Quantities vs. Capacities: Minimizing the Social Cost of Renewable Energy Promotion

Mark Andor[*], Kai Flinkerbusch[†], Achim Voß[‡]

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Abstract

This article shows how different promotion schemes for renewables affect economic welfare. Given that the abatement of greenhouse gases is optimally internalized by taxes or emissions trading, our starting point is that the external benefits from renewable energy promotion are not related to actual electricity generation, but to producing and installing capacity. We argue that generation-based subsidies such as feed-in tariffs and bonus payments can only be a second-best solution. Our model framework allows us to explain how these second-best instruments cause welfare losses in an environment of volatile demand. We postulate that capacity payments for renewables should be implemented in order to avoid unnecessary social costs.

Keywords: Renewable Energy Sources, Energy Policy, Promotion Instruments

JEL Codes: Q41, Q48, H23

[*]Division of Environment and Resources, Rheinisch-Westfälisches Institut für Wirtschaftsforschung, Hohenzollernstr. 1-3, 45128 Essen, Germany, Tel.: +49 201 8149 216, e-mail: andor@rwi-essen.de.

[†]Department of Economic Theory, University of Münster, Universitätsstr. 14-16, 48143 Münster, Germany, Tel.: +49 251 83 22842, e-mail: 15kafl@wiwi.uni-muenster.de.

[‡]Department of Economic Theory, University of Münster, Universitätsstr. 14-16, 48143 Münster, Germany, Tel.: +49 251 83 22872, e-mail: 15acvo@wiwi.uni-muenster.de.

"If you want the energy transition, it will not come without a change in prices."

- Angela Merkel, quoted in Focus (2012)

1 Introduction

So spoke the German chancellor in October 2012 in response to a political uproar over an anticipated 50% increase in the levy households are obligated to pay for the feed-in of renewable energies in their electricity mix. In 2002, Germany paid a total of 2.23 billion Euros to a *feed-in tariff* (FIT) scheme that obligates grid operators to accept and remunerate the feed-in of renewable energies at fixed rates. By 2012, this payment had increased nearly nine-fold to 17.9 billion Euros. Currently, the typical German household pays over 25 Cents per kWh of electricity, roughly double the rate of neighboring France (cf. Eurostat 2012).

Despite these costs, Germany's support scheme for renewables has long been regarded as a role model, one that sets "a shining example in providing a harvest for the world" (Seager, 2007). Such accolades owe to the country's impressive success in expanding renewable energy capacities. It is home to 44% of the world's photovoltaic capacity and 14% of global wind energy turbines (Sawin and Martinot, eds, 2010).

The question addressed in this article is whether such an expansion could have been reached with lower social cost: Feed-in tariffs block operators of renewable energy sources of electricity (RES-E) from price signals, which makes them flood the market in times of oversupply. These welfare losses due to the promotion scheme's perverse incentives are the more relevant, the larger existing or planned RES-E capacities are. Our results imply that large welfare losses in the German electricity market could have been avoided, whereas other countries could avoid walking into the same trap.

Our starting point is to address why governments support RES-E at all. The most common justification is the abatement of greenhouse gases. However, the economic literature suggests that direct caps on or prices for emitting greenhouse gases are first-best instruments for internalizing this external effect (cf. Pizer 2002, Gillingham and Sweeney 2010 and Lehmann 2011). Therefore, greenhouse-gas avoidance cannot justify RES-E promotion, at least not as an optimal instrument.

If there is a further market failure, a separate promotion of RES-E can be justified in its own right (cf. Lehmann 2011). In political discussions as well as in the economic literature, there are several proposed reasons for promoting RES-E. Internalizing positive externalities from technology spillovers – as analyzed, for example, by Fischer and Newell (2008) and Gerlagh et al. (2009) – seems to be the most convincing rationale. While other motives seem to lack a solid theoretical foundation, they are part of political considerations nonetheless: Reducing the dependence on fossil fuel supply and resource imports, security of supply, and raising employment (cf. del Río González 2007).

A key distinction, if often overlooked, is between subsidizing capacity as opposed to generation: It is striking that all of the reasons to support RES-E – aside from abatement – are connected to RES-E capacity rather than RES-E generation. Security of supply, for example, is grounded on available capacity, while technology spill-over effects arise from the production of new capacity. At the same time, however, the instruments used to promote RES-E are typically targeted not at capacity but rather at generation.[1] There is thus a fundamental disconnect between the policy instrument and the policy objective; capacity may well increase from the promotion of generation, but only as a side effect.[2]

Moreover, instruments that are generation-based frequently lead to undesired market outcomes. For instance, the main support instrument in the EU is a generation-based feed-in tariff (cf. Ecofys et al. 2011). Given that a FIT covers variable costs, RES-E operators always make use of their full available capacity – independent of electricity demand. This leads to situations in which RES-E technologies produce energy in spite of strongly negative prices, although they can reduce supply almost

[1]For an up-to-date overview of RES-E support in Europe, cf. Kitzing et al. (2012).

[2]Newbery (2012) also argues that in the case of wind turbines capacities, not electricity generation should be promoted: "Almost all of these benefits derive from the original investment, rather than the subsequent operation of the wind turbine, which suggests targeting the support on that investment, rather than the output." Newberry concludes that "the logical contract is a payment per MW of available connected capacity, and a fixed payment per metered MWh equal to the expected average local wholesale price." However, it does not seem natural to us that such a price guarantee is necessary. In the model analyzed in this paper, such a combination would still incentivize an inefficient feed-in in times of low demand.

costlessly.[3] In Germany, wind power plants generated 17,000 MWh of electricity on October 4th 2009 between 2 a.m. and 3 a.m., although the day-ahead market price was −500 Euro/MWh. Negative prices are the most obvious sign that FIT give misleading incentives. Unfortunately, these circumstances – a high supply of RES-E in conjunction with low demand – are likely to occur more often in the future due to Germany's ambitious target to produce 35% of electricity with renewables by 2020.

This article analyzes the effect of different promotion schemes on welfare in a model of variable demand. We compare the most prominent instruments: Feed-in tariffs as market price-independent payments for generated electricity, bonus payments as a generation subsidy on top of the market price, and generation-independent capacity subsidies. We show that capacity subsidies minimize costs and demonstrate the additional costs of instruments that are generation-based.

The structure of this article is as follows. Section 2 relates the article to the literature. Section 3 describes the socially optimal supply rule for RES-E electricity. In section 4, we show the effects of different support instruments on the operators' supply and investment decision. We then compare their decision to that of the social planner. Section 5 discusses the applicability of our model to the real-world electricity market. Section 6 summarizes the results and offers suggestions for further research.

