Generation Capacity Expansion in a Risky Environment: A Stochastic Equilibrium Analysis

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The views expressed in this presentation are the views of the speaker and do not necessarily reflect the views of GDF SUEZ.
Private investors operate in a merchant world with different sources of uncertainty. These uncertainties have been increasing over time and are very hard to value.

- **Commodity Prices Risk**
  - Costs of fuels determine the marginal prices of the electrical system and the market prices; their relative behavior has an impact on the profitability of the different technologies.

- **Residual Demand Risk**
  - Uncertainty in the total demand growth (or decline)
  - Development of non-competitive but CO₂ friendly technologies through various subsidies
  - Decommissioning of nuclear and old conventional plants
  - Demand behavior

- **Regulation risk**
  - Market architecture
  - Carbon policy: uncertainty around the targets
  - Sustainability of Subsidy Mechanisms
Summary

This presentation:
Very stylized two stage Investment model:
   A two stage problem:
   1. Decide investment today (2010–2011)
   2. that will come on stream after 2016 (on which we know nothing)

Approach:

1. start from capacity expansion models because they allow for considerable
details in the representation of the system
2. cast them in an economic equilibrium context because this better represents
   a competitive economy
3. and expand on the representation of risk because it can no longer be simply
   passed to the consumer

Questions:
1. Do results from a risk neutral case differ much from a risk averse case?
2. Do capacity markets change this finding?
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- Investment incentives
- Risk factors and the price of risk
- Assessment
- Conclusion
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In this presentation: A simple two stage model and the corresponding equilibrium model with fixed price insensitive demand

<table>
<thead>
<tr>
<th>Optimization</th>
<th>Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can be written as stochastic optimization model</td>
<td></td>
</tr>
</tbody>
</table>
| Benefit: some features of power systems are amenable to optimization but not to equilibrium  
  - e.g. unit commitment characteristics |
| A stochastic version of the equilibrium model |
| Benefit: the equilibrium model can embed features that cannot be accommodated in optimization mode  
  - price sensitive storage possibilities arising from smart grids  
  - market imperfection such as average cost price |

What we need is a margin by plant, indexed by scenario from an adequate short term model to make an investment decision
1. The traditional capacity expansion model

- The simplest view: two periods
  - period 0: invest in a mix of technologies
  - period 1: operate the capacities

- Objective
  Satisfy a time segmented, price insensitive demand so as to minimize total (annual in this simple case) cost

- Early models go back to the sixties

- They expanded and progressively became quite sophisticated
2. Some notation

- Capacities $x(k)$ in technology $k$ operate at level $y(k, \ell)$ to satisfy demand level $d(\ell)$ of duration $\tau(\ell)$.
- Capacity cost is $I(k)$, operating cost is $c(k)$
- $e(k)$ are emission coefficients and NAP is the total allowed emission
- $PC$ is interpreted as a shortage cost or as a price cap
- $z(\ell)$ is the unsatisfied demand in time segment $\ell$
3. And a standard optimization model

- Operations

\[ Q(x) \equiv \min_{y \geq 0} \sum_{\ell \in L} \tau(\ell) \left[ \sum_{k \in K} c(k) y(k, \ell) + PC \ z(\ell) \right] \]  

s.t.

\[ 0 \leq x(k) - y(k, \ell) \quad \mu(k, \ell) \]  

\[ 0 \leq \sum_{k \in K} y(k, \ell) + z(\ell) - d(\ell) \quad \pi(\ell) \]  

\[ 0 \leq NAP - \sum_{\ell \in L} \tau(\ell) \sum_{k \in K} e(k) y(k, \ell) \quad \lambda \]  

\[ 0 \leq y(k, \ell). \]  

- Investment

\[ \min_{x \geq 0} \sum_{k \in K} I(k) x(k) + Q(x). \]
4. Resource adequacy and security of supply

- Former capacity expansion models used under the obligation to serve guaranteed the necessary capacity

- Do these models still make sense in a competitive system?

- If not, what should replace them?

