Stochastic Models, Auctions, Wind and Demand
Should we guess who is coming the dinner?
Should we set an extra place at the table?
Should they have reservations?

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Early contribution to statistical decision theory

Pascal's wager (hedge):

Pascal is unimpressed by *a priori* demonstrations that God exists.

"Endeavour ... to convince yourself, not by increase of proofs of God..., "we do not know if He is ...".

Pascal seeks *prudential* reasons for believing in God.

We should wager that God exists because it is the best bet.

<table>
<thead>
<tr>
<th></th>
<th>God exists</th>
<th>God does not exist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wager for God</td>
<td>Gain all</td>
<td>Status quo</td>
</tr>
<tr>
<td>Wager against God</td>
<td>Misery</td>
<td>Status quo</td>
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</tbody>
</table>

Decision theoretic formulation of the reasoning:

Maximizes expected utility
RISK AND THE REGULATORY COMPACT

- Utilities are usually given risk premia in ROE
- Often these risks are not very specific.
- What risks are we compensating for?
  - cost passthroughs ⇒ PGA, FAC, uplift
  - loss of customers ⇒ raise rates
  - recovery of stranded costs ⇒ 100%
  - prudence/used and useful?
- What are the compensated risks?
- Can we be more specific?
Sources of Risks

Market: competition, demand, input markets ($CH_4$, $NO_x$, $SO_2$, $CO_2$), liquidity, counterparty, incomplete contracts, contract breach, technology

Regulatory: FERC, PUCs, EPA, State gov, Federal gov

Financial: interest rates, bankruptcy, creditworthy

Natural: rain, snow, storms, heat, cold, quakes
Natural sources of risks

- Rain
- Snow
- Storms
- Heat
- Cold
- Wind
- Earthquakes
- Volcanoes

And after Global Warming has happened...

WHAT GOOD IS SECOND-GUESSING??
WHAT'S YOUR POLICY TO FIX THIS?

I have decided to call this a "tumble."

GLOBAL WARMING

I will be greeted with flowers.

Those went extinct...
False risk evaluation

- Cognitive dissonance
- Controllable: air vs. car
- Catastrophic:
  - Nuclear
  - Drought
  - Cancer
- Natural v. anthropogenic:
  - Global climate: sun v. man
  - Radiation: sun v. cell phones
- Risk/benefit tradeoffs: drugs
- Imposed v. voluntary: smoking
- Trust v. distrust
Big betters/big losers

- Long Term Capital Management
  Trillion Dollar Bet
- Amaranth Advisors
  - 2005 made an estimated $1 billion on rising energy prices in
  - 2006 lost more than $6 billion
- MotherRock Energy Fund
  - a $400 million portfolio,
  - 2006 shut down after losing money on its bets that natural gas prices would fall
Uncertainty

- How good is the data?
  - How are they measured?
- What are the important uncertainties?
  - How do they change the market outcome?
- Can the problem be solved?
- Is the market model correct?
  - Turn a stochastic problem into a deterministic equivalent
  - How are market participants compensated?
  - How to dealing with incomplete markets
- What are you buying and selling?
  - Option
  - Hedge
  - Commodity
Different types of uncertainties

- Lumpy outage: $s_{d_t} \approx s_{d_{t+1}}$
  - e.g., equipment outage
  - $sd$ is the standard deviation

- Time decreasing uncertainty: $s_{d_t} < s_{d_{t+1}}$
  - e.g., weather: heat, cold, wind, humidity

- demand, generation, transmission = $f$(weather)

- solution uncertainty finding the optimal solution and operator intervention.
ISO market design
a three-stage game

First: The market design itself can be analyzed as a cooperative game
- cooperation is encouraged
- the market rules are decided by voting rules
- This part is often taken as a given in the electricity market literature.

The ISO operates several planning processes, reliability assessments, and rights and cost allocation systems

The third stage is the markets themselves
- Incomplete and indefinitely repeated
Public goods or externalities?

- When is a public good not a public good?
- Should winners compensate the losers?
- Public goods need a market definition.
- What happens to those who do not benefit?
- This turns them into club goods since those outside the market don’t pay
- Clubs have ownership and usage rights and fees
- We should analyze the expected positive and negative both social and pecuniary externalities?
- the Lindahl equations define the club membership.
<table>
<thead>
<tr>
<th>Good type</th>
<th>quantity</th>
<th>price</th>
</tr>
</thead>
<tbody>
<tr>
<td>private</td>
<td>private</td>
<td>public</td>
</tr>
<tr>
<td>Public</td>
<td>public</td>
<td>Private</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Club</th>
<th>membership</th>
<th>price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>private</td>
<td>private</td>
</tr>
<tr>
<td></td>
<td>usage</td>
<td>public</td>
</tr>
</tbody>
</table>
Deterministic public goods

Buyer $i$ given $p_i$: $\text{Max}_{q_i \geq 0} u_i(q_i) - p_i q_i$

first order condition: $q_i^* [u'_i(q_i^*) - p_i] = 0$

if $u'_i(q_i^*) < p_i$ $q_i^* = 0$ no benefit

if $u'_i(q_i^*) = p_i$ $q_i^*$ benefit

Supplier: $\text{Max}_{q \geq 0} \sum_{i,k} p_i q - c(q)$

first order condition: $\sum_i p_i = c'(q)$
Stochastic Club Goods
two part tariffs

