Regulatory Design and Incentives for Renewable Energy

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Motivation

- Increasing electric power production from renewable energy sources is now widely perceived as a sensible goal for energy policy
- Ambitious targets for 2020:
    - EU (20%), China (15%), US (20%) *on average*.
- A consensus seems to exist on the need for regulatory intervention.

Regulatory Design

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- *Feed-in tariff* (FIT): The wholesale electricity market is forced to buy all renewable output at a fixed, pre-established price.
- *Renewable Portfolio Standard* (RPS): Utilities must invest so that renewable output is no less than a given fraction of their total output.

Regulatory Design

Regulation in motion:

- (Germany) Phase-out of nuclear power, feed-in tariffs for new roof-mounted photovoltaic solar arrays are seen as “too high”.
- (UK) Lively debate on the need to increase the Feed-in Tariff.
- (US) Current discussion on mandatory RPS.

Outline

- Model for optimal investment in renewable (intermittent) and conventional capacity.
- Is there need for incentives in an energy only market where the price of electricity is set by the marginal technology ?
- What is the "optimal" feed-in tariff ? What is the "optimal" portfolio standard ?
- What are the pros and cons of each approach ?

Model Setup

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    - Let $\bar{W}_i \geq 0$ denote the potential for renewable energy at site $i \in \{1, \cdots, N\}$. We assume $\bar{W}_i = \alpha_i \xi$ where $\alpha_i > 0$ and $\alpha_i > \alpha_j$ for $i < j$

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  - If the capacity installed at site i is K_i, then $W_i(K_i) = \min\{\bar{W}_i, K_i\}$
  - $W(K_1, \ldots, K_N) = W_1(K_1) + \ldots + W_N(K_N)$ is the aggregate random output.

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- Demand $D(p) = D$ given electricity prices $p \in [0, v]$ where $v > c_T$ and $D(p) = 0$ if $p > v$
- The optimal dispatch of resources is one in which the conventional capacity supplies the residual demand,

$$Q_T = \min(D - W(K_1, \ldots, K_N), K_T)$$

Socially Optimal Investment

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- The capacity configuration that maximizes expected output is:

$$K_i^*(n, K) = \begin{cases} \frac{\alpha_i}{\sum_{i=1}^{n} \alpha_i} K & i \leq n \\ 0 & i > n \end{cases}$$

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- Let $\alpha(n) = \sum_{i=1}^n \alpha_i$. It follows that

$$W^{n,K} = \begin{cases} \alpha(n)\xi & \xi < \frac{K}{\alpha(n)} \\ K & \xi \geq \frac{K}{\alpha(n)} \end{cases}$$

Socially Optimal Investment

- Expected social surplus can be written as:

$$E[S^{n,K,K_T}] = vE[W^{n,K}] + (v - c_T)E[Q_T] - \kappa K_T - (\kappa + \delta)K - n\gamma$$

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- Assume $K_T + K > D$ (i.e. installed capacity is *nominally* enough to supply demand.
- Rationing may occur when

$$\Pr(K_T + W^{n,K} < D) = H\left(\frac{D - K_T}{\alpha(n)}\right) > 0.$$

Socially Optimal Investment

Proposition 1.a: *Suppose n sites are to be developed and $H(\frac{D}{\alpha(n)}) \geq 1 - \frac{\kappa+\delta}{c_T} > \frac{\kappa}{v-c_T}$. Socially optimal investment in conventional $K_T^*(n)$ and in renewable technology $K^*(n)$ is characterized by*

$$
\begin{aligned}
H\left(\frac{D-K_T^*(n)}{\alpha(n)}\right) &= \frac{\kappa}{v-c_T} \\
1 - H\left(\frac{K^*(n)}{\alpha(n)}\right) &= \frac{\kappa+\delta}{c_T}
\end{aligned}
$$

and $D \geq K^*(n) > D - K_T^*(n)$.

Socially Optimal Investment

Proposition 1.b: *Let* $\xi_1 = H^{-1}\left(\frac{\kappa}{v-c_T}\right)$ *and* $\xi_2 = H^{-1}\left(1-\frac{\kappa+\delta}{c_T}\right)$ *and* $H(\frac{D}{N\alpha_1}) \geq 1-\frac{\kappa+\delta}{c_T} > \frac{\kappa}{v-c_T}$. *The optimal capacity mix is given by* $K_T^*(n^*)$ *and* $K(n^*)$ *where* n^* *is the unique solution to*

$$\begin{aligned} \alpha_{n^*}(v\int_0^{\xi_1} udH(u) + c_T\int_{\xi_1}^{\xi_2} udH(u)) &\geq \gamma \\ \alpha_{n^*+1}(v\int_0^{\xi_1} udH(u) + c_T\int_{\xi_1}^{\xi_2} udH(u)) &< \gamma \end{aligned}$$

and $D \geq K^*(n^*) > D - K_T^*(n^*)$.

Equilibrium Investment without Regulatory Intervention

- Assuming price-taking behavior, the spot price for electricity $\widetilde{p}$ can be expressed as follows:

$$\widetilde{p} = \begin{cases} 0 & D - W(K_1, \ldots, K_N) = 0 \\ c_T & D - W(K_1, \ldots, K_N) \in (0, K_T] \\ \bar{p} & D - W(K_1, \ldots, K_N) > K_T \end{cases}$$

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- Aggregate expected producer surplus for both conventional and renewable technologies can be written as:

$$\begin{aligned} E[\Pi_T] &= E[(\widetilde{p} - c_T)Q_T] - \kappa K_T \\ &= [(\bar{p} - c_T)G^W(D - K_T) - \kappa]K_T \end{aligned}$$

  where G^W denotes the probability distribution of W.

