Conventional Power Plants in Liberalized Electricity Markets with Renewable Entry

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Introduction: Renewable Energy and CCGTs

- The expansion of renewable capacity fostered by its decreasing costs and environmental goals has disrupted the operation of other technologies.
- Interestingly, renewable technology has lead opposing effects on the electricity markets:
  - It has reduced energy prices and diminished the utilization of conventional power plants, particularly when they cover peak demand such as those fueled by natural gas (CCGTs).
  - At the same time, the volatility of renewable capacity has made CCGTs more important in guaranteeing the security of supply.
- Regulators have expressed their concern recently. For example, the EC has emphasized it recently:

Electricity generation from renewable energy sources is growing rapidly. This has resulted in lower wholesale electricity prices, but has also reduced the use of conventional generation technologies, such as coal and gas, because renewable energy generally has lower running costs. Declining demand, lower prices and lower utilisation rates have all reduced the profitability of conventional electricity generation. At the same time, flexible conventional technologies continue to play a very important role: the growing share of renewable energy sources like wind and solar energy, the output of which varies with weather conditions and from daytime to night time, requires flexible energy systems, including reliable back-up capacity, that can take the form of conventional generation, demand-response or storage, to ensure security of supply at all times (European Commission, 2016).

Capacity Payments

- Regulators in many countries are responding to this concern by establishing **capacity remuneration** schemes, which are related to plant availability.
- They aim to provide back-up capacity by discouraging the decommissioning of existing plants and fostering investment in newer (and cleaner) ones. For example,
  - The UK has conducted auctions in 2015 and 2016 to provide additional capacity.
  - The New England system operator has proposed a two-stage capacity mechanism to provide the right signals to renewable and CCGTs plants.
  - Other schemes are in operation in Germany and the Canadian province of Alberta.
- Capacity payments are usually determined using auctions, where bidders incorporate in their decisions future capacity investment goals and the subsidies finance necessary to make them happen.

This Paper

- In this paper we aim to clarify the impact of renewable power on conventional plants and how capacity payments should be adjusted in this case.
- We propose a simple model of investment in conventional power and illustrate conditions (price caps and/or externalities) under which capacity payments are optimal.
- Our results help in explaining
  - How the volatility of renewable sources make conventional power plants (mainly CCGTs) complements in production.
  - The determinants in the optimal adoption of renewable power plants.
  - How a simple mechanism can redress the distortions created when plans to introduce renewable capacity are changed.

A Simple Model

- Consider an electricity market with uncertain demand q, independent of the price p.
- Demand q arises from a distribution $G(q)$ with full support $[0, \infty]$ and density $g(q)$.
- Total capacity is composed of two technologies:
  - K_R units of renewable power with marginal cost of 0 and fixed cost of F.
  - K_C units of conventional power with marginal cost of c and fixed cost of fK_C.
- Firms are price takers and are subject to a price cap $\bar{p} > c$. As a result
  - When capacity exceeds demand the equilibrium price is the marginal cost of the marginal plant.
  - When $q > K_R + K_C$, the equilibrium price is $\bar{p}$.

- The expected price can be determined as

$$E(p) = c\,[G(K_C + K_R) - G(K_R)] + \bar{p}\,[1 - G(K_C + K_R)]\,.$$

Renewable plants are dispatched first and only when $q > K_R$ the price is positive.

- All plants of the same technology are dispatched with the same probability.
- Thus, the expected profits of a firm with conventional capacity k are

$$\Pi(k) = [(\bar{p} - c)(1 - G(K_C + K_R)) - f]\,k.$$

- Given K_R, governments might induce any total capacity $K > K_R$ by offering a per-unit capacity payment

$$t(K) = f - (\bar{p} - c)(1 - G(K)). \tag{1}$$

- This payment can be administratively set or determined in equilibrium through an auction.

Optimal Conventional Capacity

- Suppose that demand is composed of a continuum of consumers with a per-unit valuation $v \geq \bar{p}$.
- The government maximizes total welfare. As it is well-known the results hold if consumers had a higher weight (Armstrong and Sappington, 2007).
- For a given renewable capacity K_R, the socially optimal K_C^* is the solution to

$$\max_{K_C} \int_0^{K_R} vqg(q)dq + \int_{K_R}^{K_R+K_C} \left[vq - c(q - K_R)\right] g(q)dq$$
$$+ \left[v(K_C + K_R) - cK_C\right]\left[1 - G(K_C + K_R)\right] - fK_C - F.$$

Lemma

The socially-optimal conventional capacity, K_C^*, is 0 if K_R is sufficiently large so that $(v-c)(1-G(K_R)) \leq f$ and it is implicitly defined as

$$(v-c)(1-G(K_C^* + K_R)) = f, \tag{2}$$

otherwise. This capacity is increasing in v and decreasing in c and f.