2 Literature review

There is a large literature on RES-E support instruments, but to our knowledge, the distinction between subsidizing capacity as opposed to paying for generated electricity has not yet been discussed in a theoretical analysis. For example, the contrast that many studies draw is between RES-E quantity based instruments (identified as green energy certificates or auctioned quotas) and RES-E price based instruments such as feed-in tariffs (e.g. Butler and Neuhoff (2008), Haas et al. (2011), Menanteau et al. (2003) and Verbruggen and Lauber (2009)). However, note that all these instruments

[3] Negative prices can occur because conventional power plants in certain situations have a willingness to pay to continue generating even when demand is low to avoid the costs associated with shutting down and starting up the plant, see Andor et al. (2010) and Nicolosi (2010).

are electricity-generation payments and thus this distinction misses our point.

Fischer and Newell (2008) derive an optimal policy, taking RES-E technology spillover as well as negative fossil-fuel externalities into account without modelling RES-E capacity explicitly. Positive learning externalities of RES-E are explicitly analyzed by Bläsi and Requate (2010) as well. However, in their model, capacity subsidies are, in effect, a market-entry premium for RES-E operators and "capacity" is the number of firms, i.e. each firm owns one wind turbine. Both models rely on rising marginal cost of RES-E electricity generation. By contrast, our own framework assumes competitive operators and incorporates the case of zero generation cost, which is of particular relevance to wind and solar power generation.

Negative electricity prices are a relatively new phenomenon. Nevertheless, there are a couple of articles that discuss this phenomenon from various perspectives. Knittel and Roberts (2005) observe negative prices when studying the distributional and temporal properties of hourly electricity prices in California. For the German electricity market, trade at negative prices was made possible by the European Energy Exchange (EEX) in 2008. Nicolosi (2010) empirically analyzes extreme events in Germany under the negative price regime, focusing on factors limiting market flexibility. Fanone et al. (2012) develop a model for day-ahead spot prices with the aim of capturing the main features of the German electricity spot market. Besides the well known peculiarities of electricity prices (seasonality, mean reversion, fat tails, positive spikes), their model is able to generate negative spikes and negative prices. Andor et al. (2010) and Brandstätt et al. (2011) discuss the influence of the German FIT on the occurrence of negative prices, concluding that the RES-E support scheme cause welfare losses. Andor et al. (2010) suggest limiting the obligation to sell RES-E to those cases when (short-term) marginal cost is recovered. By contrast, Brandstätt et al. (2011) propose to use voluntary curtailment agreements, while retaining the priority rule as such. Thereby the transmission system operator can organize a tender for voluntary curtailment agreements. As both Andor et al. (2010) and Brandstätt et al. (2011) suggest, an analysis of other support schemes to improve the large-scale integration of RES-E is of interest in the mid-term, which is the focus of this article.

To analyze capacity choice with variable states of demand, we employ a peak-load pricing model. Crew et al. (1995) provide an excellent survey of the respective literature. The reference analysis of peak-load pricing capacity choice with respect to the electricity market is Wenders (1976), but we do not apply his feature of heterogeneous technology. Without loss of generality, we concentrate on a single technology facing a demand curve. This simplification allows us to focus on the support schemes' incentives on RES-E supply behavior. We discuss the impact of multiple technologies on our model in section 5.

Finally, it is worth noting that our analysis applies the targeting principle of Bhagwati (1971): If a government seeks to either neutralize an economic distortion or to introduce a distortion for exogenous reasons, the cost-minimizing intervention is the one that directly aims at the distortion's source. Bhagwati formulated the principle for international trade policy, but it is oft-cited in other policy areas. Particularly, agricultural economists tend to propose direct income support for farmers – and thus, ultimately, farming capacity – decoupled from the production of specific kinds of crop – cf. Guyomard et al. (2000, 2004) and Schmook and Vance (2009).

3 Socially optimal electricity supply

Consider an electricity market in which the price p for electricity q is given by a state-dependent demand function $p(a, q)$, where $a \in \{l, h\}$ represents the state: $a = h$ means high demand, and $a = l$ means low demand, and we assume $p(h, q) > p(l, q)$ for each q. Note that our model is general enough to be applicable to other markets as well, but for concreteness we use electricity-market vocabulary.

We explicitly model only one technology for generating and supplying electricity, which represents a renewable-energy source. Thereby, we think of the demand function as residual demand for this technology. We discuss the implications of multiple-technology supply – that is, an electricity market consisting of conventional power plants and different renewable-energy technologies facing a common demand – in section 5.

Electricity supply of the renewable technology is limited by capacity, k. Manufacturing capacity costs $\Phi(k)$, with $\Phi(0) = 0$, $\Phi'(0) \geq 0$, $\Phi'(k) > 0$ for $k > 0$ and $\Phi''(k) > 0$. Generating electricity may be costly as well, where the cost function is $\Theta(q)$ with $\Theta'(q) \geq 0$, $\Theta''(q) \geq 0$. There is no intermittency problem in our model, i.e. capacity is always fully available, because we want to focus on the comparison of RES-E support schemes and these have no influence on the availability of RES-E capacity.

Consistent with our focus on distinguishing capacity and generation, we consider two periods: An investment period in which capacity is chosen under electricity demand uncertainty, and a market period in which electricity is generated. The ex-ante probability for high demand ($a = h$) is ρ and for low demand ($a = l$) it is $1 - \rho$.

Expected consumer surplus $\mathbb{E}[CS]$ and expected producer surplus $\mathbb{E}[PS]$ in the market period are given by:

$$\mathbb{E}[CS] \equiv \rho \cdot \int_0^{q_h} [p(h,q) - p(h,q_h)]\, dq + (1-\rho) \cdot \int_0^{q_l} [p(l,q) - p(l,q_l)]\, dq, \tag{1}$$

$$\mathbb{E}[PS] \equiv \rho \cdot \int_0^{q_h} [p(h,q_h) - \Theta'(q)]\, dq + (1-\rho) \cdot \int_0^{q_l} [p(l,q_l) - \Theta'(q)]\, dq, \tag{2}$$

where q_h and q_l are production quantities chosen for demand state h and l, respectively. We then have:

$$\begin{aligned}\mathbb{E}[W] &= \mathbb{E}[CS] + \mathbb{E}[PS] - \Phi(k) \\ &= \rho \cdot \int_0^{q_h} [p(h,q) - \Theta'(q)]\, dq + (1-\rho) \cdot \int_0^{q_l} [p(l,q) - \Theta'(q)]\, dq \\ &\quad - \Phi(k),\end{aligned} \tag{3}$$

where $\mathbb{E}[W]$ is total expected surplus net of investment cost – or, simply, welfare. Note that welfare may also contain external benefits. However, our starting point is that positive RES-E externalities depend on capacity, not electricity generation. Consequently, when we consider different promotion schemes and then compare welfare for a given amount of capacity, we do not have to consider external benefits explicitly since they are the same for identical amounts of capacity. Therefore, whatever raises market surplus also raises welfare.