- Do we have clear cut ideas on incentive to invest?
5. A first step: move from optimization to complementarity (or from optimization to economic equilibrium)

- Operations

\[ 0 \leq x(k) - y(k, \ell) \perp \mu(k, \ell) \geq 0 \]  
\[ 0 \leq \sum_{k \in K} y(k, \ell) + z(\ell) - d(\ell) \perp \pi(\ell) \geq 0 \]  
\[ 0 \leq NAP - \sum_{\ell \in L} \tau(\ell) \sum_{k \in K} e(k) y(k, \ell) \perp \lambda \geq 0 \]  
\[ 0 \leq c(k) + \mu(k, \ell) + e(k)\lambda - \pi(\ell) \perp y(k, \ell) \geq 0 \]  
\[ 0 \leq PC - \pi(\ell) \perp z(\ell) \geq 0. \]

- Investment

\[ 0 \leq I(k) - \sum_{\ell \in L} \tau(\ell) \mu(k, \ell) \perp x(k) \geq 0. \]
We can easily add market imperfections like free allocation of allowances (not possible in the optimization)

6. A second step: introduce some market features

Let $a(k)$ be the free allowance to unit capacity ($k$)

Replace

$$0 \leq I(k) - \sum_{\ell \in L} \tau(\ell) \mu(k, \ell) - x(k) \geq 0.$$  \hspace{1cm} (13)

by

$$0 \leq I(k) - a(k) \lambda - \sum_{\ell \in L} \tau(\ell) \mu(k, \ell) - x(k) \geq 0.$$  \hspace{1cm} (14)
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Is there a problem?

Discussion: the incentive to invest

Does one need intervention or support to incentivize investment in a competitive market

No in functioning markets
Yes in case of market failure

Are there market failures in electricity systems?
Investment in Energy-Only Markets is jeopardized for mainly 2 reasons:

- **Inefficient price caps**: Price spikes, which are needed to recover investment costs in EOM, are socially not accepted. Price caps in the energy market are too low.

- **Increasing risk**: Risk itself is not a market failure but the lack of trading possibilities of risk is

**Uncertainty** concerning the climate policies and the RES deployment may magnify the risk such that markets alone are unlikely to deliver appropriate investment responses.

**Regulations** that restrict efficient price formation (e.g. price cap) undermine the market signal for investment.

*IEA – “Securing Power during the Transition” - 2012*
Investment incentives

Remedies

- Energy only market: set regulated price $PC$ (ideally $VOLL$) during curtailment

- Capacity market: create a market for capacities; investor receive
  - electricity price when they operate
  - capacity value when they invest

- Other means not discussed here
A third step: update the model

- Energy only model: no change
  \[ 0 \leq I(k) - \sum_{\ell \in L} \tau(\ell) \mu(k, \ell) \perp x(k) \geq 0. \]

- Capacity market

  Replace
  \[ 0 \leq I(k) - \sum_{\ell \in L} \tau(\ell) \mu(k, \ell) \perp x(k) \geq 0. \]
  by
  \[ 0 \leq \sum_{k \in K} x(k) - \max_{\ell \in L} d(\ell) \perp \nu \geq 0 \]
  \[ 0 \leq I(k) - a(k) \lambda - \nu - \sum_{\ell \in L} \tau(\ell) \mu(k) \perp x(k) \geq 0 \]
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We pick only three risk factors for the discussion: commodity and carbon regulation.

- **Commodity Prices Risk**
  - Costs of fuels determine the marginal prices of the electrical system and the market prices; their relative behavior has an impact on the profitability of the different technologies.

- **Residual Demand Risk**
  - Uncertainty in the total demand growth (or decline)
  - Development of non-competitive but CO₂ friendly technologies through various subsidies
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- **Regulation risk**
  - Market architecture
  - Carbon policy: uncertainty around the targets
  - Sustainability of Subsidy Mechanisms
1. The EU-ETS: a 2007/early 2008 view

- Investors at time of decision to invest do not know
  - the total amount of allowances (the NAP) $NAP(n)$
  - the amount of free allowances $(a(k)) a(k,b)$
  that their plants will receive when coming on line.

- The new Directive removes some uncertainties but intro-
  duces other risks.
2. The standard risk factors

- Fuel prices and demand evolution

- Here only fuel prices: \( c(k, f) \)

- We do not consider demand risk. **But** we suppose that other risk factors have an impact on demand. This turns out to be technically and economically important.
3. A fourth step (1): introduce uncertainty in operations model

for all \((f, n, b)\)

\[0 \leq x(k) - y(k, \ell, f, n, b) \perp \mu(k, \ell, f, n, b) \geq 0\]

for all \((f, n, b)\)

\[0 \leq \sum_{k \in K} y(k, l, f, n, b) + z(\ell, f, n, b) - d(\ell, f, n, b) \perp \pi(\ell, f, n, b) \geq 0\]

for all \(n\)

\[0 \leq NAP(n) - \sum_{\ell \in L} \sum_{k \in K} e(k) y(k, l, f, n, b) \perp \lambda(\ell, f, n, b) \geq 0\]

for all \((f, n, b)\)

\[0 \leq c(k, f) + \mu(k, \ell, f, n, b) + e(k) \lambda(f, n, b) - \pi(\ell, f, n, b) \perp y(k, \ell, f, n, b) \geq 0\]

for all \((f, n, b)\)

\[0 \leq PC - \pi(\ell, f, n, b) \perp z(\ell, f, n, b) \geq 0.\]
4. A fourth step (2): update the investment part accordingly

