stability, energy portfolio diversification, administrative complexity, and potential economic development. (For details, see Couture *et al*. 2010; del Río, 2012; and UNEP, 2012.) The choice of design elements will in general have implications for the attainment of policy goals.

There are several notable recent contributions to the literature on the implications of instrument and FIT design element choice for the attainment of environmental/energy goals. del Río (2012) studies the manner in which various FIT design elements affect dynamic efficiency (i.e., achievement of technological diversity, stimulating learning, innovation, and private R&D investment, etc.) of FIT regimes. In addition, del Río (2010) examines the impact of policy instrument and design element choice on the interaction between energy efficiency and renewable energy (RE) promotion via FITs. Most recently, del Río and Cerdá (2014) study “cost effectiveness” (minimization of consumer costs versus minimization of generation costs) and policy instrument choice in the development of RES. Other contributions include Mendonça *et al*. (2010) and Ragwitz *et al*. (2007).

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[1] Couture *et al.* (2010) note that in Spain and Germany more than 50 distinct FIT subsidy levels are employed.

As noted by del Río (2012), reduced investor risk can be expected to have positive (dynamic) impacts on the promotion of technological diversity; the development of immature RE technologies; learning effects; and "research, development, demonstration, and deployment." Thus, an important policy objective should be to reduce the risk associated with RE investments by ensuring *efficient* renewable producers' revenue sufficient to recover project costs and to allow for a "reasonable" rate of return on the investment.

In this paper, we consider a differentiated FIT scheme that is linked with a mandated "green quota"/ RPS and funded by an end-user tax on electricity.[2, 3] We first characterize the FIT equilibrium and analyze its formal mathematical structure so as to determine the number of policy instruments that are available to the policy maker. We show in particular that the FIT subsidies and the level of the RE target cannot be simultaneously employed as exogenously specified policy instruments without perverse consequences. We next establish several simple propositions regarding the properties of a FIT equilibrium. Finally, we provide a simple numerical example and examine some comparative statics properties of (i) using the end-user tax and the green quota as the exogenously specified policy instruments, and (ii) using the FIT subsidies as the exogenously specified policy instruments. While the merits of any policy can only be assessed in terms of its distribution of benefits and costs to all interest groups, our results suggest that employing the FIT subsidies as exogenously specified policy instruments to achieve a RE target will likely lead to more predictable and stable profits for green producers and hence less uncertainty and risk for investors. Our results thus imply a FIT implementation method that can in principle avoid perverse consequences and improve prospects for rapid deployment of efficiently operated RE installations and attainment of an ultimate RE target.

2. The Model

We consider a closed competitive electricity market consisting of a single black (fossil fuel) producer and n green (renewable) producers. We assume that black electricity y is produced under constant returns to scale at constant marginal and average cost c_y.[4] Green firm i produces output x_i with cost function $c_i(x_i)$ satisfying $c_i'(x_i) > 0$ and $c_i''(x_i) > 0$, $i = 1, \ldots, n$. Emissions e are proportional to black production: $e = \theta y$. Damages from emissions are $D(e)$ with $D' > 0$ and $D'' \geq 0$. There are no emissions from green production.

Total electricity is $q = y + \sum_{i=1}^{n} x_i$. Consumers are price takers, and demand is formed by the maximization of consumer surplus $V = U(q) - pq$ where U denotes total utility and p denotes the end-user price of electricity. We assume $U' > 0$ and $U'' < 0$. Inverse demand $p = D(q)$ and therefore satisfies $D'(q) < 0$.

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[2] Mendonça *et al*. (2010) argue that rate payer (end-user) financed FITs lead to lower investor risk than government financed FITs.

[3] FITs have been used to achieve RPS objectives in the U.S., Germany, India, and the Philippines, among others (UNEP, 2012).

[4] In our model, output levels should be interpreted as generating capacity (Tamas *et al.* 2010). For evidence that black electricity generation is subject to constant returns to scale, see Christensen and Green (1976) and Josko and Schmalensee (1983).

