Dual gas and electric modeling

Pablo Dueñas, Universidad Pontificia Comillas
Tommy Leung, MIT

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Motivation

“In New England, a Natural Gas Trap” – NY Times

Five-Year High Power Prices

The price of electricity in New England is running way above normal because the price of natural gas, which is used to generate electricity, has spiked. Related Article »

Wholesale electricity in New England

Natural gas in New England

$120 per megawatt-hour

$15 per million B.T.U.’s
Objective

From wellheads to plugs

- Gas purchases
- Pipeline capacity contracting
- Power plants operation

Balancing zone
- Imports
- Exports
- Regasification
- Liquefaction

Households
- Industries
- Inter-zonal flows
- Injection
- Withdrawal

Power plants
- Households
- Regasification
- Liquefaction

Price vs. Quantity

Uncertainty

Short-term
- Gas purchases
- Pipeline capacity contracting
- Power plants operation

Medium-term
- Gas purchases
- Pipeline capacity contracting
- Power plants operation

Long-term
- Gas purchases
- Pipeline capacity contracting
- Power plants operation
Methodology

Purchasing in a gas spot market

\( z \equiv \text{gas pipeline} \)
\( e \equiv \text{gas consumer} \)
\( d \equiv \text{day} \)
\( k \equiv \text{scenario} \)

\[
c(zd) = \alpha_0 + \alpha_1 \cdot zd
\]

\[
\min_{zdk} \sum_{zdk} \omega_k \cdot c(HUB) = \sum_{zdk} \omega_k \cdot \left( \alpha_0 + \alpha_1 \cdot zd \right)
\]

\[
\text{s.t.} \quad HUB = \sum_{e} \left( d^{NGPP} + D^{CNV} \right) \quad \forall z, e, d, k
\]

\[
\sum_{e} \left( d^{NGPP} + D^{CNV} \right) \leq Q^{OUT} \quad \forall z, d, k
\]
Methodology

Contracting of pipeline capacity

\[ z \equiv \text{gas pipeline} \]
\[ e \equiv \text{gas consumer} \]
\[ m \equiv \text{month} \]
\[ d \equiv \text{day} \]
\[ k \equiv \text{scenario} \]

\[
\min_{h_{ze}^{\text{OUT}}, h_{zem}^{\text{OUT}}, h_{zedk}^{\text{OUT}}, d_{\text{GFPP}}, d_{\text{CNV}}} \sum_{z,e} \omega_k \left[ F_{\text{z}}^{\text{OUT}} \cdot h_{ze}^{\text{OUT}} + \sum_{m} \left( F_{\text{zm}}^{\text{OUT}} \cdot h_{zem}^{\text{OUT}} \right) + \sum_{d,k} \left[ F_{\text{zd}k}^{\text{OUT}} \cdot h_{zedk}^{\text{OUT}} + V_{\text{z}}^{\text{OUT}} \cdot \left( d_{\text{GFPP}}^{\text{zedk}} + d_{\text{CNV}}^{\text{zed}} \right) \right]\right]
\]

s.t.  \[
\begin{align*}
th_{zedk}^{\text{OUT}} &= h_{ze}^{\text{OUT}} + h_{zem}^{\text{OUT}} + h_{zedk}^{\text{OUT}} + h_{zd}^{\text{OUT}} - h_{zedk}^{\text{OUT}} \quad \forall z, e, d, (m/d \leq m), k \\
\sum_{e} h_{zedk}^{\Delta\text{OUT}} &= \sum_{e} h_{zedk}^{\text{V\text{OUT}}} \quad \forall z, d, k \\
\sum_{e} th_{zedk}^{\text{OUT}} &\leq (Q_{\text{z}}^{\text{OUT}} - D_{\text{CNV}}^{\text{zed}}) \quad \forall z, d, k \\
d_{\text{NGPP}}^{\text{zedk}} + D_{\text{zed}}^{\text{CNV}} &\leq th_{zedk}^{\text{OUT}} \quad \forall z, e, d, k
\end{align*}
\]
Methodology

A different way to define the load levels

Demand

Transition matrix

<table>
<thead>
<tr>
<th>Transition matrix</th>
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<tbody>
<tr>
<td>l₁</td>
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<tr>
<td>l₁</td>
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<tr>
<td>l₂</td>
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<tr>
<td>l₃</td>
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<tr>
<td>l₄</td>
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</tbody>
</table>
Methodology

