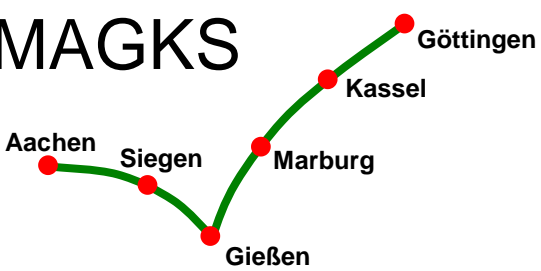


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# Feed-in-Tariffs Financed by Energy Taxes: When do They Lower Consumer Prices?

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## **1. Introduction**

The share of renewable energies in the electricity sector ('green' electricity production) relative to overall electricity supply has been growing steadily over the last years in most industrialized countries. This expansion was due to economic support either by subsidies or quota requirements for green energy. Without such support, green electricity would not be competitive to electricity supply from conventional production capacities ("black" electricity production) – e.g. coal and gas fired or nuclear power plants. In this paper, we study the effects of the two most prominent forms of economic support: surcharge-financed guaranteed Feed-in Tariffs (sfgFIT) that are most common in European, and proportional quotas which are implemented in several U.S. American jurisdictions.

Under the sfgFIT system, electricity from renewable sources is guaranteed a minimum price (Feed-in Tariff) which is financed by a constant surcharge on the market price of all electricity sold to consumers of electricity. Priority for green electricity in grid access ensures the regulation's effectiveness. Under the proportional quota system, producers of black electricity have to ensure that the production of black energy is matched by the production of green energy in a fixed ratio. Enforcement is usually secured by a system in which black energy producers have to buy a corresponding number of tradable certificates of green energy production.

In analyzing the price effects of both the sfgFIT and the proportional quota system, the interaction of two countervailing effects needs to be considered. The first one is the pass-through of the constant surcharge and the costs of the certificates, respectively. The second is the 'Merit Order' effect, which describes the reduction in marginal costs of black energy production when green energy crowds out the most expensive sources of black energy. As we will show, the relative strength of the two effects not only depends on the type of economic support for green energy, but also on the structure of the market for black energy described by

the Herfindahl-Hirschmann-Index. We neglect emission trading in our model not to obfuscate the interaction of market concentration and the price effects green energy promotion.

Existing publications on the effects of economic support for renewable energies either focus on other market-based instruments than sfgFIT or neglect the relevance of the market structure. Fischer & Newell (2008) and Fischer (2010), who start from the insight that all market-based promotion policies can be expressed by a combination of taxes and subsidies, focus on promotion strategies as they are applied on US-American markets. They find that for Bertrand-structured competitive markets the price effects of such policies depends on relative size of marginal costs of green and black electricity production, a result which also follows from our model (Section 6). Drawing on the same framework, Fischer & Peronas (2010) stress that different instruments in action need to be coordinated. In a Cournot oligopoly model, Tamás et al. (2010) compare the proportional quota system to Feed-in Premiums financed from general taxes as the Danish law provides for. It is obvious, that such a per-unit subsidy can only lead to declining retail prices.

Empirical studies of the effect of sfgFIT and quota systems are ambiguous and neglect the interaction with market concentration which is at the center of our argument. Traber & Kemfert (2009) see a positive effect of the German sfgFIT on the domestic electricity price, but a consequential reduction of prices of emission permits both in Germany and abroad. Frondel et al. (2009) and Lechtenböhrer & Samadi (2010) derive similar results. Rathmann (2007) and Sensfuß & Ragwitz (2007) show that the reverse may be true for certain parameters. Sensfuß & Ragwitz (2007) argue, however, that the merit order effect fails to decrease consumer prices when market power of black energy producers is large, a claim which we show to contradict microeconomic theory.

In the following section, we develop a model of a market with black and green electricity in which green electricity is supported by an sfgFIT. The following four sections study the effects of the sfgFIT on retail prices of electricity for different market structures. Section 7 compares the effects of sfgFIT to support by a proportional quota system. Section 8 concludes.

