Bonus Payments for Electricity Production from Renewable Energy Sources and the Impact on the Market Participants' Capacity Choice

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Abstract

Promoting the use of renewable energy sources is a central goal of most industrialized countries. Up to today, fixed feed–in tariffs are a commonly used support scheme. However, these have major disadvantages concerning market integration. Thus, more market-conforming solutions come into focus. One of these are bonus payments. Their fundamental characteristic is an augmented market price for the production of electricity from renewable energy sources.

This paper takes a closer look at the mechanics of bonus payments in an environment of market power and negative externalities connected to conventional electricity supply. We analyze the market participants' behavior in a long-term context: Suppliers react to an augmented price by adapting their level of capacity. It is an important question whether a social optimum can be reached by means of bonus payments or whether welfare losses occur. We use a two-stage model. In the first stage, the public sector implements the bonus payment. In the second stage, the suppliers engage in Cournot competition, choosing their profit maximizing level of capacity. We find that in this setting, bonus payments can strongly increase overall welfare. However, they do not prove to be superior instruments for the promotion of renewable energy as they, like fixed feed–in tariffs, have major disadvantages compared to more market–conforming instruments.
Keywords: renewable energy, bonus payments, capacity investment

1. Introduction

Many countries implemented feed-in tariffs (FIT) to promote the use of electricity generation from renewable energy sources (RES) (cf. [7]). As market penetration of RES has been increasing strongly, this

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support scheme comes unter criticism for its lacking efficiency. As is shown in [1], the link of FIT with priority dispatch leads to a loss of welfare. There are two sources of welfare-losses. First, periods may occur in which the value of electricity, i.e. the market price, drops below the short term marginal cost of production. This becomes most apparent when prices become negative, e.g. in periods of high wind penetration and a low level of demand. In these periods the production from RES sources is inefficient.[1] Second, by priority dispatch conventional supply is pushed out of the market. This means that producers' surplus, as a part of social welfare, is crowded out. These problems arise because when fixed FIT are paid, RES suppliers are not prone to price signals any more.

Consequently, more market–conforming instruments are postulated by researchers and policy makers alike. With still no global emissions trading scheme in sight, a favoured (national) approach to promote RES are bonus payments. By this instrument, RES suppliers compete with conventional suppliers in the wholesale market but receive a bonus that is added to the market price (cf. [13] or [2]). Compared to fixed FIT, the advantage is that the RES suppliers receive a price signal, albeit a distorted one because they receive a payment of price *plus* bonus payment. In the short run, this still allows for negative prices, but performance is somewhat increased as RES supply is not completely inelastic in prices as in the case of fixed FIT.

With this paper we investigate the long–term impacts of bonus payments. Long–term means that we do not deal with aspects like load volatility, technical availability etc. but that we focus on capital investment alone.[2] We assume that there is one conventional supplier who exercises market power to some extend. Conventional production is associated with a negative externality (e.g. due to the emission of CO_2). The government implements the bonus payment to increase the RES suppliers' competitiveness. There may be multiple RES suppliers. All suppliers engage in a competition in quantities, and "‘quantity"’ corresponds to the installed level of capacity. We adress the question of how the bonus payments affects overall social welfare compared to the case without governmental intervention.

The remainder of this paper is organized as follows. In the second chapter the calculus of the suppliers' optimal capacity choice is introduced. In the third chapter the model is extended to incorporate the government which knows how the suppliers act and implements a welfare maximizing bonus payment. In the fourth chapter policy recommendations are made. The fifth chapter concludes.

2. The Supply Side

We begin with the establishment of the suppliers' optimal capacity choice calculus.[3] The setting is kept as simple as possible to bring out the main points. Assume there are two ways to produce electricity:

[1] This effect and the consequences are also discussed in [15].
[2] A brief and rather technical outline of the long-term impacts give [11]. Here, RES impacts are analyzed with respect to technical restrictions such as load volatility, (non-)storability, wind availability, and others.
[3] As capacity is chosen after the bonus payment is introduced, this step is, technically speaking, the second stage of the model.