For any given level of capacity, a social planner would maximize welfare by choosing quantities of electricity. Due to the restriction that generation may not exceed capacity, we formulate a Lagrangian objective function with inequality constraints, Z, to be maximized:

$$\max_{q_h, q_l} Z = \rho \cdot \int_0^{q_h} [p(h,q) - \Theta'(q)]\, dq + (1-\rho) \cdot \int_0^{q_l} [p(l,q) - \Theta'(q)]\, dq$$
$$- \Phi(k) + \lambda_h \cdot [k - q_h] + \lambda_l \cdot [k - q_l]\,. \tag{4}$$

Optimality conditions for electricity generation are then defined by:

$$\frac{\partial Z}{\partial q_h} = \rho \cdot [p(h, q_h) - \Theta'(q_h)] - \lambda_h \leq 0 \qquad q_h \geq 0$$
$$q_h \cdot \frac{\partial Z}{\partial q_h} = q_h \cdot [\rho \cdot [p(h, q_h) - \Theta'(q_h)] - \lambda_h] = 0, \tag{5}$$
$$\frac{\partial Z}{\partial q_l} = (1-\rho) \cdot [p(l, q_l) - \Theta'(q_l)] - \lambda_l \leq 0 \qquad q_l \geq 0$$
$$q_l \cdot \frac{\partial Z}{\partial q_l} = q_l \cdot [(1-\rho) \cdot [p(l, q_l) - \Theta'(q_l)] - \lambda_l] = 0 \tag{6}$$

and the Kuhn-Tucker conditions for capacity utilization are:

$$\frac{\partial Z}{\partial \lambda_h} = k - q_h \geq 0 \qquad \lambda_h \geq 0 \qquad \lambda_h \cdot \frac{\partial Z}{\partial \lambda_h} = \lambda_h \cdot [k - q_h] = 0, \tag{7}$$
$$\frac{\partial Z}{\partial \lambda_l} = k - q_l \geq 0 \qquad \lambda_l \geq 0 \qquad \lambda_l \cdot \frac{\partial Z}{\partial \lambda_l} = \lambda_l \cdot [k - q_l] = 0. \tag{8}$$

The interpretation of the optimality conditions is straightforward. Consider the case where we have $p(a, q_a) = \Theta'(q_a)$ for a positive generation quantity $q_a < k$. In this case, capacity is used only up to this quantity and the shadow price of capacity is zero, because there is still some amount of capacity left idle. If, however, $p(a, k) > \Theta'(k)$ for generation at the capacity limit, the capacity restriction is binding and we have

$q_a = k$; the shadow price of capacity, λ_a, then equals the excess of price above marginal generation cost weighted with the probability of state a.

This means that full capacity is used in both demand states if capacity is very scarce: We then have $q_l = q_h = k$. As $p(h,q) > p(l,q)$, this implies that the price in state h is higher than marginal generation cost and the price in state l is at least as high as marginal cost. If more capacity is available, then in the low-demand state it is only used up to the point where price equals marginal generation cost, while in the high-demand state capacity is still the limit. Finally, if very much capacity is available, it is used up to the point where price equals marginal generation cost in both demand states.

In what follows, we call the quantities defined by the equality of price and marginal generation cost $\widetilde{q_a}$ for demand state a. This case reflects the efficient supply rule, which implies maximal expected welfare for any capacity level. Welfare for capacity level k then reads:

$$\mathbb{E}[W^*] = \begin{cases} \int_0^k \left[\rho \cdot p(h,q) + (1-\rho) \cdot p(l,q)\right] dq & \\ -\Theta(k) - \Phi(k) & \text{for } k \leq \widetilde{q_l}, \\ \rho \cdot \int_0^k p(h,q)dq + (1-\rho) \cdot \int_0^{\widetilde{q_l}} p(l,q)dq & \\ -\left[\rho \cdot \Theta(k) + (1-\rho) \cdot \Theta(\widetilde{q_l})\right] - \Phi(k) & \text{for } \widetilde{q_l} \leq k \leq \widetilde{q_h}, \\ \rho \cdot \int_0^{\widetilde{q_h}} p(h,q)dq + (1-\rho) \cdot \int_0^{\widetilde{q_l}} p(l,q)dq & \\ -\left[\rho \cdot \Theta(\widetilde{q_h}) + (1-\rho) \cdot \Theta(\widetilde{q_l})\right] - \Phi(k) & \text{for } \widetilde{q_h} \leq k. \end{cases} \tag{9}$$

If the planner desires to expand capacity beyond the $\widetilde{q_l}$ level, it is optimal to leave capacity idle if low demand is realized. Likewise, if the government wants to expand capacity beyond $\widetilde{q_h}$, the excess capacity should be left idle in both demand states. It seems unlikely that a real-world government would build capacity without planning to ever use it. Hence, the current situation in many electricity markets likely resembles our intermediate case. In the following we analyze three different instruments that a government can use to set incentives for firms to reach capacity targets. Thereby we analyze whether and when such second-best policies deviate from the first-best solution of equation (9).

4 Instruments

4.1 Capacity payments

Consider the investment and supply decision of competitive, profit-maximizing suppliers under demand uncertainty. Firms are price takers and their revenue is denoted $p(a) \cdot q_a$. As in the previous section, generation cost is $\Theta(q)$ and capacity cost $\Phi(k)$. Now consider a support scheme that grants a payment depending on installed capacity, denoted σ. The payment can either be made directly for each MW of capacity, or we can think of concepts like tenders. In our model framework, these concepts are identical. Let τ be a lump-sum tax that is needed to finance the capacity payments. By definition of a lump-sum tax, it does not cause allocative distortions. The firms' total profits in state a, given capacity payments and the tax, are defined as:

$$\Pi_a^\sigma \equiv p(a) \cdot q_a - \Theta(q_a) - \Phi(k) + \sigma \cdot k - \tau, \tag{10}$$

so that expected total profits are given by:

$$\begin{aligned} \mathbb{E}\left[\Pi^\sigma\right] \equiv \rho \cdot \left[p(h) \cdot q_h - \Theta(q_h) - \Phi(k) + \sigma \cdot k - \tau\right] \\ + (1-\rho) \cdot \left[p(l) \cdot q_l - \Theta(q_l) - \Phi(k) + \sigma \cdot k - \tau\right]. \end{aligned} \tag{11}$$