The green quota in the electricity market requires the share α of total production to be provided by green production: $\sum_{i=1}^{n} x_i \geq \alpha q, 0 < \alpha < 1$. We assume throughout that as a design element, this constraint is mandated to hold as an exact equality. The green quota is implemented via a system of differentiated FITs financed by an end-user tax *t* on electricity. The vector of FITs is $(s_1, \ldots, s_n)$. Black firm profits are $\pi_y = (p - t - c_y)y$, and green firm profits are $\pi_i = (p - t + s_i)x_i - c_i(x_i)$, $i = 1, \ldots, n$. All firms are price-taking profit maximizers. Using "*" to denote equilibrium values, equilibrium under the FIT system satisfies:

$$p\left(y^* + \sum_{i=1}^{n} x_i\right) = p^* . \tag{1}$$

$$p^* - t^* = c_y, \tag{2}$$

$$p^* - t^* + s_i^* = c_i'\left(x_i^*\right), i = 1, ..., n , \tag{3}$$

$$\sum_{i=1}^{n} x_i^* = \alpha^*\left(y^* + \sum_{i=1}^{n} x_i^*\right), \tag{4}$$

$$\sum_{i=1}^{n} s_i^* x_i^* = t^*\left(y^* + \sum_{i=1}^{n} x_i^*\right). \tag{5}$$

Equations (2) and (3) are the profit maximization conditions. It should be noted that the cost efficiency (equimarginal) condition $c_1'(x_1) = ... = c_n'(x_n)$ can only be achieved with a uniform (i.e., technology neutral) subsidy. However, with non-identical green producers, a uniform subsidy sufficient to permit the highest cost firm to earn a normal return could lead to unacceptably high rents for lower cost producers.[5] Equations (4) and (5) are the green quota and budget constraint under the FIT system. Figure 1 provides an illustration of the equilibrium for the case of $n = 2$, where consumer surplus is indicated by area A and budget balance (5) ensures that area B equals the sum of areas C, D, E, and F.

3. Choice of Policy Instruments

For ease of notation, we shall henceforth omit the "*" from the equilibrium values. Now define:

$$\phi_1(y, x_1, ..., x_n, p, t, s_1, ..., s_n, \alpha) \equiv p\left(y + \sum_{i=1}^{n} x_i\right) - p ,$$

$$\phi_2(y, x_1, ..., x_n, p, t, s_1, ..., s_n, \alpha) \equiv p - t - c_y ,$$

$$\phi_3(y, x_1, ..., x_n, p, t, s_1, ..., s_n, \alpha) \equiv p - t + s_1 - c_1'(x_1),$$

$$\begin{array}{cc} \bullet & \bullet \\ \bullet & \bullet \\ \bullet & \bullet \end{array}$$

$$\phi_{n+2}(y, x_1, ..., x_n, p, t, s_1, ..., s_n, \alpha) \equiv p - t + s_n - c_n'(x_n),$$

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[5] The fact that FIT subsidies are widely differentiated in applications around the world is *prima face* evidence that policy makers are not *primarily* concerned with satisfaction of the equimarginal condition. As noted by Couture *et al.* (2010), subsidy differentiation can sometimes be in conflict with cost efficiency.

$$\phi_{n+3}(y, x_1, ..., x_n, p, t, s_1, ..., s_n, \alpha) \equiv \sum_{i=1}^{n} x_i - \alpha\left(y + \sum_{i-1}^{n} x_i\right),$$

$$\phi_{n+4}(y, x_1, ..., x_n, p, t, s_1, ..., s_n, \alpha) \equiv \sum_{i=1}^{n} s_i x_i - t\left(y + \sum_{i-1}^{n} x_i\right).$$

Observe that with $\phi = (\phi_1, ..., \phi_{n+4})$, we have a mapping $\phi : R_+^{2n+4} \to R^{n+4}$. The set of FIT equilibria is $\phi^{-1}(0)$, which we assume is non-empty. It is straightforward to show that $\phi^{-1}(0)$ has dimension $(2n + 4) - (n + 4) = n$, which is thus the number of policy instruments that the policy maker may select exogenously. Equivalently, the system of equations above is neither underdetermined nor overdetermined when the number of endogenously determined variables equals the number of equations $n + 4$. Since $n + (n + 4) = 2n + 4$, the policy maker has n "degrees of freedom," i.e., n policy variable values may be *exogenously* specified, with the remainder *endogenously* determined.