## **2. The Model**

We consider a wholesale and a retail market. On the wholesale market supply is given by production. Production of electricity may stem from black (b) or from green (g) sources. Let

there be  $n$  producers of black electricity with production costs  $c_i(b_i)$  with strictly positive first and second derivatives  $c'_i(b_i) > 0$  and  $c''_i(b_i) > 0$  for all  $i \in \{1, 2, \dots, n\}$ . Overall production of black energy is  $b = \sum_{i=1}^n b_i$ . Green electricity is produced by a large number of small producers with minimal marginal costs of aggregate production given by  $k'(g)$  where  $k'(0) > c'_i(0) \forall i$  and  $k''(g) > 0$ . In slight abuse of notation, we write  $g(k')$  as the inverse of  $k'(g)$ .

Demand on the wholesale market is given by the amount of energy purchased by competitive retailers at the wholesale market price  $p_w$ . For simplicity of the model, retailers incur no costs from trade, transportation or the like, but sell electricity on the retail market at the price they pay on the wholesale market plus the surcharge  $\sigma$  they possibly have to pay to finance the guaranteed FIT for green electricity. Hence the retail price  $p_r$  is equal to  $p_w + \sigma$ . Total surcharges cover the difference between the guaranteed FIT  $p_o$  and the wholesale price for all green electricity produced:  $(b + g)\sigma = \max(0, p_o - p_w)g$ . Finally, demand on the retail market is given by an inverse demand function for electricity  $p_r^d(e)$  with a negative first derivative  $p_r^{d'}(e)$ . Black and green electricity are perfect substitutes:  $e = b + g$ . Both markets are in equilibrium when  $p_w + \sigma = p_r = p_r^d(e)$ , which after inserting  $\sigma$  implies:

$$p_w = p_r^d(e) - \max(0, p_o - p_r^d(e))g/b \quad (1)$$

With respect to the supply of black electricity, we consider four different market structures on the wholesale market: perfect competition with an endogenous large number of homogeneous producers, Bertrand competition in an oligopoly with a given number of producers, Cournot competition in an oligopoly with a given number of producers, and monopoly.

### 3. Perfect competition

Perfect competition among a large number of homogeneous black energy producers may be considered as an extreme case with an unambiguous result. All producers supply at their (homogeneous) average cost minimum  $c_{i,\min}^\emptyset = \min_{b_i} (c_i(b_i)/b_i)$ . Should the market price be higher, more firms enter; should it be lower, firms leave the market. Thus the equilibrium market price on the wholesale market is  $p_w^P = c_{i,\min}^\emptyset$ , where the superscript P marks

equilibrium values for perfect competition on the wholesale market. For the sake of realism, we assume that the average cost minimum of producers of green energy is larger than  $c_{i,\min}^\emptyset$  so that there is no supply of green electricity without a guaranteed FIT ( $g^P = 0$ ).

Without a guaranteed FIT and hence no surcharge ( $p_o = \sigma = 0$ ), market equilibrium is given by the prices  $p_w^P = p_r^P = c_{i,\min}^\emptyset$  and the equilibrium quantity of black electricity  $b^P$  is determined by  $c_{i,\min}^\emptyset = p_r^d(b^P)$ . If government guaranteed a FIT  $p_o$  at or above the minimum of average costs of production of green electricity for all quantities of green electricity, the amount of supply of green electricity would be undefined, respectively infinite. We therefore assume for the perfect competition case that government guarantees a FIT at or above the minimum of average costs of production of green electricity only for a given quantity  $g_o$ . Hence  $\hat{g}^P = g_o$ , where the hat denotes here and in what follows equilibrium values with the sfgFIT. Assuming  $p_o > p_r^d(g_o)$  equation (1) implies  $c_{i,\min}^\emptyset = p_w = p_r^d(b + g_o) - (p_o - p_r^d(b + g_o))g_o/b$  which is equivalent to:

$$\hat{p}_r^P = p_r^d(\hat{b}^P + g_o) = (c_{i,\min}^\emptyset \hat{b}^P + p_o g_o) / (\hat{b}^P + g_o) > c_{i,\min}^\emptyset \quad (2)$$

where the inequality follows from the fact that the penultimate term is a weighted average of  $c_{i,\min}^\emptyset$  and  $p_o > c_{i,\min}^\emptyset$ . We thus get:

**Result 1:** Under perfect competition among an endogenous large number of homogeneous black energy producers the introduction of a sfgFIT increases the retail price of electricity.

#### 4. Monopoly

Turning to the other extreme, the monopolist supplier of black electricity, allows us to clarify the intuition of the following results. Assuming for simplicity that without effective FIT, no green energy is supplied on the market ( $e = b$ ), the monopolist's profits are

$$\Pi_m = p_r^d(b)b - c_m(b) = p_r^d(e)e - c_m(e) \quad (3)$$

With a guaranteed surcharge-financed FIT, due to equation (1) the monopolist's profits become

$$\hat{\Pi}_m = p_r^d(e) b - c_m(b) - (p_o - p_r^d(e)) g(p_o) = p_r^d(e) e - c_m(e - g(p_o)) - p_o g(p_o). \quad (4)$$

The difference between the two expressions for profits is thus a smaller term in the argument of the cost function and additional costs which are fixed from the monopolist's point of view ( $p_o g(p_o)$ ).

Taking derivatives of both profit terms yields:

$$\frac{d\Pi_m}{db} = p_r^d(e) \left( 1 - \frac{1}{\varepsilon_{e,p}} \right) - c'_m(e) \quad (5)$$

and

$$\frac{d\hat{\Pi}_m}{db} = p_r^d(e) \left( 1 - \frac{1}{\varepsilon_{e,p}} \right) - c'_m(e - g(p_o)), \quad (6)$$

where  $\varepsilon_{e,p} = -\frac{p_r^d(e)}{e} \bigg/ \frac{dp_r^d(e)}{de}$  is the price elasticity of demand for electricity. Setting  $d\Pi_m/db = 0$  yields  $e^M$  and  $p^M = p_r^d(e^M)$ . Inserting  $e^M$  into equation (6) yields  $d\hat{\Pi}_m/db|_{e=e^M} = c'_m(e^M) - c'_m(e^M - g(p_o)) > 0$  due to  $c''_m(b_m) > 0$ . The monopolist will thus choose  $\hat{b}^M$  large enough to get  $\hat{e}^M = \hat{b}^M + g(p_o) > e^M$ . Obviously, this implies  $\hat{p}_r^M = p_r^d(\hat{e}^M) < p_r^M = p_r^d(e^M)$ . We hence get:

**Result 2:** When black electricity is produced by a monopolist the introduction of a sfgFIT lowers the retail price of electricity.

The intuition for this result is that the monopolist's fixed costs increase, but the marginal costs decline as a consequence of the introduction of the FIT. The sfgFIT system is tantamount to forcing the monopolist to buy a certain amount of green electricity at a given price and then allowing the monopolist to decide on the total quantity of electricity to be sold. Obviously, the monopolist's decision does not depend on the fixed costs he must incur for the green electricity, but only on the marginal costs of producing additional electricity. His profits will decline when the sfgFIT is introduced or increased.