The firms' Lagrangian is given by:

$$\begin{aligned} \max_{q_h, q_l, k} Z^\sigma = \rho \cdot \left[p(h) \cdot q_h - \Theta(q_h) - \Phi(k) + \sigma \cdot k - \tau\right] \\ + (1-\rho) \cdot \left[p(l) \cdot q_l - \Theta(q_l) - \Phi(k) + \sigma \cdot k - \tau\right] \\ + \lambda_h^\sigma \cdot \left[k - q_h\right] + \lambda_l^\sigma \cdot \left[k - q_l\right]. \end{aligned} \tag{12}$$

The maximization conditions for supply are:

$$\frac{\partial Z^{\sigma}}{\partial q_h} = \rho \cdot [p(h, q_h) - \Theta'(q_h)] - \lambda_h^{\sigma} \leq 0 \qquad q_h \geq 0$$

$$q_h \cdot \frac{\partial Z^{\sigma}}{\partial q_h} = q_h \cdot \left[\rho \cdot [p(h, q_h) - \Theta'(q_h)] - \lambda_h^{\sigma}\right] = 0, \tag{13}$$

$$\frac{\partial Z^{\sigma}}{\partial q_l} = (1 - \rho) \cdot [p(l, q_l) - \Theta'(q_l)] - \lambda_l^{\sigma} \leq 0 \qquad q_l \geq 0$$

$$q_l \cdot \frac{\partial Z^{\sigma}}{\partial q_h} = q_l \cdot \left[(1 - \rho) \cdot [p(l, q_l) - \Theta'(q_l)] - \lambda_l^{\sigma}\right] = 0, \tag{14}$$

where prices depend on q_h and q_l in equilibrium. The Kuhn-Tucker conditions are given by:

$$\frac{\partial Z^{\sigma}}{\partial \lambda_h^{\sigma}} = k - q_h \geq 0 \qquad \lambda_h^{\sigma} \geq 0 \qquad \lambda_h^{\sigma} \cdot \frac{\partial Z^{\sigma}}{\partial \lambda_h^{\sigma}} = \lambda_h^{\sigma} \cdot [k - q_h] = 0, \tag{15}$$

$$\frac{\partial Z^{\sigma}}{\partial \lambda_l^{\sigma}} = k - q_l \geq 0 \qquad \lambda_l^{\sigma} \geq 0 \qquad \lambda_l^{\sigma} \cdot \frac{\partial Z^{\sigma}}{\partial \lambda_l^{\sigma}} = \lambda_l^{\sigma} \cdot [k - q_l] = 0. \tag{16}$$

Concerning capacity, the first order condition is

$$\frac{\partial Z^{\sigma}}{\partial k} = -\Phi'(k^*) + \sigma + \lambda_h^{\sigma} + \lambda_l^{\sigma} \leq 0 \qquad k^* \geq 0$$

$$k^* \cdot \frac{\partial Z^{\sigma}}{\partial k} = k^* \cdot \left[-\Phi'(k^*) + \sigma + \lambda_h^{\sigma} + \lambda_l^{\sigma}\right] = 0, \tag{17}$$

where k^* is the firms profit-maximizing capacity choice.

When we compare the social planner's case with the capacity-payments case, we can see that the supply decision for a given capacity is identical. This finding is confirmed by the identity of the respective maximization conditions: If in state a the capacity restriction is binding, λ_a^{σ} is positive and $q_a = k$. If, by contrast, capacity is large, then q_a is chosen to equalize price and marginal generation cost so that the shadow value λ_a^{σ} equals zero. Additionally, from (17), we can see that the marginal cost of capacity net of the capacity payment must equal the sum of the state shadow values of capacity if a positive amount of capacity is to be built.

It may happen that both λ_a^{σ} are zero, which implies excess capacity in both demand states. Firms then always supply below their capacity limit at a price equal to their marginal generation cost. However, we assume increasing cost of capacity, so that suppliers are only willing to install such an abundant amount of capacity when the capacity payment covers marginal investment cost. Stated alternatively, the planner can adjust subsidies to induce a desired level of capacity, even if it is never completely used.

As electricity supply decisions are not distorted, welfare equals the planner's solution for any level of k. Capacity payments are thus the benchmark for assessing the welfare implications of the following two instruments.

4.2 Fixed feed-in tariff

We now derive what happens if the government pays a fixed feed-in tariff (FIT) ν for each kWh of electricity that a firm generates and feeds into the grid. Again, the FIT is paid for by a lump-sum tax. Along the lines of (11), expected profits can be stated as follows:

$$\begin{aligned}\mathbb{E}\left[\Pi_a^\nu\right] \equiv\ & \rho \cdot \left[\nu \cdot q_h - \Theta(q_h) - \Phi(k) - \tau\right] \\ & + (1-\rho) \cdot \left[\nu \cdot q_l - \Theta(q_l) - \Phi(k) - \tau\right]. \qquad (18)\end{aligned}$$

The firms' Lagrangian is then given by:

$$\begin{aligned}\max_{q_h, q_l, k} Z^\nu =\ & \rho \cdot \left[\nu \cdot q_h - \Theta(q_h) - \Phi(k) - \tau\right] \\ & + (1-\rho) \cdot \left[\nu \cdot q_l - \Theta(q_l) - \Phi(k) - \tau\right] \\ & + \lambda_h^\nu \cdot \left[k - q_h\right] + \lambda_l^\nu \cdot \left[k - q_l\right]. \qquad (19)\end{aligned}$$

This implies the following optimality conditions for supply:

$$\frac{\partial Z^{\nu}}{\partial q_h} = \rho \cdot [\nu - \Theta'(q_h)] - \lambda_h^{\nu} \leq 0 \qquad q_h \geq 0$$

$$q_h \cdot \frac{\partial Z^{\nu}}{\partial q_h} = q_h \cdot \left[\rho \cdot [\nu - \Theta'(q_h)] - \lambda_h^{\nu}\right] = 0, \tag{20}$$

$$\frac{\partial Z^{\nu}}{\partial q_l} = (1-\rho) \cdot [\nu - \Theta'(q_l)] - \lambda_l^{\nu} \leq 0 \qquad q_l \geq 0$$

$$q_l \cdot \frac{\partial Z^{\nu}}{\partial q_l} = q_l \cdot \left[(1-\rho) \cdot [\nu - \Theta'(q_l)] - \lambda_l^{\nu}\right] = 0. \tag{21}$$