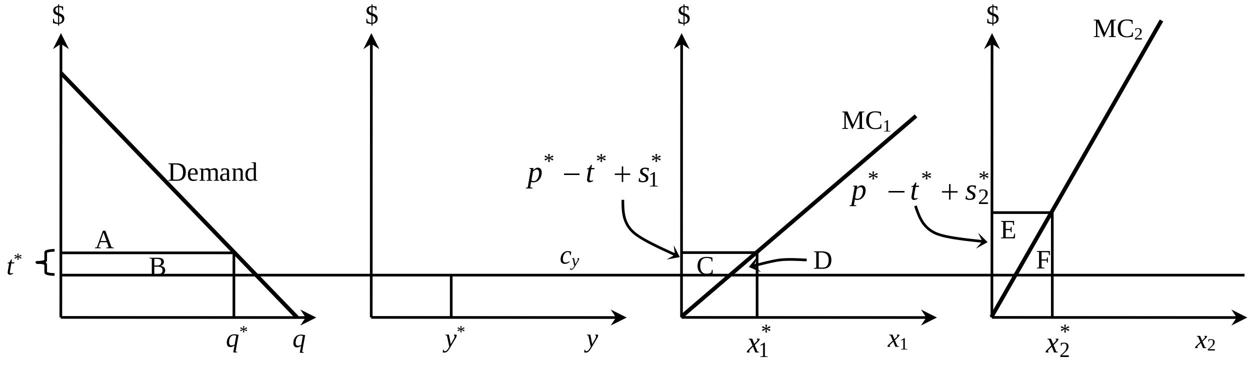

Figure 1. FIT Equilibrium

We have then the following proposition.

Proposition 1: The policy maker can always use the FITs (s_1, …, s_n) as the exogenously specified policy instruments, letting the tax rate and the green quota be determined endogenously.

The following two corollaries are immediate.

Corollary 1: The policy maker may not employ the FITs *and* the green quota as exogenously specified policy instruments simultaneously without violating (4) and/or (5).[6]

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[6] Forecasting errors could result in underfunding the FIT program. In phase 3 of the German FIT plan, there is increased emphasis on ensuring that revenue received from rate payers is sufficient to fund the FIT program (Couture *et al.,* (2010)).

The result is of obvious importance in situations where a FIT regime is linked with a green quota.

Corollary 2: If the green quota is an exogenously specified policy instrument, then at least one green firm's FIT subsidy must be endogenously determined.

In the following sections, we explore some implications of Proposition 1 and its corollaries. In view of the preceding results, we shall henceforth consider the case of two green producers ($n = 2$) and thereby consider situations where (i) s_1 and s_2 are exogenously specified policy instruments, with t and α determined endogenously; and (ii) t and α are exogenously specified policy instruments with s_1 and s_2 determined endogenously.

4. Properties of FIT Equilibria

In this and the following section, we examine some properties (including numerical comparative static properties) of FIT equilibria under cases (i) and (ii). The following simple results are central to our analysis.

Proposition 2: $\frac{\partial \pi_i}{\partial x_i} > 0$, $i = 1, 2$.

Proof: Green profits are $\pi_i = (p - t + s_i)x_i - c_i(x_i)$. Using (3), we have $\pi_i \equiv c_i'(x_i)x_i - c_i(x_i)$, implying that $\frac{d\pi_i}{dx_i} = c_i'(x_i) + x_i c_i''(x_i) - c_i'(x_i) = x_i c_i''(x_i)$. The result follows since $c_i'' > 0$, $i = 1, 2$.

Proposition 2 states that green firms' equilibrium profits increase if and only if output is expanded.

Case (i): $s_1$and s_2 are exogenously specified policy instruments with α and t endogenously determined.

Proposition 3: A *ceteris paribus* increase in s_i will increase green firm i's profit π_i, $i = 1, 2$.

Proof: Under this scenario, p and t will be endogenously determined with $p - t = c_y$. Thus (3) implies $c_y + s_i \equiv c_i'(x_i)$, $i = 1, 2$. Implicit differentiation yields $1 = c_i'' \frac{dx_i}{ds_i}$, implying $dx_i / ds_i > 0$. Thus, an increase in s_i raises firm i's production. The result then follows from Proposition 2.

Proposition 3 states that promotion of renewable production in the sense of increasing any green firm's subsidy must enhance profitability of that firm.

Case (ii): α and t are exogenously specified policy instruments with s_1 and s_2 endogenously determined.

Proposition 4: A *ceteris paribus* increase in either α or t must reduce the profits of some green producer.

Proof: Considering first the case of an increase in green quota α, assume that an increase in α reduces black output y. Since $p(y + x_1, x_2) = t + c_y$ = constant and y falls, some x_i (without loss of generality, say x_1) must increase, which can happen only if s_1 increases. Since $s_1x_1 + s_2x_2 = t(y + x_1 + x_2)$ = constant and s_1x_1 increased, s_2x_2 must decrease, which implies x_2 decreases. By Proposition 2, π_2 must decrease.