- Energy only market

  for all $k$

  $$0 \leq I(k) - \sum_{f \in F, n \in N, b \in B} pb(b)pf(f)pn(n)a(k, b)\lambda(f, n, b)$$

  $$- \sum_{\ell \in L, f \in F, n \in N} \tau(\ell)pb(b)pf(f)pn(n)\mu(k, \ell, f, n, b) \Downarrow x(k) \geq 0.$$  

- Capacity market

  $$0 \leq \sum_{k \in K} x(k) - \max_{L,F,N,B} d(\ell, f, n, b) \Downarrow \nu \geq 0$$

  for all $k$

  $$0 \leq I(k) - \sum_{f \in F, n \in N, b \in B} pf(f)pn(n)pb(b)a(k, b)\lambda(f, n, b) - \nu$$

  $$- \sum_{\ell \in L, f \in F, n \in N, b \in B} \tau(\ell)pf(f)pn(n)pb(b)\mu(k, \ell, f, n, b) \Downarrow x(k) \geq 0.$$
How to price risk?

5. Risk neutral (RN) vs. risk averse (RA) investors

- Sometimes heard about the EU-ETS
  
  - “risk is not an issue! The industry is used to deal with it”
  
  - “bankruptcy is just a transfer of ownership”

- Suppose one wants to go beyond these comforting statements. Apply CAPM or APT: the $\beta$ are not always significantly $\neq 0$?

- What else? Introduce risk functions
We assume that risks are not traded and need to be priced by the investor \( \rightarrow \) we adjust the probabilities

6. Risk averse investors

- Invest according to a different probability

- Recall from mathematical finance \( P \) and \( Q \)
  
  \( P: \) the “statistical probability”
  here \( pf(f)pn(n)pb(b) \): given

  \( Q: \) a “risk adjusted probability” (risk neutral)
  noted \( \phi(k; f, n, b) \): to be found

- Principle: replace \( pf(f)pn(n)pb(b) \) by \( \phi(k; f, n, b) \)

- Question: where does \( \phi(k; f, n, b) \) come from?
The CVAR weights scenarios and hence changes the distribution

7. Reminder: the CVaR

Illustration of the CVaR$_\alpha$

Assume investors behave according to a CVaR (which is a coherent risk function (Artzner et al., 1989))
A new probability can easily be used in the equilibrium formulation

8. The net margin and the investment criterion

- Let

\[ \text{margin}(k; f, n, b) \equiv \sum_{\ell \in L} \tau(\ell) \mu(k; \ell, f, n, b) + \nu + a(k, b) \lambda(f, n, b) - I(k) \]

for the capacity market

\[ \text{margin}(k; f, n, b) \equiv \sum_{\ell \in L} \tau(\ell) \mu(k; \ell, f, n, b) \]

\[ + a(k, b) \lambda(f, n, b) - I(k) \]

for the energy only market

- Investment criterion

\[ 0 \leq - \sum_{f \in F, b \in B, n \in N} \phi(k; f, n, b) \text{margin}(k; f, n, b) \perp x(k) \geq 0 \]
How do we relate the CVAR to the risk adjusted probabilities?

\[ 0 \leq -\text{CVaR}_\alpha[\text{margin}(k; f, n, b)] \perp x(k) \geq 0 \]

and

\[ 0 \leq -\sum_{f \in F, b \in B, n \in N} \phi(k; f, n, b) \text{margin}(k; f, n, b) \perp x(k) \geq 0 \]

are identical expressions provided one uses the duality theory introduced by Artzner et al. (1989) and developed in computational form by Rockafellar and Uryasev (2002).
We can derive the risk adjusted probabilities from an additional complementarity constraint

- Applying Rockafellar and Uryasev, one formulates $\text{CVaR}(\text{margin}(\cdot))$ as an LP.

- One writes its dual with $\phi(\cdot)$ being some variables of it.