The Kuhn-Tucker conditions are given by:

$$\frac{\partial Z^{\nu}}{\partial \lambda_h^{\nu}} = k - q_h \geq 0 \qquad \lambda_h^{\nu} \geq 0 \qquad \lambda_h^{\nu} \cdot \frac{\partial Z^{\nu}}{\partial \lambda_h^{\nu}} = \lambda_h^{\nu} \cdot [k - q_h] = 0, \tag{22}$$

$$\frac{\partial Z^{\nu}}{\partial \lambda_l^{\nu}} = k - q_l \geq 0 \qquad \lambda_l^{\nu} \geq 0 \qquad \lambda_l^{\nu} \cdot \frac{\partial Z^{\nu}}{\partial \lambda_l^{\nu}} = \lambda_l^{\nu} \cdot [k - q_l] = 0. \tag{23}$$

The optimality condition for capacity is

$$\frac{\partial Z^{\nu}}{\partial k^*} = -\Phi'(k^*) + \lambda_h^{\nu} + \lambda_l^{\nu} \leq 0 \qquad k^* \geq 0$$

$$k^* \cdot \frac{\partial Z^{\nu}}{\partial k^*} = k^* \cdot \left[-\Phi'(k^*) + \lambda_h^{\nu} + \lambda_l^{\nu}\right] = 0. \tag{24}$$

At this point we provide an intuitive interpretation of these conditions. A more technical interpretation can be found in appendix A.

First, note that the price for electricity is absent from the optimality conditions. For the suppliers, only marginal cost and the tariff matter. So as long as the feed-in tariff exceeds marginal generation cost, they produce at the capacity level. If the tariff lies below marginal generation cost, they produce nothing. Assuming that the tariff exceeds marginal generation cost at the capacity limit (which is the case with real-world tariffs because they would otherwise be useless), higher tariffs induce a higher level of installed capacity. Consequently, as in the previous section, by setting the tariff the government can induce any desired level of capacity k and by setting a lump-sum tax $\tau = \nu \cdot k^*$, it can neutralize distributional effects. However, we now have a direct welfare effect of the promotion scheme. Firms only build the capacity they intend to use; so as all capacity is always used, the distinction of cases that we used in the welfare formula for the planner's solution, (9), reduces to:

$$\mathbb{E}[W_v] = \int_0^k [\rho \cdot p(h,q) + (1-\rho) \cdot p(l,q)]\, dq - \Theta(k) - \Phi(k), \tag{25}$$

for all levels of capacity. We will later compare this amount of expected welfare to the first-best solution.

4.3 Bonus payments

A bonus payment system grants producers a bonus on top of the market price for each kWh, instead of guaranteed payments for electricity as in the FIT system. Denoting the subsidy by η, expected profits can be stated as follows:

$$\begin{aligned}\mathbb{E}\left[\Pi_a^\eta\right] \equiv \rho \cdot [[p(h) + \eta] \cdot q_h - \Theta(q_h) - \Phi(k) - \tau] \\ + (1-\rho) \cdot [[p(l) + \eta] \cdot q_l - \Theta(q_l) - \Phi(k) - \tau]\,.\end{aligned} \tag{26}$$

We analyze this as a constrained maximization problem as in the previous sections, where Z^η is the Lagrangian. Maximization conditions for electricity supply are:

$$\begin{aligned}\frac{\partial Z^\eta}{\partial q_h} &= \rho \cdot [p(h,q_h) + \eta - \Theta'(q_h)] - \lambda_h^\eta \leq 0 \qquad q_h \geq 0 \\ q_h \cdot \frac{\partial Z^\eta}{\partial q_h} &= q_h \cdot \left[\rho \cdot [p(h,q_h) + \eta - \Theta'(q_h)] - \lambda_h^\eta\right] = 0,\end{aligned} \tag{27}$$

$$\begin{aligned}\frac{\partial Z^\eta}{\partial q_l} &= (1-\rho) \cdot [p(l,q_l) + \eta - \Theta'(q_l)] - \lambda_l^\eta \leq 0 \qquad q_l \geq 0 \\ q_l \cdot \frac{\partial Z^\eta}{\partial q_l} &= q_l \cdot \left[(1-\rho) \cdot [p(l,q_l) + \eta - \Theta'(q_l)] - \lambda_l^\eta\right] = 0,\end{aligned} \tag{28}$$

where prices depend on q_h and q_l in equilibrium. The Kuhn-Tucker conditions are given by:

$$\frac{\partial Z^\eta}{\partial \lambda_h^\eta} = k - q_h \geq 0 \qquad \lambda_h^\eta \geq 0 \qquad \lambda_h^\eta \cdot \frac{\partial Z^\eta}{\partial \lambda_h^\eta} = \lambda_h^\eta \cdot [k - q_h] = 0, \tag{29}$$

$$\frac{\partial Z^\eta}{\partial \lambda_l^\eta} = k - q_l \geq 0 \qquad \lambda_l^\eta \geq 0 \qquad \lambda_l^\eta \cdot \frac{\partial Z^\eta}{\partial \lambda_l^\eta} = \lambda_l^\eta \cdot [k - q_l] = 0. \tag{30}$$

Concerning capacity, the first-order condition is

$$\frac{\partial Z^\eta}{\partial k} = -\Phi'(k^*) + \lambda_h^\eta + \lambda_l^\eta \leq 0 \qquad\qquad k^* \geq 0$$
$$k^* \cdot \frac{\partial Z^\eta}{\partial k} = k^* \cdot \left[-\Phi'(k^*) + \lambda_h^\eta + \lambda_l^\eta\right] = 0, \tag{31}$$

where k^* is the firms' profit-maximizing capacity choice.

The analysis of investment follows along the lines of section 4.1: The marginal cost of capacity must equal the sum of capacity's shadow values in the different states. However, while with capacity payments it is possible to expand to any amount of capacity and leave part of it idle, the bonus payment incentive implies that the shadow value of capacity has to be positive in at least one state, implying full capacity utilization. As demand is always higher in the high-demand state than in the low-demand state, full capacity has to be used in either both states or in the high-demand state only. Note that if the bonus incentivizes full capacity utilization in both demand states, the supply decision of the firms is equal to the decision when a FIT is granted.

If capacity utilization is below maximum in the low-demand state, we have $p(l, \widetilde{q_l^\eta}) + \eta - \Theta'(\widetilde{q_l^\eta}) = 0$, where $\widetilde{q_l^\eta}$ is the quantity fulfilling this equation, instead of $p(l, \widetilde{q_l}) - \Theta'(\widetilde{q_l}) = 0$ as in the capacity payment system. Thus, the bonus payment equals the difference between marginal cost and willingness to pay. So capacity utilization must be larger than $\widetilde{q_l}$ and smaller than or equal to capacity k.