either by conventional sources such as coal or gas, or by renewable ones like wind or biomass. The conventional supply side is represented by one big supplier, called supplier A. This is a reasonable assumption because in real world power markets, sunk costs connected to conventional supply prevent perfectly competitive markets to emerge. The renewable supply side does not face the problem of sunk costs and is assumed to consist of multiple symmetric suppliers. The ith RES supplier is called supplier i, where $i \in 1 \dots n$. RES supply has a cost disadvantage, i.e. the long term marginal costs c_i are greater than marginal costs of conventional supply, c_A. For simplicity we normalize c_A to zero. The suppliers engage in Cournot competition, with installed capacity x_A and x_i as endogenous variables. Assuming that one unit of capacity allows to produce one unit of output and that in long–run equilibrium capacities are fully utilized,[4] the market clearing price p calculates as

$$p = a - (x_A + x_i + (n-1)x_{-i}), \tag{1}$$

where x_{-i} denotes all RES suppliers except supplier i. Now suppose the RES suppliers are not paid the marktet price p but the market price plus a bonus payment m, so instead of being paid p, they receive an augmented payment $p + m$. When profits calculate as $\pi_A(x_A, x_i) = p \cdot x_A$ and $\pi_i(x_A, x_i; m) = (p + m - c_i) \cdot x_i$, the market participants' Cournot reaction functions are

$$R_A : x_A = \frac{1}{2}\left(a - x_i - (n-1)x_{-i}\right) \tag{2}$$

$$R_i : x_i = \frac{1}{2}\left(a - x_A - (n-1)x_{-i} + m - c_i\right). \tag{3}$$

These functions tell us which level of capacity each supplier chooses, taking the other's capacity level as given.[5]

Imposing symmetry (i.e. $i = -i$) we can calculate long–run equilibrium quantities as the intersection of the reaction functions:

$$x_A^N = \frac{a - nm + nc_i}{2+n} \tag{4}$$

$$x_i^N = \frac{a + 2m - 2c_i}{2+n} \tag{5}$$

where index N indicates the Nash equilibrium. When the bonus increases, each RES supplier i wants to install more capacity and thus his equilibrium level of capacity increases. As all RES suppliers expand capacity symmetrically, a part of supplier A's capacity is crowded out of the market. To investigate the effect of an increase in the bonus payment on total installed capacity, we have to multiply (5) by n and differentiate total capacity ($x = x_A^C + n \cdot x_i^C$) with respect to m. Then we have $\frac{\delta x}{\delta m} = \frac{-n}{2+n} + \frac{n \cdot 2}{2+n}$, which

4 It could be argued that this leads to a two stage game where capacity is set in the first stage and production takes place in the second stage by Bertrand competition. However, [8] have shown that, under the assumption of a certain rationing rule, this setting yields Cournot outcomes. Despite the argument of [5] that Kreps/Scheinkman's result depends strongly on the assumed rationing rule, actual power market design does not contradict Kreps/Scheinkman's results. Consequently, we restrict our analysis to the case of Cournot competition.

5 A very similar model setup, albeit with a different research focus, can be found in [3]. In their model, the bonus payment is considered to be an export tariff and the rival is not a domestic but a foreign competitor.

is positive.[6]

3. Public Sector

The public sector, or government, knows the market setting as well as the suppliers' reaction functions and wants to maximize overall welfare.[7] The welfare function is given by

$$W = \underbrace{\left[\frac{1}{2}(a-p)\cdot(x_A + n\cdot x_i) - \tau\right]}_{gross\ consumers'\ surplus} + \underbrace{[p\cdot x_A] + [n\cdot(p+m-c_i)\cdot x_i]}_{gross\ producers'\ surplus} - \overbrace{[n\cdot m\cdot x_i]}^{subsidy} + \overbrace{\tau}^{tax\ income} - \overbrace{[e\cdot x_A^2]}^{damage\ function} \quad . \tag{6}$$

The lump sum tax τ is assumed to be paid by the consumers and is needed to finance the bonus payments, but as it is "'lump sum"' it does not have any allocative effects and is just a redistribution from the consumers to the government. The second and third term show the gross producers' surplus including the bonus payment. The subsidy, $n \cdot m \cdot x_i$, represents the payments from the government to the RES producers. The latter term shows the damage function, which is assumed to be quadratic in x_A, weighted with some positive parameter e.[8]

Before we consider optimal bonus payments we can turn to the question which quantities the government would choose from a social planner point of view. This will constitute a reference case (indicating the social optimum) for later comparison. Therefore, we choose optimal quantities rather than an optimal bonus and maximize the welfare function with respect to x_A and x_i. $\frac{\partial W}{\partial x_A}$ and $\frac{\partial W}{\partial x_i}$ yields x_A^* and x_i^*, where the asterisk indicates social optimality. The welfare maximizing quantities of conventional and total RES supply are plotted in figure 1. The quantities are functions of the damage parameter e, and for some small but positive value of e, x_i^* becomes zero. This is due to the assumed cost disadvantage of renewable energy: When marginal costs are high and environmental impact is low, RES should not be used.[9]