For the case of an increase in t, observe that an increase in t must increase the end-user price p, which means total production $y + x_1 + x_2$ must fall. Since $x_1 + x_2 = \alpha(y + x_1 + x_2)$, total green production must fall, implying some x_i (without loss of generality, say x_1) must fall. By Proposition 2, π_1 must fall.

Proposition 4 states that promotion of renewable production, in the sense of increasing the green quota or the end-use tax that finances it, must reduce the profits of some green producer. It is important to note that the notion of a *ceteris paribus* increase in α or t is only meaningful in the case of *differentiated* subsidies. Indeed, under a uniform subsidy s, the policy maker has one degree of freedom and $t/\alpha = s$. Therefore, if (for example) α is increased, endogenous adjustments in t and s must occur. With a uniform subsidy, an increase in α will increase the profits of all green producers.

It is also important to observe the possibility of multiple equilibria in case (ii) due to the fact that subsidies are differentiated. This can be seen by considering the case of symmetric green producer variable costs $c_1(x_1) = c_2(x_2)$ in which case, due to the budget balance equation (5) there exist two pairs of equilibrium subsidies of the form $(s_1, s_2) = (\mu, \nu)$ and $(s_1, s_2) = (\nu, \mu)$. Multiplicity of equilibria holds (generically) for the nonsymmetric cost case by a continuity argument.

5. An Example

In this section, we present a numerical example that yields additional insights. Assume consumer utility $U(q) = Aq - \frac{q^2}{2}$, $A > 0$, where $q = y + x_1 + x_2$. Black output is produced under constant marginal and average cost $c_y > 0$. Furthermore, green output is produced with cost functions $c_1(x_1) = c_1x_1^2$ and $c_2(x_2) = c_2x_2^2$, $c_1, c_2 > 0$. Let the parameter values be $A = 100$, $c_y = 15$, $c_1 = ½$, and $c_2 = 3/5$.

Suppose that the initial FIT equilibrium is $s_1 = 10.33$, $s_2 = 17.69$, $y = 22.53$, $x_1 = 25.33$, $x_2 = 27.24$, $p = 24.90$, $t = 9.90$, and $\alpha = .70$. Note that (1) − (5) are satisfied.[7]

Assume now that the policy maker wishes to increase the green quota to $\alpha = .72$. Employing α and t as the exogenously specified policy instruments with $\alpha = .72$ and $t = 10.35$, the new FIT

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[7] Nothing is assumed here about the historical forces/policy instrument choice that brought this equilibrium about other than at any point in time only two of the policy variables could have been exogenously specified.

equilibrium is $s_1 = 15.51$, $s_2 = 12.89$, $y = 20.90$, $x_1 = 30.51$, $x_2 = 23.24$, $y = 20.90$ and $p = 25.35$. Observe that by Proposition 3, π_1 must increase and π_2 must decrease relative to their values at the initial equilibrium.[8]

Alternatively, again suppose that the policy maker wishes to increase α to .72 but employs the FIT subsidies s_1 and s_2 as the exogenously specified policy instruments. Increasing the subsidies to $s_1 = 10.88$ and $s_2 = 18.25$, the new FIT equilibrium is $y = 20.83$, $x_1 = 25.88$, $x_2 = 27.71$, $p = 25.58$, $t = 10.58$, and $\alpha = .72$. Since both subsidies are higher than their initial values, Proposition 3 implies that both π_1 and π_2 must exceed their initial values.

In the following section, we discuss some preliminary policy implications of the results contained in Sections 3 through 5.

6. Policy Implications and Discussion

It is well known that electricity generation is a major source of carbon emissions around the world. Substitution of renewable generating capacity (geothermal, biomass, wind-powered turbines, etc.) for fossil-fuel generating capacity can substantially reduce these emissions. It is clear that the design and implementation of renewable support policies such as FITs represents an important and formidable policy challenge.

One important policy design element involves the possibility of linking a system of differentiated FITs to other renewable support mechanisms such as a green quota/RPS. Moreover, while a number of welfare/policy objectives can be and are pursued in energy markets around the world, investor confidence and security are fundamental prerequisites for successful RE deployment. Couture *et al.* (2010) argue that combining a system of FITs with a green quota (including formal compliance requirements and penalties) can enhance investor confidence by providing additional evidence of governmental commitment to RE development, etc.