- The marginal unit of capacity generates a net value equal to the cost of its provision.
- Renewable and conventional capacity are perfect substitutes.
- The result extends to the case of multiple non-marginal technologies (Zöttl, 2011).

Corollary (Missing Money)

Without capacity payments, when $v > \bar{p}$, K_C^*, is higher than K_C^c, which arises from the free-entry condition

$$(\bar{p} - c)(1 - G(K_C^c + K_R)) = f,$$

if $K_C^c > 0$ and 0 otherwise.

- The efficient capacity will be provided under a capacity payment

$$t(K^*) = f - (\bar{p} - c)(1 - G(K^*)) > f - (v - c)(1 - G(K^*)) = 0.$$

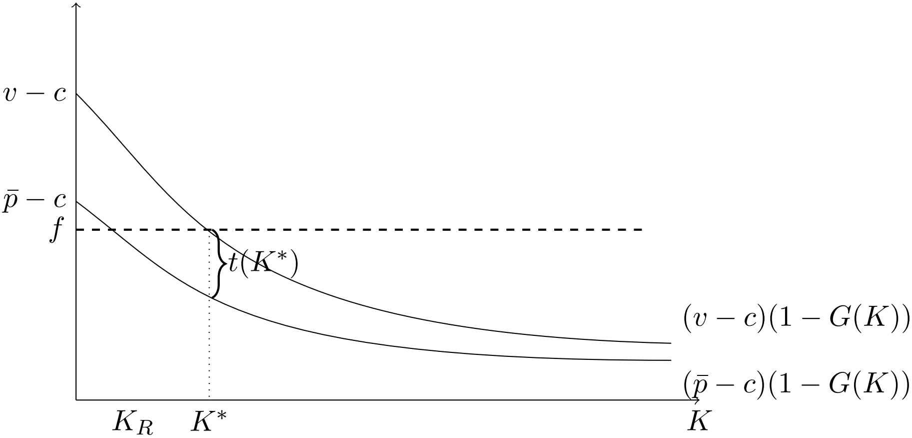


Figure: Capacity choices and capacity payments when $(v-c)(1-G(K_R)) > f$.

Externalities

- The same results arise if $v = \bar{p}$, once we account for the negative externalities from power disruptions (e.g. blackouts).
- Suppose that blackouts entail costs to third parties with a per-unit cost $b > 0$. Then, the optimal capacity would be the result

$$(v + b - c)(1 - G(K_C^{**} + K_R)) = f,$$

with K_C^{**} increasing in b, and $K_C^{**} > K_C^c$.

- Blackouts might also generate a political cost. When $v = \bar{p}$ and under no capacity payments, the probability of a blackout is

$$1 - G(K_C^* + K_R) = \frac{f}{v - c}.$$

If this blackout has a political cost $B \geq 0$, a regulator will choose a higher capacity, defined as

$$(v - c)(1 - G(K_C^{**} + K_R)) = f - Bg(K_C^{**} + K_R).$$

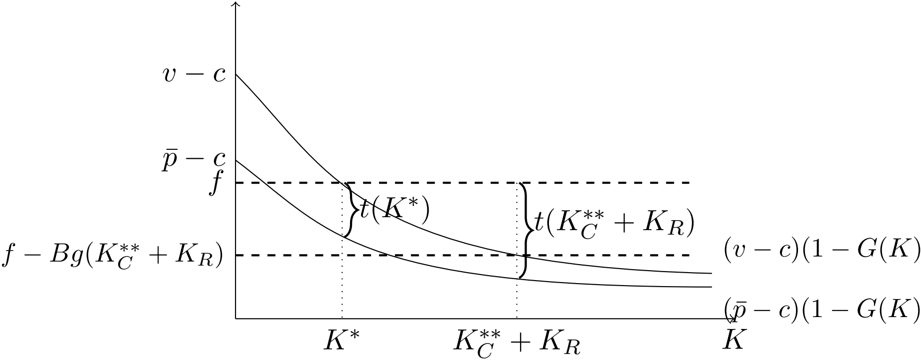


Figure: Effect of blackout costs on capacity payments.