It remains to analyze whether it is possible to incentivize capacity expansion without using all of it in the low-demand state: If an increase in the bonus lets $\widetilde{q_l^\eta}$ grow stronger than k, then at some point $\widetilde{q_l^\eta}$ would be larger than capacity, which is impossible – we then must have full capacity utilization in both demand states. Whether this happens is discussed in detail in appendix B. It depends on the forms of cost and demand functions and therefore must be considered an empirical question. For many reasonable functions the bonus payment's incentives and the suppliers' behavior indeed converge to those of the FIT.

Once more, the lump-sum tax τ can be set equal to expected payments. Expected welfare with bonus payments, $\mathbb{E}[W_\eta]$, is given by

$$\mathbb{E}[W_\eta] = \begin{cases} \int_0^k [\rho \cdot p(h,q) + (1-\rho) \cdot p(l,q)]\, dq \\ -\Theta(k) - \Phi(k) & \text{for } k \le \widetilde{q_l^\eta}, \\ \\ \rho \cdot \int_0^k p(h,q)dq + (1-\rho) \cdot \int_0^{\widetilde{q_l^\eta}} p(l,q)dq \\ -\left[\rho \cdot \Theta(k) + (1-\rho) \cdot \Theta(\widetilde{q_l^\eta})\right] - \Phi(k) & \text{for } \widetilde{q_l^\eta} \le k \le \widetilde{q_h^\eta}. \end{cases} \tag{32}$$

Note that $\widetilde{q_h^\eta} < k$ is not feasible because, as shown above, we need full capacity utilization in at least one state of demand. We will analyze the welfare effects of the bonus payment in detail in the next section, contrasting them with those of the other two instruments.

4.4 Comparison

FIT and capacity payment: We first compare the FIT with the capacity payment by substracting (25) from (9) to find the expected advantage of capacity payments as a function of capacity, ΔW:

$$\Delta W = \mathbb{E}[W^*] - \mathbb{E}[W_\nu] = \begin{cases} 0 & \text{for } k \le \widetilde{q_l}, \\ \\ -(1-\rho) \cdot \int_{\widetilde{q_l}}^k [p(l,q) - \Theta'(q)]\, dq & \text{for } \widetilde{q_l} \le k \le \widetilde{q_h}, \\ \\ -\rho \cdot \int_{\widetilde{q_h}}^k [p(h,q) - \Theta'(q)]\, dq \\ -(1-\rho) \cdot \int_{\widetilde{q_l}}^k [p(l,q) - \Theta'(q)]\, dq & \text{for } \widetilde{q_h} \le k. \end{cases} \tag{33}$$

As long as the capacity desired by the planner is scarce in each demand state, there is no difference in welfare. The reason for this is that both the capacity payment and the tariff induce full capacity utilization, which is efficient. The additional amount of capacity has identical cost according to $\Phi(k)$, so by substracting $\mathbb{E}[W_\nu]$ from $\mathbb{E}[W^*]$, capacity cost cancel out of the equation.

It follows that if capacity is larger than necessary to equate marginal cost and the demand price for a low demand realization (i.e. $k > \widetilde{q_l} \wedge k < \widetilde{q_h}$), the allocative equality of both promotion schemes is only given with probability ρ, that is, if high demand is realized and capacity is scarce. If, however, low demand is realized, then with a FIT too much is produced and further production reduces welfare: For $\widetilde{q_l}$, we have $p(l, \widetilde{q_l}) = \Theta'(\widetilde{q_l})$ by definition, so that for further production, the integral turns negative and the welfare difference ΔW positive. Finally, if capacity is even larger than $\widetilde{q_h}$ in both states of demand, the FIT induces an inefficiently high feed-in in both states.

Bonus payment: Following the line of reasoning from above, if capacity is so small that the market's willingness to pay implies scarce capacity with high and low demand, the bonus performs as well as the other two support schemes because all three instruments induce a complete utilization of available capacity.[4] However, we have a difference to the other instruments when capacity is large enough to be abundant in at least one state ($k > \widetilde{q_l}$). In this case, from (28), we see that the bonus payment drives a wedge between the identity of marginal cost and marginal benefits, which implies sub-optimal behavior. Inefficient supply occurs only when demand is low, in other words with probability $1 - \rho$, so that we have:

$$\mathbb{E}[W^*] - \mathbb{E}[W_\eta] = -(1-\rho) \cdot \int_{\widetilde{q_l}}^{\widetilde{q_l^\eta}} [p(q) - \Theta'(q)]\, dq, \tag{34}$$

where $\mathbb{E}[W_\eta]$ denotes expected welfare with bonus payments in the case where $\widetilde{q_l} < k \leq \widetilde{q_h}$. The loss is zero for a bonus of zero, because then $\widetilde{q_l} = \widetilde{q_l^\eta}$. The loss grows with η, because $\frac{\partial \mathbb{E}[W^*] - \mathbb{E}[W_\eta]}{\partial \eta} = (1-\rho) \cdot \left[\Theta'(q_l^\eta) - p(\widetilde{q_l^\eta})\right] \cdot \frac{\partial \widetilde{q_l^\eta}}{\partial \eta} > 0$ per definition of the case at hand. When capacity is abundant in both states ($k > \widetilde{q_h} > \widetilde{q_l}$), there is inefficient supply all the time.

Compared to the FIT, where the loss (cf. (33)) is given as:

$$\Delta W = -(1-\rho) \int_{\widetilde{q_l}}^{k} [p(q) - \Theta'(q)]\, dq, \tag{35}$$

[4] With positive shadow values in the bonus payment system, we get $\Phi'(k^*) + \Theta'(k^*) - \rho \cdot p(h, k^*) - (1 - \rho) \cdot p(l, k^*) = \eta$ from (27) to (31) for the suppliers' optimal capacity choice. Substituting the bonus payment η by the capacity payment σ, this is the same condition we get from capacity choice in a capacity payment regime, (13) to (17).