We have shown that when a system of differentiated FITs (financed by an end-user tax) is combined with a binding green quota, an additional design element emerges with respect to the choice of exogenously specified policy instruments since the green quota and the n-FIT subsidies *cannot* be employed simultaneously as exogenously specified policy instruments. While a variety of combinations may be considered in general, we have considered two possibilities: (i) employing the end-user tax and the green quota as the exogenously specified policy instruments while allowing the FIT subsidies to be endogenously determined; and (ii) employing the FIT subsidies as the exogenously specified policy instruments while allowing the end-user tax and green quota to be endogenously determined.[9] With the green quota and the end-user tax as policy instruments, we have shown that relative to the status quo, *ceteris paribus* increases in either the tax or the green quota will create winners and losers in the sense of increasing the profits of at

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[8] When $\alpha = .7$ and $t = 9.90$, there also exists a second FIT equilibrium: $s_1 = 17.02$, $s_2 = 9.66$, $y = 22.53$, $x_1 = 32.02$, $x_2 = 20.55$, and $p = 24.9$. If α and t are the exogenously specified policy instruments and are increased to $\alpha = .72$ and $t = 10.35$, then the equilibrium values of s_1 and x_1 fall and the equilibrium values of s_2 and x_2 increase, implying that π_1 falls and π_2 increases. Total green production is constant across equilibria ($x_1 + x_2 = 52.57$) and the equilibria differ only in the manner in which green profits are distributed across producers.

[9] Another possibility is that of employing the green quota and $n - 1$ of the FIT subsidies as exogenously specified policy variables, letting the end-user tax and the nth subsidy be endogenously determined. Alternatively, a "combination" policy that operates by linking the end-user tax, FIT subsidies, and green quota could be investigated.

least one green producer and decreasing the profits of at least one other. Moreover, as our example illustrates, the same result can occur when the tax rate and the green quota are increased *simultaneously*. In addition, the problem is further complicated by the fact that within the context of our example, it is easy to specify (α, t) pairs for which no equilibria exist.

Alternatively, we have shown that when the FIT subsidies are the exogenously specified policy instruments (and the end-user tax and green quota adjust endogenously), each green producer's profit is increased if and only if that producer's FIT subsidy is increased. Therefore, stimulating RE deployment via subsidy increases will have a known and certain effect on green producers' profits, thus enhancing investor confidence. Our results suggest that rather than initially mandating a binding green quota, the policy maker should systematically increase the individual subsidies from the status quo (allowing the tax and the green quota to be determined endogenously) until the desired green quota is ultimately satisfied, as in our example.[10]

Fundamentally, our analysis demonstrates that (i) in order to avoid perverse consequences, the policy maker must exercise caution with respect to the number of *exogenously specified* policy instruments employed; and (ii) the choice of these policy instruments may have implications with respect to the attainment of policy objectives. While we emphasized investor security/green producer viability, it is important to point out that this is but one of many (potentially conflicting) policy objectives and it is for this reason that our results must be regarded as preliminary.[11] Subsequent research should examine the impacts of exogenously specified policy instrument choice on other policy objectives. More generally, the formulation of a welfare function embodying the relevant considerations and "weights" is itself a formidable challenge. The standard unweighted sum of consumer and producer surplus net of environmental damages is $W = V(q) + \pi_y + \sum_{i=1}^{n} \pi_i - D(e)$ where π_y denotes black firm profits and $q = y + \sum_{i=1}^{n} x_i$. When (1) − (5) are satisfied, this may be alternatively expressed as $W = U\left(y + \sum_{i=1}^{n} x_i \right) - c_y y - \sum_{i=1}^{n} c_i\left(x_i\right) - D(e)$. With the n FIT subsidies as the exogenously specified policy instruments, the solution to (1) − (5) may be expressed as $y = y(s)$, $x_i = x_i(s)$, $i = 1, \ldots, n$, $e = \theta y(s)$ where $s = (s_1, \ldots, s_n)$, in which case $W = W(s)$. If W subsumes all policy objectives, the policy maker could in principle attempt to determine the welfare maximizing FIT subsidy vector s. If one or more green producers earn deficits in this situation (due to fixed costs), the subsidies could be systematically adjusted upward (thereby increasing profits) until "acceptable" levels of profit are achieved as a second-best solution.

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[10] As the FIT subsidies are increased, green production displaces black production. If there exist subsidies sufficiently high such that all black production is displaced by green production, implying that $\alpha = 1$, by continuity, there must exist FIT subsidies for which the equilibrium value of the green quota is equal to *any* value of $\alpha \leq 1$.

[11] As an illustration, in our example when the subsidies are increased so as to achieve the renewables target of $\alpha = .72$, the end-user price of electricity increases from 24.90 to 25.58. del Río (2012) notes the importance of balancing the desire for high investor confidence with low consumer prices.

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