Long Term Capacity Contracting with Renewables

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*Joint work with Nur Sunar
``Massachusetts Utilities Sign PPA for Wind Energy

National Grid, Northeast Utilities, and Unitil have filed documents with the Massachusetts Department of Public Utilities seeking to add 565 MW of wind energy from six projects across Maine and New Hampshire.’’

Huge investments in renewables by Fortune 100 companies...

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...We've invested over a billion dollars in 15 renewable projects that have the
capacity to produce two gigawatts of power around the world, mostly in the U.S.,
but that's the equivalent of Hoover's Dam worth of power generation...
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*Rick Needham, Google's director of Energy and Sustainability, 2014*
Most common way to invest: Power Purchase Agreements

- Signed a power purchase agreement with a wind farm (Keechi Wind project) in 2013.
- Bought the entire energy generated by the wind farm.
- The agreement duration is 20 years long.
- A new wind farm is constructed with this PPA.
## PPA Offers to a University

<table>
<thead>
<tr>
<th>Supplier</th>
<th>10 years</th>
<th>15 years</th>
<th>20 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy only</td>
<td>Energy+REC</td>
<td>Energy+GATS</td>
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<tr>
<td>A</td>
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<td>$39.00</td>
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<td>B</td>
<td>$35.90</td>
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<td>C</td>
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<td>$48.67</td>
<td>$41.14</td>
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</table>
• What is the optimal design of a power purchase agreement (PPA) with renewables?

• When is it optimal for a firm/utility to sign a PPA?

• In equilibrium, how much renewable energy capacity is added to the electricity supply?
Problem Formulation

- Time is continuous.

- A firm (or a utility) needs to satisfy an uncertain electricity demand at each time instant $t$:

  \[ \{U_t, t \geq 0\} \]

- To satisfy the demand, the firm can
  - procure electricity from spot market at spot market price and/or
  - make a long term capacity contract with a new renewable generator.
Electricity Spot Price Dynamics

- **Total demand** for electricity in the spot market is such that

\[ \{D_t, t \geq 0\} \]

such that

\[ dD_t = \mu D_t dt + \sigma D_t dW_t, \quad t \geq 0. \]

- **Production from one unit of the renewable facility** is a general stochastic process

\[ \{Q_t, t \geq 0\} \]

- Building a new renewable energy facility of size K will result in **net electricity demand** process

\[ \{N_t = D_t - KQ_t, t \geq 0\} \]
• Spot market consists of $M > 1$ conventional generators, each of which
  — bids a supply function in the spot market, and
  — has a quadratic production cost function.

• As a result, electricity spot price at time $t$ is equal to

$$p_t = \theta N_t = \theta(D_t - KQ_t)$$
• Fixed capacity investment cost

\[ I(k) = c k^2, \quad k \geq 0. \]

• Based on the value of the contract, the renewable generator gets a non-recourse loan for project finance.

• Amount of loan = the value of the contract

• If the value of contract is \( V \), then the renewable generator invests in capacity \( K \) such that

\[ I(K) = V \]
Incentive Compatibility of the Firm

• The contract duration is $T > 0$.

• IC condition to sign a PPA with a renewable generator of capacity $K$ is:

\[
\text{cost of satisfying entire electricity demand from the spot market} \geq \text{net cost of having a long term contract with a renewable generator of size } K + \text{purchasing the residual demand from spot market}
\]
Proposition 1:

For any demand process, the firm’s gain from signing the optimal contract of length $T$ at time $t$ is

$$\theta^2 \left[ \int_t^{T+t} \mathbb{E} \left[ Q_s (U_s + D_s) | \mathcal{F}_t \right] ds \right]^2$$

$$\frac{4 \left( \theta \int_t^{T+t} \mathbb{E} [Q_s^2 | \mathcal{F}_t] ds + c \right)}{4 \left( \theta \int_t^{T+t} \mathbb{E} [Q_s^2 | \mathcal{F}_t] ds + c \right)}$$

In equilibrium, new renewable capacity added in the electricity market is

$$K^* = \frac{\theta \int_t^{T+t} \mathbb{E} \left[ Q_s (U_s + D_s) | \mathcal{F}_t \right] ds}{2 \left( \theta \int_t^{T+t} \mathbb{E} [Q_s^2 | \mathcal{F}_t] ds + c \right)}$$
Proposition 2:

For any demand process, new renewable capacity in the electricity market at time $t$

- decreases with the production variability,
- can be non-monotonic with respect to the mean of the production process (depending on its coefficient of variation).
Proposition 3:

Suppose that $U_t = \rho D_t$ for each $t$.

There exists a threshold demand $D^*$ such that it is optimal for the firm to sign a PPA with a renewable generator at the following time:

$$\tau = \inf\{t \geq 0 : D_t \geq D^*\}$$
Summary

- Optimal timing of long term contract
- Value of optimal power purchase agreement
- Renewable investment dynamics