As the social planner is not prone to market power, total capacity corresponds to that of perfect competition. Remarkably, this is true independently of the damage parameter, so no matter how high the environmental impact, overall supply remains constant. This is explained as follows: In equilibrium, two conditions have to be met. First, marginal (social) benefit of one unit of capacity of conventional *and* RES supply have to be equal. Second, the social cost of one unit of capacity of each supplier has to be equal to the social willingness to pay. Both conditions are met when $p = e * x_A^2 = c_i$. Let us assume

6 For proof of the existence and stability conditions see the appendix.

7 Following the reasoning of the previous chapter, this constitutes the first stage of the model.

8 Besides analytical advantages, compared to linear cost functions a quadratic function is a more realistic approach to actual climate change damages, cf. [14].

9 In fact, when $e \to 0$, $x_A^* \to \infty$ and $x_i^* \to -\infty$. As we want to restrict installed capacity to be positive, we have to restrict e to values where $x_i^* > 0$: $\frac{\partial W}{\partial x_A} > 0$ yields $e > \frac{c_i}{2\cdot(a-c_i)}$.

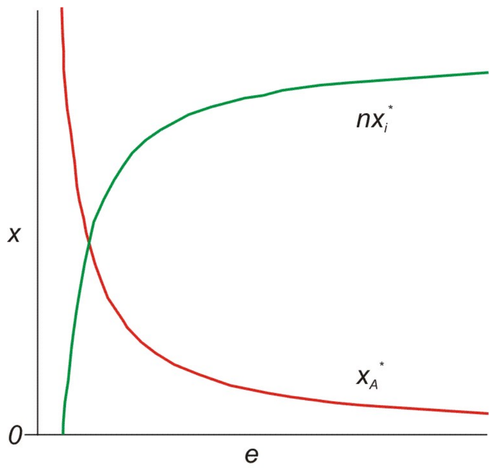

Figure 1: Welfare maximizing quantities: Social planner's case

we have reached an equilibrium. When e increases, supplier A's social costs increase and as supplier i's social costs remain constant. In order to restore equilibrium, capacities are substituted in favour of the RES supply. Total capacity thereby remains constant at the quasi–competitive level $x^* = a - c_i$.[10]

To sum up we just constituted the benchmark case of a social optimum. An efficient instrument for renewable energy promotion should achieve similar results. When this is not the case, we need to identify the source of inefficiency.

Optimal Bonus Payments

We can now turn towards optimal bonus payments: the suppliers choose their profit maximizing level of capacity on their own, following equations (4) and (5). So the government is left to influence the suppliers' capacity choice by means of the bonus payment. Substituting Nash equilibrium quantities x_A^N and x_i^N into the welfare function and differentiating with respect to m yields the welfare maximizing bonus payment $m^* = \frac{2c_i e - c_i}{2e+1} + \frac{a+2ae-4c_i}{(2e+1)\cdot n}$. These are shown in figure 2 for alternate numbers of RES suppliers. Resulting quantities are shown in figure 3.

Internalization Effect

The payment increases in e ($\frac{\partial m^*}{\partial e} > 0$), so the more damage is caused by conventional production, the higher is the support for renewable electricity production.[11] However, comparing figures 3 and 1 indicates that internalization is not perfectly achieved. This is because there is no accurate price for the emission

[10] A formal proof of this proposition can be found in the appendix.

[11] In order to avoid infeasible market results we have to restrict m^*: The capacity of both suppliers must be lower or equal than market saturation (as in equilibrium, prices should be positive and no excess capacity should exist (cf. [10]). In our case, the market is saturated when a units of electricity are produced, so $x = x_A^C + x_i^C \leq a$. Solving this inequality for m^*, we obtain that $m^* \leq a + c_i$.