## 5. Cournot Competition

We now turn to the Cournot-oligopoly case. Here, due to equation (1), profits of black-electricity producers are given by:

$$\Pi_i = p_r^d(e) b_i - c_i(b_i) - \max(0, p_o - p_r^d(e)) g \frac{b_i}{b} \quad (7)$$

Optimization without FIT, and thus without any production of green electricity, requires

$$0 = \frac{\partial \Pi_i}{\partial b_i} = p_r^d(e) + \frac{dp_r^d(e)}{de} b_i - c'_i(b_i) = p_r^d(e) \left( 1 - \frac{1}{\varepsilon_{e,p}} s_i \right) - c'_i(s_i e), \quad (8)$$

and with the guaranteed surcharge-financed FIT

$$\begin{aligned} 0 &= \frac{\partial \hat{\Pi}_i}{\partial b_i} = p_r^d(e) + \frac{dp_r^d(e)}{de} \left( 1 + \frac{g}{b} \right) b_i - c'_i(b_i) - (p_o - p_r^d(e)) \frac{g}{b} \left( 1 - \frac{b_i}{b} \right) \\ &= p_r^d(e) \left( 1 - \frac{1}{\varepsilon_{e,p}} s_i \right) - c'_i(s_i(e - g(p_o))) - (p_o - p_r^d(e)) \frac{g(p_o)}{b} (1 - s_i), \end{aligned} \quad (9)$$

where  $s_i$  is the market share of producer  $i$ . The derivatives in equations (8) and (9) differ by the argument of the marginal cost terms and by the last term in equations (9), which reflects the per-unit surcharge on electricity ( $(p_o - p_r^d(e))g(p_o)/b$ ) and the reduction of this surcharge resulting from an increase in producer  $i$ 's quantity ( $s_i(p_o - p_r^d(e))g(p_o)/b$ ).

Solving equations (8) yields equilibrium values for total electricity supply  $e^0$  and black-electricity producers' market shares  $s_i^0$  in the absence of any effective FIT. Inserting  $e^0$  into the retail market demand function returns the corresponding retail market equilibrium price:  $p_r^0 = p_r^d(e^0)$ . We first concentrate on the case of  $n$  symmetric black-electricity producers ( $c_i(\tilde{b}) = c(\tilde{b}) \forall i \forall \tilde{b}$ ). Symmetry implies  $s_i = 1/n \forall i$  independently of the level of  $e$ .

Inserting  $e^0$  into equation (9) then yields

$$\left. \frac{\partial \hat{\Pi}_i}{\partial b_i} \right|_{e=e^0} = c'_i\left(\frac{e^0}{n}\right) - c'_i\left(\frac{e^0 - g(p_o)}{n}\right) - (p_o - p_r^d(e^0)) \frac{g(p_o)}{b} \frac{n-1}{n}, \quad (10)$$

where both the difference between the marginal cost terms and the surcharge term are strictly positive. The latter is more likely to supersede the former, the larger the number  $n$  of oligopolists. If it does, we have  $\left. \frac{\partial \hat{\Pi}_i}{\partial b_i} \right|_{e=e^0} < 0$  and thus all oligopolists will reduce their quantities below  $(e^0 - g(p_o))/n$ , so that  $\hat{e}^0 < e^0$  and thus  $\hat{p}_r^0 = p_r^d(\hat{e}^0) > p_r^0 = p_r^d(e^0)$ . If the difference between the marginal cost supersedes the surcharge term, the quantity of electricity will increase and the price decrease.

We get a similar result, when the oligopolists are asymmetric. We compare the sums of the derivatives in equations (8) and (9) weighted by the oligopolists market shares:

$$0 = \sum_{i=1}^n s_i \frac{\partial \Pi_i}{\partial b_i} = p_r^d(e) \left( 1 - \frac{1}{\varepsilon_{e,p}} \sum_{i=1}^n s_i^2 \right) - \sum_{i=1}^n s_i c'_i(s_i e) = p_r^d(e) \left( 1 - \frac{1}{\varepsilon_{e,p}} H_b \right) - \sum_{i=1}^n s_i c'_i(s_i e) \quad (11)$$

and

$$0 = \sum_{i=1}^n s_i \frac{\partial \hat{\Pi}_i}{\partial b_i} = p_r^d(e) \left( 1 - \frac{1}{\varepsilon_{e,p}} H_b \right) - \sum_{i=1}^n s_i c'_i(s_i (e - g(p_o))) - (p_o - p_r^d(e)) \frac{g(p_o)}{b} (1 - H_b), \quad (12)$$

where  $H_b = \sum_{i=1}^n s_i^2$  is the Herfindahl-Hirschmann-Index of the black-electricity producers.