Operating in an electricity market

g \equiv \text{thermal group}
m \equiv \text{month}
d \equiv \text{day}
l, l' \equiv \text{system state}
k \equiv \text{scenario}

\[
\begin{align*}
\min_{q_{gm}, u_{gmlk}, u_{gmlk'}} & \left( \sum_{g,m,l,k} \omega_k \cdot \left( \sum_{d \in m} T_{dlk}^{ST} \cdot (C_{g} \cdot q_{gm} + CF_{gmlk} \cdot u_{gmlk}) + \sum_{f} N_{fmlk}^{TRN} \cdot (C_{g}^{UP} \cdot u_{gmlk}^{UP} + C_{g}^{DN} \cdot u_{gmlk}^{DN}) \right) \right) \\
\text{s.t.} & \quad \left| D_{mlk}^{PWR} = \sum_{g} q_{gm} \right| \forall m,l,k : p_{mlk}^{PWR} \\
& \quad q_{gm} \leq Q_{g}^{MAX} \cdot u_{gmlk} \quad \forall g,m,l,k \\
& \quad q_{gm} \geq Q_{g}^{MIN} \cdot u_{gmlk} \quad \forall g,m,l,k \\
& \quad u_{gmlk} - u_{gmlk'} = u_{gmlk}^{UP} - u_{gmlk}^{DN} \quad \forall g,m,l,l',k 
\end{align*}
\]
Methodology

Coupling gas and electricity decisions

\[ d_{zedk}^{NGPP} = \sum_{g \in (z,e),l} F_g^{G\to P} \cdot T_{dlk}^{ST} \cdot q_{gmlk} \quad \forall z,e,d,(m/d \in m),k \]
Case study

The gas system

- Gas spot market
  - Minimum price 13 €/MWh-t, about 5 $/MMBtu
  - Price slope 0.05 €/MWh-t per GWht-t, about 5.6 $/MMBtu per Bcf

- Gas pipeline
  - Maximum capacity 85 GWh-t/day
  - City demand

- Gas power plants
  - 2 CCGTs + 2 OCGTs, 184 days at maximum power
  - 2 CCGTs, 325 days at maximum power
  - 2 OCGTs, 349 days at maximum power
Case study

The electricity power system

- Inelastic known electricity demand and five scenarios of wind power generation

  - Five net monthly demand
  - Seven states of the system per month

- Thermal groups
  - Four CCGT’s
  - Two coal power plants
  - Four OCGT’s
  - One gas-oil power plant

Variable cost [€/MW-e] vs Quantity [GW-e]

- CCGT
- Coal
- OCGT
- Gas-oil
Results

Electricity prices vs. Gas prices

![Graph showing electricity vs. gas prices](image)

- Electricity price
- Gas price
- Free capacity

- Coal
- CCGT
- OCGT
- Gas-oil

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Results

Pipeline capacity contracting

- How uncertainty affects the contract portfolio
- How secondary markets affect the contract portfolio

Margins:
- Margin – 25%
  - 311 days above 10%
- Margin – 9%
  - 126 days above 10%
Conclusions

- We have developed an optimization model
  - Gas purchases
  - Capacity contracting
  - Power plants operation

- Importance of uncertainty and efficient markets

- Future steps
  - Gas spot market is rather simplified
  - Other gas consumers, other priority levels
    - Risk-aversion
  - Power network, hydro power plants, other technologies
    - Competition, ramps
  - Sources of uncertainty
Short- & medium-term decision space for a portfolio owner of gas-fired power plants

3 years out

1 year out

Day Ahead

Intraday

Long-term gas supply and storage

Long-term electricity auctions

Maintenance agreements

Forward capacity market bids

Maintenance scheduling

Gas spot market purchases

Electricity market bids

Sources of uncertainty: (1) demand for generation, (2) fuel & electricity spot prices, (3) gas network capacity
Given this **multistage, time- and market-coupled decision process** subject to **uncertainty** from **fuel and electricity prices, gas availability, and electricity demand**, how does a portfolio owner make **strategic decisions** about **long-term fuel procurement contracts, long-term service agreements, forward capacity markets, spot market fuel purchases**, and **electricity bids**?
Thank you for your attention