- As the effects are the same as with a price cap, we will focus on that interpretation in the rest of this presentation.

Volatile Renewable Production

- Volatility is a relevant to many renewable power sources.
- Denote as $\bar{K}_R$ the installed (or *nameplate*) renewable capacity.
- Production corresponds to $\theta\bar{K}_R$, where $\theta \sim H(\theta)$ with density $h(\theta)$. Define $K_R \equiv E(\theta)\bar{K}_R$.
- The socially optimal capacity, K_C^*, arises from

$$\max_{K_C} \int_0^1 \left\{ \int_0^{\theta\bar{K}_R} vqg(q)dq + \int_{\theta\bar{K}_R}^{\theta\bar{K}_R+K_C} \left[vq - c(q-\theta\bar{K}_R)\right] g(q)dq \right.$$
$$\left. + \left[v(K_C+\theta\bar{K}_R) - cK_C\right]\left[1 - G(K_C+\theta\bar{K}_R)\right] \right\} h(\theta)d\theta$$
$$- fK_C - F. \quad (3)$$

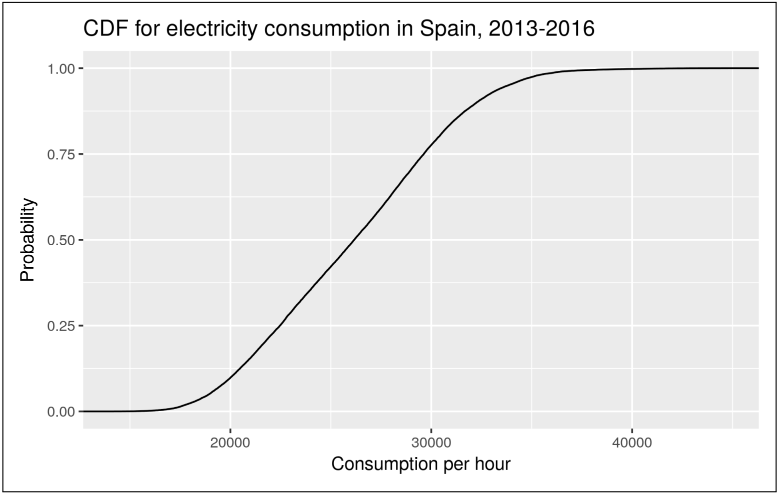
with FOC

$$\int_0^\infty (v-c)(1-G(\tilde{K}_C+\theta\bar{K}_R))h(\theta)d\theta = f.$$

Proposition

Consider two alternative renewable tecnologies $i = 1, 2$ with distribution functions $H_1(\theta)$ and $H_2(\theta)$, with the same expected production, K_R, but where $H_2(\theta)$ second-order stochastically dominates $H_1(\theta)$. If $G(p)$ is concave, the welfare maximizing conventional capacity, $\tilde{K}_C$, is higher under $H_2(\theta)$.

- $G(q)$ concave implies that $g(q)$ is decreasing in q.
- Under this assumption, conventional power is more necessary when the volatility of renewable plants increases $\longrightarrow$ The gain of renewable energy from meeting high demand due to volatility is lower than the loss from failing to meet a low demand, which is more likely.
- Is $G(q)$ concave in practice?


CDF for electricity consumption in Spain, 2013-2016
Probability
1.00
0.75
0.50
0.25
0.00
20000
30000
40000
Consumption per hour

- When q is high, concavity of $G(q)$ in an uncontroversial assumption.
- When q is low, $G(q)$ is likely to be convex. However, in this case the production would be covered anyway with conventional power (e.g. nuclear plants), making the effect of renewable energy less important.
- Furthermore, notice that the substitution affects mainly to CCGTs, which are useful when renewable energy is not available, as opposed to base-load technologies. This results is consistent with Cullen (2013).
- The model assumes that θ and q are uncorrelated. If they were negatively correlated (e.g. windmills) the previous effects would be reinforced.

Renewable Capacity Increases

- We start from a situation in which the efficient K^* has been reached using only conventional capacity ($K_R = 0$, $K_C^* = K^*$).
- Suppose that the government sets an (exogenous) target for renewable power K_R.
- We assume that CCGT plants can be decommissioned with a redeployment value (per-unit of capacity) of γf.
- We study how conventional power should be adjusted.

For simplicity, we focus on the case in which price caps generate a missing-money problem, but there are no externalities or volatility of renewable power since their effects are similar and/or additive.