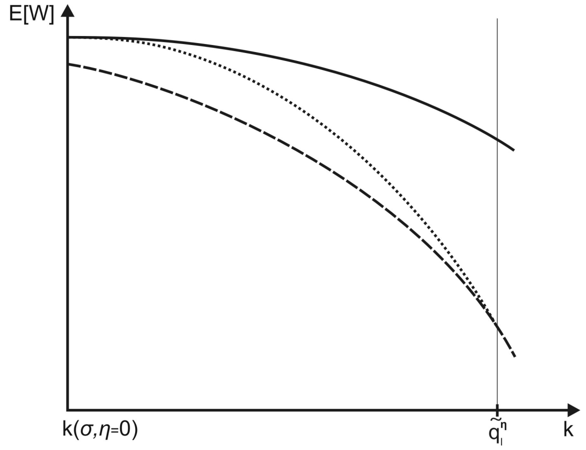

Figure 1: Comparison of promotion schemes in terms of economic surplus. $k(\sigma, \eta = 0)$ indicates the level of capacity without capacity or bonus payment. The solid line indicates the capacity payment system, the dashed line indicates the FIT system, and the dotted line shows welfare with the bonus payment.

the bonus actually performs better, because $\widetilde{q_l^\eta}$ is smaller than or equal to k. Hence, as $\widetilde{q_l^\eta}$ approaches k, the losses of the two schemes become equal. When $\widetilde{q_l^\eta} = k$, we have a complete utilization of available capacity when demand is low, which corresponds to the FIT case. In the high-demand state, supplier behavior of FIT and bonus payment schemes is equal anyway. To summarize, the bonus-payment scheme induces less welfare losses than the FIT scheme as long as $\widetilde{q_l^\eta} < k$, but resembles the FIT otherwise.

Figure 1 summarizes the findings for linear demand and linear-quadratic cost functions. We assume a case where capacity is scarce only when demand is high, which seems to be realistic in many electricity markets. The figure shows overall expected welfare levels in the three respective support schemes depending on the desired level of capacity.[5] The capacity payment performs best. The bonus payment yields lower surplus, but for the market level where no bonus and no capacity payment are granted (where $\sigma, \eta = 0$), both surplus levels are equal. The surplus level of the FIT lies below both curves. At the market-level of capacity it fails to achieve the performance of the former instruments, because in the low-demand state where capacity is not scarce, the

[5]Recall that this "welfare" equals market surplus. There may or may not be additional social benefits depending on capacity.

FIT causes losses at *any* capacity level due to its incentive to use all available capacity. We assumed functional forms for which the inefficiencies of the FIT and bonus payment-regime converge at some capacity level (cf. section 4.3); for high levels of capacity the bonus payment is so high that suppliers always generate at full capacity. Consequently, from this level onwards both instruments yield the same inefficiency.

5 Discussion

Our model is deliberately simple and, thus, general: It can represent any market for which a difference between capacity and production quantity is relevant and for which the government aims at incentivizing a capacity expansion via subsidies of either capacity or production. However, the question arises if such a simplification implies limited validity for electricity markets with their distinguishing features or for certain policy objectives. Therefore, we discuss the effects of such extensions in this section.

First of all, the distinguishing feature of electricity markets is that multiple electricity-generation technologies co-exist. The peak-load problem of electricity markets without renewables is well understood (cf. Crew et al., 1995). It turns out that the existence of different technologies has a negligible effect on the conclusion of our model if we understand the demand curve as residual demand for the technology of interest. We derive this residual demand curve by subtracting from the demand curve the electricity supply of all other technologies. Our "high-demand" situation may then either indeed be high demand (peak-load) or it may even be a situation in which for some reason the supply of other technologies is not fully available, while the "low-demand" situation is the complementary case to this.

The situation changes a bit if the maximal supply of other technologies is intertemporally interdependent. For example, in the introduction we mentioned that large, inflexible power plants have a willingness to pay to continue electricity generation if a drop in demand occurs for a short period of time, as they want to avoid the cost of shutting down and starting up their plants. In this case, the merit order implies negative prices for small quantities, which turns out to be even lower than the marginal generation cost of zero that we can ascribe to wind and photovoltaics. For our model, this means that if we explicitly had more and successive time-periods, the effects of forcing operators to supply in times of low residual demand (by setting bad incentives) have intertemporal effects. Residual demand for conventional technologies' electricity is then reduced by promoted RES-E capacity, which leads to more inflexible plants shutting down, which in turn means that in a period later less overall capacity is available.

Related to this is the topic of intermittency. In order to clearly show the effects of the promotion schemes' incentives, we assume in our model that our renewable technology is completely available in the period of interest. Obviously, this is unrealistic for wind and solar capacity. Given any amount of RES-E capacity, the inefficiency that arises from feed-in tariffs depends on the amount of available capacity that is used. Therefore, intermittency might make the effects of perverse incentives worse in some situations (when more capacity is available) and less bad in others (when less is available).

A topic related to intermittency is price risk and trading cost. In a FIT scheme, the price risk is not borne by the operators but it is distributed among the other market participants. The distribution of risk may affect investment if investors are risk-averse. We have modelled operators as risk neutral, so this issue does not arise in our model. However, we consider the social distribution of risk to be more of a question of credit and insurance markets and not a reason for a governmental intervention in product markets like that of electricity. Concerning trading cost, with a market for RES electricity trading, we can expect service providers to offer marketing services to capacity owners at a market price, thereby disclosing the true costs of RES electricity trading. These costs will then be borne by those who cause them.

What if there were external benefits of RES-E electricity generation? Obviously, this would negate the central assumption of our model. However, this does not speak for feed-in tariffs but instead for a combination of capacity subsidies and bonus payments, where the former should cover marginal external benefits of capacity and the latter should cover marginal external benefits of electricity.

Finally, there is the possibility that capacity payments (instead of FIT or bonus payments) could lead to investment in capacity that will never be used because the operators have no incentives to generate electricity. This can only be true if the capacity payment system was designed badly, because RES plant operators have the same incentives to produce electricity as every other market participant, i.e. the market price. Naturally, it must be assured that the promoted capacity is in general qualified to produce electricity. Capacity will then be used whenever there is positive demand for its electricity.

6 Implications and conclusion

Our analysis has interesting implications for the promotion of renewable energy sources, for the choice of optimal promotion schemes and for the appraisal of the schemes used in several countries. Starting from the assessment that renewable-energy capacity, not electricity, is undervalued from a social point of view and should be promoted, we have analyzed the effects of wrong incentives. Expanding capacity by a bonus-payment – a per-kWh subsidy – means that operators feed in too much electricity on average. Feed-in tariffs, which have been the main support instrument in Germany and other countries and which are widely understood as successful, come with even higher cost: By replacing all electricity price signals with a constant tariff, RES-E operators are led to always use their full (available) capacity, even if the market's willingness to pay is far below variable generation cost. Our analysis is an application of the idea that to correct a market failure, policy should directly aim at this market failure without introducing additional distortions.

In the last years, concern has grown about temporary RES-E electricity oversupply, and our analysis supports these concerns. It also shows why such concerns, and the promotion scheme, are irrelevant as long as RES-E capacity is small. With scarce capacity, it does not matter whether a direct capacity subsidy, a bonus scheme, or a FIT is used: All of them incentivize full capacity-utilization as long as the electricity price is above marginal generation cost at the capacity limit, which is efficient. The problem with the latter schemes is exactly that they still rely on such incentives for larger capacities. However, if there are political or other reasons for preferring one instrument over the others, then we can state that it may be reasonable to let these reasons dominate as long as capacity is small, but they have to be weighed against growing welfare losses with increasing capacity. At least for the German electricity market with its huge amount of RES-E capacity in conjunction with glaring signals of oversupply and welfare losses in certain time periods, we can conclude that it is time for a change of the promotion scheme.