Equilibrium Investment without Regulatory Intervention

- In competitive equilibrium, the aggregate investment in conventional capacity K_T^e induces zero expected surplus. Thus, we have:

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- Note that when $\bar{p} = v$, the probability of rationing under equilibrium investment in conventional technology is the same as in the optimal capacity configuration.

Equilibrium Investment in Renewable Capacity

Definition 1: *Let $\mathcal{A} \subseteq \{1, 2, \ldots, N\}$. We say that capacity configuration (K_i^e, K_{-i}^e) is a constrained equilibrium if:*

1. *For all $i \notin \mathcal{A}$, $K_i^e = 0$* and
2. *For all $i \in \mathcal{A}$*

$$E[\Pi^i(K_T^e, K_i^e, K_{-i}^e)] \geq E[\Pi^i(K_T^e, K_i, K_{-i}^e)] \qquad \text{for all } K_i \geq 0$$

Definition 2: *We say that renewable capacity configuration (K_i^e, K_{-i}^e) is an equilibrium if for all $i \in \{1, \ldots, N\}$:*

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Equilibrium Investment in Renewable Capacity

Lemma: *Let* $\mathcal{A} \subseteq \{1, 2, \ldots, N\}$ *and* $\alpha(\mathcal{A}) = \sum_{i \in \mathcal{A}} \alpha_i$. *If* $H(\frac{D}{N\alpha_1}) \geq 1 - \frac{\kappa+\delta}{c_T} > \frac{\kappa}{\bar{p}-c_T}$, *the capacity configuration*

$$
\begin{aligned}
K^e &= \alpha(\mathcal{A}) H^{-1}\left(1 - \frac{\kappa+\delta}{c_T}\right) \\
K_i^e &= \frac{\alpha_i}{\alpha(\mathcal{A})} K^e \\
&= \alpha_i H^{-1}\left(1 - \frac{\kappa+\delta}{c_T}\right)
\end{aligned}
$$

for $i \in A$ *and* $K_i^e = 0, i \notin \mathcal{A}$ *is the unique constrained equilibrium and* $D \geq K^e > D - K_T^e$.

Equilibrium Investment in Renewable Capacity

- By Lemma, for fixed n, the equilibrium capacity configuration maximizes output.
- If first n projects are developed *optimally*, what are the incentives at the margin ?

$$E[\Pi^n] = \alpha_n(\bar{p}\int_0^{\xi_1} udH(u) + c_T\int_{\xi_1}^{\xi_2} udH(u)) - \gamma$$

Equilibrium Investment in Renewable Capacity

Proposition 2: *There exists a unique equilibrium capacity configuration which equals the socially optimal configuration if* $\bar{p} = v$.

- Rationales for incentives ?

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- Consider a situation in which the fixed cost for developing the *n*-th site, *given that* the first $n-1$ sites have been developed, is γ_n and $\gamma_n > \gamma_{n+1} > 0$.
- We show this leads to under-investment in renewable technology.
- Note that a monopoly in renewable technology could fully exploit the economies associated with "learning by doing"

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- When $\bar{p} < v$ investment in conventional capacity is incentivized via capacity markets.
- High levels of "resource adequacy" for conventional technologies preempt investment in renewables.

Feed-in Tariffs

- All renewable output from a developed site is remunerated according to a single pre-specified rate $p < v$.
- The expected profit for the $i-$th site is

$$E[\Pi^i(K_i; p)] = pE[\min\{\bar{W}_i, K_i\}] - (\kappa + \delta)K_i - \gamma$$

Thus, the first order condition is:

$$\frac{\partial E[\Pi^i(K_i; p)]}{\partial K_i} = p(1 - H(\frac{K_i}{\alpha_i})) - (\kappa + \delta)$$

Hence, the optimal capacity $K_i^*(p)$ at this site given a feed-in tariff p is:

$$K_i^*(p) = \alpha_i H^{-1}\left(1 - \frac{\kappa + \delta}{p}\right)$$

Feed-in Tariffs

- For a fixed value of $p \in (c_T, v)$ the equilibrium number of sites developed at optimal capacity, say n^e, is defined by:

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  In words, the i-th site is over-developed whenever $p > c_T$.

- Only when $p = c_T$ we have $K_i^*(p) = K_i^*$. However, by assumption, there is under-investment in renewable capacity without a feed-in tariff.

Feed-in Tariffs (FIT)

Proposition 3: *There is no single feed-in tariff that incentivizes socially optimal investment in renewable capacity.*

Renewable Portfolio Standard (RPS)

Proposition 4: *There does not exist an RPS standard that induces socially optimal investment.*

FIT *vs* RPS

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- However, feed in tariffs appear to be easier to manipulate (regulatory capture).
- An RPS standard may serve as coordination device for the exercise of market power.

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- Economies of scale (learning by doing) play an important role in justifying incentives.
- By weakening investment incentives in conventional technology, an RPS regime is likely to cause problems in *resource adequacy*.
- A "clinical" regulatory design, that is, one that promotes the right amount of renewable capacity without affecting conventional capacity is a challenging proposition.