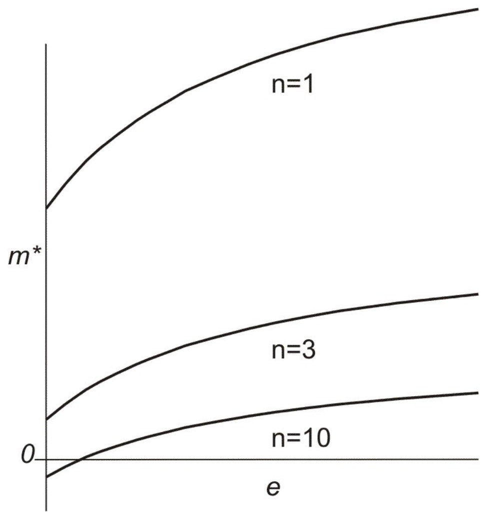

Figure 2: Optimal bonus payments

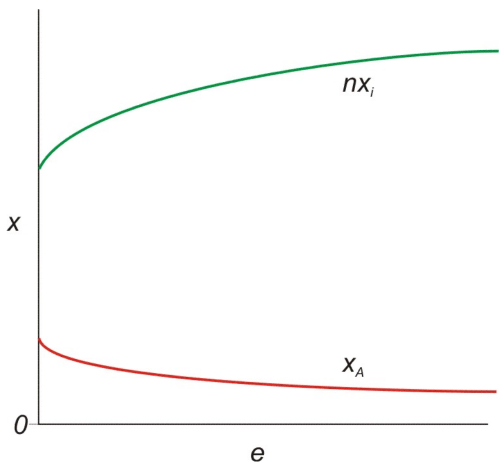

Figure 3: Optimal quantities conditional on the bonus payment

of CO_2 but a subsidy that approaches two goals at once: First, internalization. Second, the reduction of market power (see below). Thereby, the signal for CO_2–abatement is distorted.[12]

Competition Effect

Note that the intercept in figure 2 is positive. Why would the government support RES supply even in the absence of external damages? The answer is straightforward: With the bonus payment, it encourages the RES suppliers to install more capacity. And as we have seen above, overall capacity increases in m. Hence, by implementing a bonus payment the government realizes a *competition increasing effect*. Obviously, m^* decreases in n, so the higher the competition level, the lower is the demand for RES support. Interestingly, total installed RES capacity is thereby independent of the number of suppliers. When n increases, the government achieves identical levels of RES supply by adjusting the bonus payment.

One might argue that the promotion of RES supply is not a satisfying way to combat market power. However, our finding might nonetheless explain some empirical evidence: Even when there are no externalities, e.g. because there already is an emissions trading scheme like the EU ETS in place, the promotion of RES may increase welfare. Recent papers suggest that this is the case in Germany (cf. [4] or [12]). Therefore, some publications do not tell the whole truth when they state that renewable energies are so expensive that they actually *reduce* welfare (cf. [9].) Higher welfare levels are possible when the inefficiency of the use of RES is overcompensated by the competition increasing effect. By promoting RES a new competitor is introduced to the market, forcing the incumbents to lower prices (or, equivalently, quantities).[13]

Impact on overall welfare

How do bonus payments affect overall welfare in the long run? We can compare different market settings:

(a) the market result without governmental intervention ("‘market"’),

(b) the optimal bonus payment ("‘bonus"’)

(c) the social planner choosing optimal quantities ("‘social planner"’).

Figure 4 depicts overall welfare dependend on the damage parameter. Market performance in the case without bonus (a) is lowest, but increases as the number of RES suppliers increases. With bonus payment m^* (case b) overall welfare clearly exceeds the levels achieved by (a). The bonus achieves two major goals: When environmental impact e is low, it only alleviates market power. As e increases, it also (partly) internalizes the external damage. Since the government cannot control the levels of capacity perfectly

[12] Even when there is perfect competition, or $n \to \infty$, internalization is not perfect: Total quantity increases in e, given optimal bonus payments. This, however, does not correspond to the social planner's case and thus cannot be optimal.

[13] Assuming market power exists it is an interesting challenge to econometrically test whether the competition effect actually overcompensates the inefficiency.

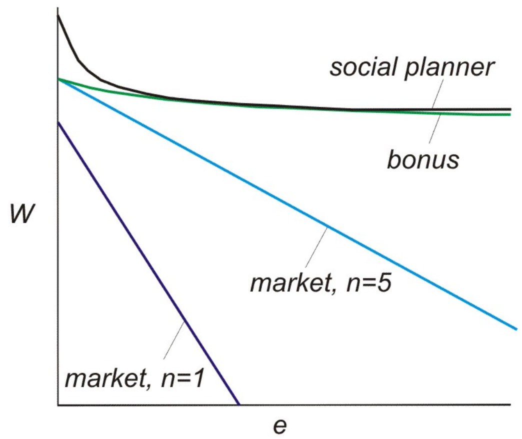

Figure 4: Market settings and Welfare

(compare figures 1 and 2), market performance is slightly worse than in the social planner–case, especially for either very low or very high levels of e. This is due to two reasons: When e is low, it would be best for the RES supplier to produce nothing. The bonus fails to achieve this as it is positive even for $e = 0$. When e is high, the subsidy increases strongly and total installed capacity expands beyond the social optimum. This indicates that bonus payments are not an efficient instrument to abate external CO_2-damages.