Membership of $i$ given $p_i$ over $k$ with prob $\rho_k$:

$$\text{Max } q_{ik} \sum_k \rho_k [u_i(q_{ik}) - p_i q_{ik}]$$

first order condition: $\sum_k \rho_k [u_i'(q_{ik}^*) - p_i] = 0$

if $\sum_k \rho_k u_i'(q_{ik}^*) < p_i$, $q_i^* = 0$ no membership

if $\sum_k \rho_k u_i'(q_{ik}^*) = p_i$, $q_i^* > 0$ membership

$\sum_{i,k} \rho_k [u_i(q_{ik})] = q$

Club: $\text{Max } q \geq 0 \sum_{i,k} [\rho_k p_i q - c(q)]$

$q^* [\sum_i p_i - c'(q^*)] = 0$
Private, public and club goods

- Real power is a private good.
- Reactive power is a private good, but we treat it as a semi public good.
  - Pay opportunity costs
  - Creates regulatory must run generators
- Frequency is an interconnection-wide public good
- Voltage is a local public (club) good
## Energy Markets

<table>
<thead>
<tr>
<th>Energy Markets</th>
<th>Economic characterization</th>
<th>Engineering characterization</th>
<th>Pricing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>collective call option</td>
<td>reliability</td>
<td>one part market-clearing price</td>
</tr>
<tr>
<td>day-ahead market</td>
<td>private hedge</td>
<td>unit and energy commitment</td>
<td>two part market-clearing price</td>
</tr>
<tr>
<td>Residual unit commitment</td>
<td>public hedge reliability</td>
<td>additional unit commitment</td>
<td>one part (startup) pay as bid</td>
</tr>
<tr>
<td>Real-time market</td>
<td>private realization</td>
<td>energy</td>
<td>one part</td>
</tr>
</tbody>
</table>
Stochastic MIP unit commitment

K is the set of an random events, $k \in K$, $

\rho_k$ is the probably of $k$ and $\sum_k \rho_k = 1$. 

Max $\sum_{i,k} \rho_k b_i q_{ik} + f_i z_i$

$\sum_i q_{ik} = 0 \quad k \in K$

$q_{ik} - q^+_{ik} z_i \leq 0 \quad k \in K$

$-q_{ik} + q^-_{ik} z_i \leq 0 \quad k \in K$

$z_i \in \{0, 1\}, \{0, 1\}^n = Z, \quad i = 1, ..., n$
The dual of the restricted model

Min \( z_i^* \mu_i \)

\[
p_k - \alpha_{ik} + \beta_{ik} = \rho_k b_i
\]

\[
q^-_{ik} \beta_{ik} - q^+_{ik} \alpha_{ik} + \mu_i = f_i
\]

expected market-clearing price is

\[
p = \sum_k p_k - \alpha_{ik} + \beta_{ik} = \sum_k \rho_k b^*_i,
\]

where \( b^*_i \) is the market clearing price in event \( k \).

\[
\sum_k [q^-_{ik} \beta_{ik} - q^+_{ik} \alpha_{ik}] + \mu_i = f_i
\]
transmission

- Is transmission a public good? No
- Is it a club good? Yes
- What are the property rights?
  - To congestion
  - For new club members
- SPP transmission market proposal: find a state core with side payments?
- NYISO modified Argentina approach voting
- Merchant transmission
# Transmission Markets

<table>
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<th>Transmission Market</th>
<th>Economic characterization</th>
<th>Engineering characterization</th>
<th>Pricing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>public good</td>
<td>reliability</td>
<td>cost/load</td>
</tr>
<tr>
<td>Allocation of rights</td>
<td>allocation</td>
<td>fairness</td>
<td>none</td>
</tr>
<tr>
<td>Hedge auctions</td>
<td>hedge</td>
<td>none</td>
<td>one part</td>
</tr>
<tr>
<td>day-ahead market</td>
<td>formal cash out</td>
<td></td>
<td>one part</td>
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<tr>
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<td>virtual cashout</td>
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September 23, 2008
Characterization of electricity markets

- Stochastic market models
  - Two stage models?
  - Chance-constrained?
  - Bad deterministic equivalent markets

- Make assumptions to get a deterministic market

- Chance-constrained model
Loss of load probability

- 'One day in ten years'
- Design for LOLP < 1/3650
- Actually one event in ten years
  - increase reliability
- Should it be ac MWday or an outage event
Bid strategy in the day-ahead market with stochastic outages

- Parameters and assumptions:
  - day-ahead market residual demand curve is \( p_D(y) = a - by \).
  - Real-time market price with gen 1 is \( p_R \).
  - Real-time market price without gen 1 is \( p_R^x = p_R + d \)

<table>
<thead>
<tr>
<th>capacity</th>
<th>Running cost</th>
<th>Probability of outage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator 1</td>
<td>K</td>
<td>c</td>
</tr>
</tbody>
</table>
Decision Strategy:

- the generator must decide how much to offer, $y$ into day-ahead market
- maximize expected profits: $\pi(y)$.

$$\pi(y) = p_D(y)y - p_Ry(1-\alpha) + (p_R-c)K(1-\alpha) - p_Rx\alpha$$

- For the optimal strategy, $y^*$, $\pi'(y^*) = 0$.
- $y^* = \frac{a-(p_R+d\alpha)}{2b}$.
- the monopoly result $y^* = \frac{a-c}{2b}$
Demand, capacity, wind and smart markets

- If demand is price responsive,
  - Quantity risk is converted to price risk
  - Capacity markets become financial options
  - Reliability markets have shorter lead times

- Wind can clear the real-time markets

- Electric vehicles becomes storage devices

- Smart market operator
  - Commits load, transmission and generation