Assuming that market shares do not change due to the introduction of the FIT for renewable energy we can rewrite the weighted sum of derivatives in equation (12) at the solution  $e^0$  of equation (11) as:

$$\sum_{i=1}^n s_i \frac{\partial \hat{\Pi}_i}{\partial b_i} \Bigg|_{e=e^0} = \sum_{i=1}^n s_i c'_i(s_i e^0) - \sum_{i=1}^n s_i c'_i(s_i (e^0 - g(p_o))) - (p_o - p_r^d(e^0)) \frac{g(p_o)}{b} (1 - H_b) \quad (13)$$

Again, both the difference between the marginal cost terms and the surcharge term are strictly positive and the entire sum is more likely to be positive the larger the Herfindahl-Hirschmann-Index of the black-electricity producers. Parallel to the argument for symmetric oligopolists, we therefore conclude:

**Result 3:** When black electricity is produced by Cournot oligopolists the introduction of a sfgFIT may lower the retail price of electricity. It is more likely to do so, the higher the concentration of the black-electricity market by the Herfindahl-Hirschmann-Index.



## 6. Bertrand Competition

It is a well known result that for homogeneous products such as electricity equilibrium behavior of Bertrand competition and perfect competition with a fixed number of price-taking producers is the limiting case of Cournot competition with  $n \rightarrow \infty$  and thus  $H_b \rightarrow 0$  (see textbooks like e.g. Gravelle&Rees, 2004: 409). It is then apparent from equations (8) and (9) that  $p_r^d(e^B) = c_i'(s_i e^B) \forall i$  and thus

$$\left. \frac{\partial \hat{\Pi}_i}{\partial b_i} \right|_{e=e^B} = c_i'(s_i e^B) - c_i'(s_i (e^B - g(p_o))) - (p_o - p_r^d(e^B)) \frac{g(p_o)}{b}, \quad (14)$$

which is positive, if  $g(p_o)/b$  is small enough and the second derivative of the cost functions  $c_i(\cdot)$  are large enough. Hence, under these conditions, we also get a positive effect of the FIT system on the overall amount of electricity produced and a negative effect on the retail price.

**Result 4:** When black electricity is produced by Bertrand oligopolists or a fixed number of price-taking producers, the introduction a sfgFIT may lower the retail price of electricity. It will do so, if the marginal costs of producing black electricity increase strongly in the relevant range and if the amount of green electricity induced by the FIT is small relative to the amount of black electricity.

## 7. Comparison of quota- and FIT-based support

To compare the surcharge-financed guaranteed FIT system to a quota system inducing the same amount of green electricity production, we refer to the setup in Fischer (2010) where for each unit of black electricity a certain number of certificates proving the production of green electricity actually sold on the retail market have to be purchased. This construction of a quota system corresponds to the actual legal situation in jurisdictions like California and other jurisdiction in the US. The central difference between the FIT system to the quota system is that under the former, the price of green electricity is fixed and the amount of production of green electricity is endogenous, while under the latter, the production quantity is given by the ratio of green to black electricity and the price necessary to allow for this quantity is endogenous and given by the marginal costs of producing this quantity.