4. Concluding Remarks

Our model offers some insights into a long run equilibrium when externalities exist and bonus payments are implemented. Thereby, *long run* adresses only the question of capacity investment. Short term aspects like technical restriction or uncertainties in supply and demand are not taken into account. We have shown how firms invest, given the government implements a welfare maximizing bonus payment. Welfare strongly increases due to two effects: The first effect identified by our model is the internalization of external CO_2-damages. In the past, this used to be a pro argument for renewable energy promotion by fixed FIT or bonus payments, and as we have seen, internalization somewhat takes place. On the other hand, for the purpose of internalization a cap and trade system or a carbon tax certainly perform better as these instruments offer a clear price signal for the value of CO_2.

The second effect is the competition increasing effect: The bonus increases overall supply. This is in fact a big advantage of bonus payments (and, actually, fixed FIT): These instruments are very effective concerning capacity expansion and thus in reducing market power. This finding might explain some empirical evidence of increased welfare connected to renewable energy promotion. However, subsidizing basically incompetitive technologies in order to establish a new competitor may be an effective, but certainly not an efficient way to combat market power. With regulatory entities in place, the abatement of market power should be left to them.

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Appendix

Let us first proof the existence and stability of the model. Our model framework complies with the following assumptions:

- We have $n > 2$ firms producing a homogenous product, with $x_A, x_i \geq 0$.
- The market demand function is continuous and for a finite amount of production q we have $p(q) = 0$, i.e. the commodity becomes a free good.
- The cost functions are continuous and monotonically increasing.

For this model setup, [6] have shown that an equilibrium exists. The incorporation of the bonus payment m does not alter the validity of their findings as long as m is restricted to values calculated above: Observing equation (3) one finds that $-m + c_i$ can be interpreted as the *true* long term marginal cost of firms i. Thus m changes the relation between the firms marginal costs which does not constrict [6]'s proof.

The next question is whether the equilibrium is stable. Following [10], a critical condition to be met is that the second order conditions are satisfied:

$$\frac{\partial^2 \pi_A}{\partial (x_A^*)^2} < 0 \tag{.1}$$

$$\frac{\partial^2 \pi_i}{\partial (x_i^*)^2} < 0 \tag{.2}$$

where $*$ indicates profit maximizing quantities x_A and x_i. The second order condition for supplier A yields

$$\frac{\partial^2 \pi_A}{\partial x_A^2} = \frac{\partial^2 \left[(a - x_A - x_i - (n-1)x_{-i}) \cdot x_A \right]}{\partial x_A^2} = -2 < 0 \tag{.3}$$

and for supplier i

$$\frac{\partial^2 \pi_i}{\partial x_i^2} = \frac{\partial^2 \left[(m + a - x_A - x_i - (n-1)x_{-i}) \cdot x_i - c_i \cdot x_i \right]}{\partial x_i^2} = -2 < 0 \quad \blacksquare \tag{.4}$$

It also has to be verified that own–output effects on marginal profit are greater than cross–output effects:

$$\left| \frac{\partial^2 \pi_A(x_A^*, x_i^*)}{\partial x_A^2} \right| > \left| \frac{\partial}{\partial x_i} \left[\frac{\partial \pi_A(x_A^*, x_i^*)}{\partial x_A} \right] \right|, \tag{.5}$$

$$\left| \frac{\partial^2 \pi_i(x_A^*, x_i^*)}{\partial x_i^2} \right| > \left| \frac{\partial}{\partial x_i} \left[\frac{\partial \pi_i(x_A^*, x_i^*)}{\partial x_A} \right] \right|. \tag{.6}$$

Substituting equation (1) into (.5) and (.6) yields $2 > 1$ for both suppliers, so all necessary stability conditions are satisfied. $\blacksquare$

In the social planner case, total level of capacity corresponds to that of perfect competition, independently of the damage parameter e. Substituting equation (1) into the welfare function (6) and differentiating with respect to x_A and x_i yields

$$x_A = \frac{a - nx_i}{1 + 2e} \quad (.7)$$

$$x_i = \frac{a - x_A - c_i}{n}. \quad (.8)$$

Solving the system yields welfare maximizing quantities

$$x_A^* = \frac{c_i}{2e} \quad (.9)$$

$$x_i^* = \frac{(2ae - 2c_i e - c_i}{2ne}. \quad (.10)$$

$x_A^* + nx_i^*$ yields $x^* = a - c_i$, so the welfare maximizing installed level of capacity is independend of the damage parameter e. ■