- One writes the corresponding complementarity conditions and one inserts them in the model, whether energy only or capacity market.
Two important benchmarks

- The fully incomplete market (Ehrenmann and Smeers, 2011)
  - Assemble the KKT conditions for the risk-averse producer

- The complete market (Ralph and Smeers, 2013)
  - Assuming a complete set of financial product (e.g. Arrow-Debreu securities)
  - One can solve the equilibrium by minimizing the total risk of the system

\[ \mathcal{M}^{\text{complete}} \equiv \max \rho^{\text{tot}} \left\{ \sum_{\ell} \tau_{\ell} \left( \text{VOLL}(d_{\ell}(\omega) - z_{\ell}(\omega)) - \sum_{k} C_{k}(\omega)y_{k,\ell}(\omega) \right) - \sum_{k} l_{k}v_{k} \right\} \]

0 \leq v_{k} - y_{k,\ell}(\omega)
0 \leq \sum_{k} y_{k,\ell}(\omega) + z_{\ell}(\omega) - d_{\ell}(\omega)

- Where \( \rho^{\text{tot}}(X) = \min_{Q \in Q_{\text{prod}} \cap Q_{\text{cons}}} \mathbb{E}[X] \)
- Similar to risk averse planning (minimizing total cost, except that the cost is corrected by the (exogeneous) term \( \text{VOLL} \, d_{\ell}(\omega) \)).
- The problem gives a welfare interpretation: the total risk of the system
Can we complete the market?

- Most restructured electricity markets are incomplete
  - There exists no financial product to hedge the risk factors associated with investment decisions.
  - For the relevant horizon, liquidity is simply not there

- This lack of hedging possibility disincentives investment
  - Current uncertainties are just too wide (demand, CO2 regulation, fuel prices)

- The literature advocates trading products as a remedy
  - Not yet supported by a model to quantify the effects.

First attempt

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1. A test problem

- Three technologies: Coal – CCGT – OCGT
- Three price caps: 10 000, 1000, 250 £/Mwh
- A peaky (because of wind) load duration curve decomposed in 5 time segments
- Two fuel price scenarios: steady coal; low/high gas (equally likely)
- Two NAP scenarios: - 20%; -30% (equally likely)
- Three allowance allocation scenarios: BAT benchmarking (.2); /MW(.2); full auctioning (.6)
Risk aversion matters: technology mix is substantially different. A low price cap shows high levels of scarcity.

### 4. Investment analysis: Energy only vs. capacity market

#### Price cap: 10000 Euro/Mwh

<table>
<thead>
<tr>
<th>Coal</th>
<th>CCGT</th>
<th>OCGT</th>
<th>Total</th>
<th>Shortfall</th>
<th>Hours</th>
<th>Consumer Cost in bn Euro</th>
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<td>CM/RN</td>
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#### Price cap: 1000 Euro/Mwh

<table>
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<tr>
<th>Coal</th>
<th>CCGT</th>
<th>OCGT</th>
<th>Total</th>
<th>Shortfall</th>
<th>Hours</th>
<th>Consumer Cost in bn Euro</th>
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<td>CM/RN</td>
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#### Price cap: 250 Euro/Mwh

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<th>Consumer Cost in bn Euro</th>
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<tr>
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</table>
Example: Project finance uses different cost of capital for different technologies

8. Technology dependent risk aversion

- Principle: technologies are subject to other risks than those represented in the model

⇒ We use $\alpha(\text{coal}) = 1$, $\alpha(\text{CCGT}) = 0.8$ and $\alpha(\text{OCGT}) = 0.5$

<table>
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<tr>
<th></th>
<th>Coal</th>
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Price cap: 10000 Euro/Mwh

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Price cap: 1000 €/Mwh

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<th>Total</th>
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Price cap: 250 €/Mwh
6. Risk return analysis (1)

Excess return $E(R) - R_f$  Sharpe ratio $\frac{E(R) - R_f}{\sigma(R)}$

<table>
<thead>
<tr>
<th>Investment</th>
<th>Expected net margin</th>
<th>Standard deviation</th>
<th>Excess return</th>
<th>Sharpe ratio</th>
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<tbody>
<tr>
<td>10000/CM/RA</td>
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<td>1137929</td>
<td>4409761</td>
<td>14.2 %</td>
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<td>10000/EO/RA</td>
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<td>3655756</td>
<td>9.8%</td>
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<tr>
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<td>14.2 %</td>
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<tr>
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<td>1193473</td>
<td>3671791</td>
<td>15.7%</td>
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<tr>
<td>250/EO/RA</td>
<td>6087818</td>
<td>840866</td>
<td>2697266</td>
<td>13.8%</td>
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Computation of risk premium of the whole generation system

<table>
<thead>
<tr>
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<th>Expected net margin</th>
<th>Standard deviation</th>
<th>Excess return</th>
<th>Sharpe ratio</th>
</tr>
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<tbody>
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<td>15.4%</td>
</tr>
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Computation of risk premium of the coal plant
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  - NEW: demand risk as a result of recovering from crisis

- Is all of this good?
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    * control by prices
    * control by quantities
  - a major question
    * control by prices in an imperfect/incomplete market: does it work?
The most part of the talk is based on


An extension to industrial size models was presented in


An extension for a set of contracts for risk hedging was presented in