Let  $A$  be the required ratio of green to black electricity. The wholesale price of black electricity is then given by:

$$p_w = p_r^d(e) - (p_g - p_r^d(e))A = p_r^d(b(1+A)) - (k'(bA) - p_r^d(b(1+A)))A \quad (15)$$

Inserting this into the profit function of a black-electricity producer yields:

$$\tilde{\Pi}_i = p_r^d(b(1+A))b_i - (k'(bA) - p_r^d(b(1+A)))Ab_i - c_i(b_i), \quad (16)$$

where the tilde denotes the quota system, with

$$\frac{\partial \tilde{\Pi}_i}{\partial b_i} = p_r^d(e) \left( 1 - \frac{1}{\varepsilon_{e,p}} \frac{b_i}{b} \right) - (k'(bA) - p_r^d(e))A - k''(bA)A^2b_i - c'_i(b_i) \quad (17)$$

as first derivative. For comparison with the FIT, let us assume that the quota  $A$  is chosen at the level which entails exactly the same amount of green electricity as the FIT system does with price  $p_o$ . We then have  $k'(bA) = p_o$  and thus equation (17) turns into

$$\frac{\partial \tilde{\Pi}_i}{\partial b_i} = p_r^d(e) \left( 1 - \frac{1}{\varepsilon_{e,p}} s_i \right) - (p_o - p_r^d(e)) \frac{g(p_o)}{b} - g(p_o)k''(g(p_o)) \frac{g(p_o)}{b} \frac{b_i}{b} - c'_i(b_i). \quad (18)$$

Comparing this to the derivative under the FIT system in equation (9), we see that

$$\frac{\partial \tilde{\Pi}_i}{\partial b_i} = \frac{\partial \hat{\Pi}_i}{\partial b_i} - s_i \left[ (p_o - p_r^d(e)) \frac{g(p_o)}{b} + g(p_o)k''(g(p_o)) \frac{g(p_o)}{b} \right] < \frac{\partial \hat{\Pi}_i}{\partial b_i}, \quad (19)$$

where the inequality follows from the fact that all terms in the brackets are positive. This inequality in derivatives implies that all equilibrium quantities of black electricity are smaller under the quota system than they are under the FIT system. Only when the perceived market share  $s_i$  is zero, i.e. when only price takers compete, the equilibrium quantities are the same under both systems (see Schwarz et al. 2008). Intuitively, the sfgFIT and the quota system differ in two respects, expressed by the two terms in brackets. The first term expresses that under the sfgFIT system, the oligopolist takes into account that more production means a lower surcharge for every unit, an effect which fails to exist under the quota system. The second term captures the fact that under the quota system, the oligopolist takes into account the increasing effect which his additional production has on the marginal cost of production of

green electricity (second term in brackets), an effect which does not exist under the sfgFIT system.<sup>1</sup> This allows us to state our last:

**Result 5:** The quota system induces lower quantities of black electricity and higher retail prices than the surcharge-financed guaranteed FIT system if the black-electricity market is characterized by a Cournot oligopoly or a monopoly. If this market exhibits a Bertrand oligopoly or competition among a fixed number of price-taking producers, the two systems affect the quantity of electricity consumed and the retail price of electricity in the same way.

## 8. Conclusions

This paper develops a theoretical model to highlight the bearing of market structures on retail price effects of a sfgFIT induced market entrance from green electricity. Moving from perfect competition via Bertrand and Cournot oligopoly to monopoly, we find that retail electricity prices are more likely to decline, when market concentration as measured by the HHI (from perceived market shares) is larger. In the extreme cases, the price effect is unequivocally negative (monopoly) or positive (perfect competition).

One should note, that this result only holds for a given market structure. When firms leave the market, market concentration increases and so do electricity retail prices. When running the full gamut from perfect competition to monopoly by increasing the sfgFIT and thus successively driving firms out of the market the total price effect will be positive: perfect competitors produce at the average cost minimum and the monopolist sells at a price above average costs, which have been increased by the additional costs of green energy.

We also show that in Cournot oligopoly and in monopoly markets, a required proportional quota of green energy in electricity production induces larger prices than the sfgFIT system with the same induced total amount of green electricity.

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<sup>1</sup> This second difference drives the similar result which Tamás (2010) derives for the comparison of a lump-sum-tax financed FIT and a quota system in a more restrictive model.

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