Our analysis also allows insights into the meaning and importance of negative prices that have occasionally appeared on electricity day-ahead markets at times when renewable energy sources still supplied electricity. Given that RES-E technologies are usually flexible, the only reason for not reducing supply when prices are negative is the feed-in tariff's wrong incentive: Solar and wind power have negligible marginal generation cost, but in times of a negative market price, still feeding in reflects an avoidable welfare loss. However, there are also renewable technologies with positive generation cost, like biomass plants. Such plants produce welfare losses whenever their marginal cost is above the electricity price if they still feed in.

We have not taken up whether capacity should be promoted via price based or quantity based instruments. But in our model framework that is a secondary consideration, and in reality, the usual arguments for one instrument or the other will apply (cf. Weitzman 1974, Roberts and Spence 1976, Pizer 2002 and Lehmann 2011). We also have not modeled the difference between the promotion of capacity producers – like producers of wind turbines – and RES-E operators, which install and maintain the capacity. As an example – keeping trade restrictions and market power in mind – it might make a difference whether the investor or the producer is subsidized. We leave this for further research.

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A The firms' incentives associated with feed-in tariffs

To better understand the properties of our solution to section 4, first consider whether available capacity can be left idle in any state, say, state a_l. This would require $\lambda_l^\nu = 0$ from (23) and thus, from (21), $\nu - \Theta'(q_l) \leq 0$. For positive electricity generation the latter condition must be fulfilled with equality so that $\Theta'(q_l) = \nu$. With positive electricity generation in the high-demand state, we have $\lambda_h^\nu = \nu - \Theta'(q_h) > 0$ and full capacity utilization. This together implies $\lambda_h^\nu = \Theta'(q_l) - \Theta'(k) > 0$, which is a contradition given non-decreasing marginal generation cost. If, by contrast, we assume $q_h = 0$, then we must have $\lambda_h^\nu = 0$. As then both shadow values are zero, capacity cannot be positive due to condition (24). Similarly, if we assume $q_h < k$ and, thus $\nu = \Theta'(q_h)$, we must have $\lambda_l^\nu = \Theta'(k) - \Theta'(q_l) > 0$ so that $q_l < k$ must hold as well; but this again implies $\lambda_l^\nu = 0$, which is a contradiction.[6]

Therefore, any positive amount of capacity requires full capacity utilization in both demand states and

$$\lambda_h^\nu = \rho \cdot [\nu - \Theta'(k)] > 0 \qquad \lambda_l^\nu = (1-\rho) \cdot [\nu - \Theta'(k)] > 0. \tag{36}$$

Substituting this in (24) and simplifying shows that for a positive level of capacity, we

[6]For zero marginal generation cost, the line of argument is even simpler: If e.g. $k > q_l > 0$, we must have $\lambda_l^\nu = 0$ and then $\nu = 0$, which implies $\lambda_h^\nu = 0$ so that no capacity is built.

must have

$$\nu = \Phi'(k^*) + \Theta'(k^*). \tag{37}$$

So capacity is expanded until the feed-in tariff equals the sum of marginal capacity and marginal generation costs at full capacity.

B The firms' incentives associated with bonus payments

The question of whether the incentives of bonus payments converge to those of feed-in tariffs for high capacity can be reformulated: Can capacity investment be increased via the bonus payment without inducing full capacity utilization in the low-demand state? To answer this question, we have to find out whether the capacity induced by raising the bonus payment is larger than the additional generation in the low demand state; if it is not, then there must be some point at which all capacity is always used.

By substituting the supply optimality conditions in (31) and differentiating, we can see that the change in capacity is given by

$$\begin{aligned}\Phi'' \cdot dk = \rho \cdot & \left[\left(\frac{\partial p(h,k)}{\partial q} - \Theta''(k)\right) \cdot dk + d\eta\right] \\ & + (1-\rho) \cdot \left[\left(\frac{\partial p(l,q_l)}{\partial q} - \Theta''(q_l)\right) \cdot dq_l + d\eta\right],\end{aligned} \tag{38}$$

where we already substituted $q_h = k$.

Suppose that some given capacity is abundant in the low demand state, $q_l = \widetilde{q_l^\eta}$, so that q_l does not directly react to a capacity expansion and

$$\frac{dk}{d\eta} = \left[-\frac{\partial p(h,k)}{\partial q} + \Theta''(k) + \frac{1}{\rho} \cdot \Phi''(k)\right]^{-1} (> 0). \tag{39}$$

$\widetilde{q_l^\eta}$ is defined by $p(l,q_l) + \eta - \Theta'(q_l) = 0$. If it stays below capacity with the growing bonus payment, we must have $d\lambda_l^\eta = 0$ which implies:

$$\frac{d\widetilde{q_l^\eta}}{d\eta} = \left[-\frac{\partial p(l, \widetilde{q_l^\eta})}{\partial q} + \Theta''(\widetilde{q_l^\eta})\right]^{-1} (> 0). \tag{40}$$

Now to stay below capacity, this supply quantity must grow at a smaller rate than capacity itself as the bonus payment is raised:

$$\frac{d\widetilde{q_l^\eta}}{d\eta} < \frac{dk}{d\eta}, \tag{41}$$

which means that

$$-\frac{\partial p(l, \widetilde{q_l^\eta})}{\partial q} - \left(-\frac{\partial p(h, k)}{\partial q}\right) > \Theta''(k) - \Theta''(\widetilde{q_l^\eta}) + \frac{1}{\rho} \cdot \Phi''(k) \tag{42}$$

is required. If this inequality is not fulfilled, the entire capacity is used in both demand states and the bonus-payment's incentives are equivalent to those of a FIT.

Unfortunately, we cannot say in general whether inequality (42) holds. For many combinations of cost and demand functions, however, we can state that it becomes increasingly unlikely to fulfill it the more capacity is induced by the bonus payment. This is valid in particular for a $\Phi''' > 0$ investment cost function or for parallel linear demand functions and $\Theta''' \geq 0$.

Therefore, it is likely that for large capacity targets the bonus payment's incentives and the suppliers' behaviour converge to those of the FIT. On the other hand, for small governmental targets – that is, for values near $\eta = 0$ – the suppliers' behavior resembles that in the capacity payment system. As for $\eta = 0$ and $\sigma = 0$, the shadow values in the respective demand states are exactly equal.