- Given $K_C^* = K^*$, the optimally adjusted conventional capacity after the entry of K_R results from

$$\max_{\hat{K}_C \le K_C^*} \int_0^{K_R} vqg(q)dq + \int_{K_R}^{K_R+\hat{K}_C} \left[vq - c(q - \hat{K}_R)\right] g(q)dq + \left[v(K_R + \hat{K}_C) - c\hat{K}_C\right]\left[1 - G(\hat{K}_C + K_R)\right] - fK_C^* + \gamma f(K_C^* - \hat{K}_C).$$

- As a result optimal capacity is defined as
  - equal to K_C^* if $\gamma \le \underline{\gamma}$ or
  - the solution to

$$(v - c)(1 - G(\hat{K}_C + K_R)) = \gamma f,$$

otherwise.

Is a Renewable Capacity Socially Profitable?

- Whether introducing renewable capacity is optimal or not can be *approximated* with the following condition

$$f\left[K_R - (1-\gamma)(K_C^* - \hat{K}_C^*)\right] > F - cK_R(1 - G(K_R)) - \int_0^{K_R} cqg(q)dq.$$

- Changes in γ have two effects operating in different directions:
  - Increases in γ makes the (downward) adjustment of conventional power less costly, but
  - If γ increases the difference $K_C^* - \hat{K}_C^*$ shrinks.

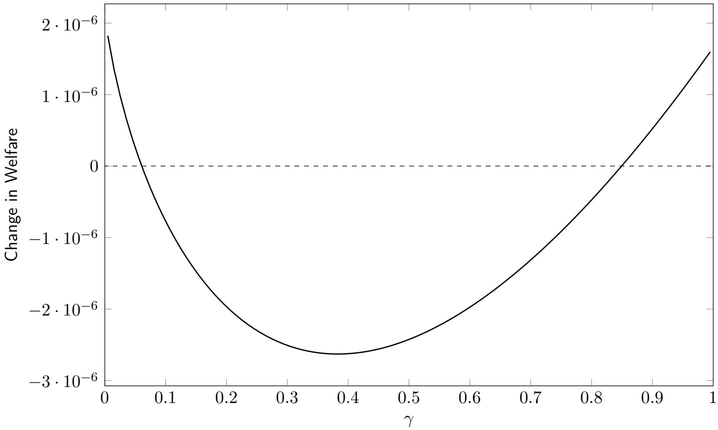


Figure: Example of the change in welfare resulting from the introduction of renewable capacity, assuming $G(K) = 1 - e^{-\alpha K}$ and using parameter values $c = 0.05$, $f = 0.1$, $K_R = 0.12$, $F = 0.013$, $\alpha = 8$.

An Adjusted Capacity Mechanism

- After the entry of renewable capacity, conventional power producers will make losses since

$$(\bar{p}-c)(1-G(\hat{K}_C^*+K_R))+t(K_C^*)-f<-(1-\gamma)f,$$

- How to restore profitability after the entry of renewable power?
- When $\gamma \leq \underline{\gamma}$ it is enough to increase the capacity payment from $t(K_C^*)$ to $t(K_C^*+K_R)$
- When the $\gamma > \underline{\gamma}$ some capacity must exit...

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Exit of Conventional Capacity: $\gamma > \underline{\gamma}$

- An ex-post capacity auction with a fixed capacity withdrawal can implement the optimal allocation.
- Suppose firms receive a payment (per-unit of capacity) of t_E if they exit the market and T_S if they stay. Firms will be indifferent if

$$\gamma f + t_E = (\bar{p} - c)(1 - G(\hat{K}_C^* + K_R)) + t_S.$$

- To implement the optimal allocation it is enough that the regulator sets an exit payment $\tilde{t}_E = (1-\gamma)f$ for the capacity that exits the market.
- Firms that decide to stay will optimally bid

$$t_S = \frac{v - \bar{p}}{v - c}\gamma f + t_E > t_E.$$

Conclusions

- This paper proposes a simple framework to talk about capacity increases and interaction between technologies.
- This framework embeds the most important reasons why capacity payments are optimal: price caps and externalities.
- Increases in volatility make, under reasonable assumptions, conventional power, and particularly CCGTs, more necessary and, as a result, increase the amount of capacity payments.
- We provide conditions under which ex-post entry of renewable capacity is optimal and capacity payments should increase as a result.
- The paper also shows that the results hold when firms have market power.

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