Synchronizing Electricity and Natural Gas Markets

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Background

Natural Gas Industry
• Increased production and reserves
• Relatively low natural gas prices

Electricity Industry
• Coal-fired generation retired
• Proposed rule for new source performance standards

*Natural Gas may be “fuel of choice” for electricity generation*

How do the natural gas and electricity markets match up?
Market Differences: Electricity

- Non-storable
- Varying demand: Peak-load problem
- Time increment of interest? Continuous balancing
- Intra-day Market
Market Differences: Natural Gas

- Declining production over life of well is optimal.
- Storable
- Time increment of interest? Depend on:
  - producer: daily or longer
  - spot market: daily
- Cyclical (seasonal) fluctuations
- Provides ability to smooth supply over time
- Time increment of interest? Depends on:
  - stored by producer?
  - stored by transporter (pipeline)
  - stored by end-user
How to Coordinate?

Electricity

Natural Gas

Storage
Solutions?

Economic Coordination (Stoddard, Tabors, and Englander 2012)

Timing and Markets (Hibbard and Schatski 2012)
Modeling the Integrated Firm: NG production

Production of natural gas at the well:

\[
\dot{R}(t) = -q(t), \quad R(0) = R^0, \quad R(T) \geq 0
\]

Cost to produce:

\[
C\left(q(t), R(t), t\right); \quad C_q > 0, \quad C_{qq} \geq 0.
\]
Modeling the Integrated Firm: Storage

Let $g(t)$ be the amount of gas used as an input for electricity generation.

At any point in time, the produced gas is either used for generation or is stored, where $X(t)$ is the total amount of gas in storage.

So;

$$
\dot{X}(t) = q(t) - g(t), \quad X(0) = 0, \quad X(t) \geq 0
$$

The cost to store gas depends in the amount in storage and capacity:

$$
c(X, \bar{X}), \quad 0 \leq X \leq \bar{X}; \quad C_X > 0, \quad C_{XX} \geq 0, \quad C_X > 0, \quad C_{XX} > 0.
$$
Modeling the Integrated Firm: Generation

Electricity production function:

\[ e(t) = f(g(t), o(t), \bar{K}) \]

Where capacity, \( \bar{K} \), must be at least as great as demand:

\[ \bar{K} \geq D(P(t), t) \quad \forall t \in [0, T]. \]
The Integrated Firm’s Profit Maximization Objective

\[ \int_0^T e^{-rt} \left[ P(t) f(g(t), o(t), K) - \alpha(t)K - \chi(o(t), t) - c(X(t), \bar{X}, t) - C(q(t), R(t), t) \right] dt \]

Subject to:

The resource stock constraint

The storage capacity constraint

The generation capacity constraint

And the requirement to meet electricity demand.
The Integrated Firm’s Profit Maximization Objective

The extended Hamiltonian consistent with this problem is:

\[
L = e^{-rt} \left[ P(t) f(g(t), o(t), \bar{K}) - \alpha(t) \bar{K} - \chi(o(t), t) - c(X(t), \bar{X}, t) - C(q(t), R(t), t) \right] \\
- \lambda(t) q(t) + \eta \left[ q(t) - g(t) \right] + \delta(t) (\bar{X} - X) + \rho(t) \left[ \bar{K} - D(P(t), t) \right].
\]

Where

- \( \alpha(t) = \) periodic cost of generation capacity,
- \( \chi(\cdot) = \) periodic cost of other generation inputs
- \( \lambda(t) = \) option value of the resource in the ground,
- \( \eta(t) = \) option value of stored gas,
- \( \delta(t) = \) shadow value of storage capacity, and
- \( \rho(t) = \) shadow value on generating capacity.
Key implications from the integrated model:

Upstream: \( \eta(t) = e^{-rt} \left[ \frac{\partial C(q, R, t)}{\partial q} \right] + \lambda(t) \)

Option Value of Storage = Marginal Cost of Producing the gas + Option Value of gas

Downstream: \( \eta(t) = e^{-rt} \left[ P \frac{\partial f(g, o, K)}{\partial g} \right] \)

Option Value of Storage = Value of the Marginal Product of gas

At equilibrium:

Value of the Marginal Product of gas =

Marginal Cost of Producing the gas + Option Value of the gas in the ground
If Markets Are Not Integrated

The Downstream Value of the Marginal Product of gas \( \eta^D \)
can be

\[
\begin{cases} 
\text{greater than} \\
\text{equal to} \\
\text{less than}
\end{cases}
\]

The Upstream Marginal Cost of Producing the gas + Option Value of the gas in the ground \( \eta^U \)
If \( g^* > q^* \)

And if upstream deviates from \( q^* \), i.e., \( q > q^* \), then \( \eta^u > \eta^* \).

Optimal for downstream, but not for upstream:

- Natural gas producers over-produce today
- reduce profits over the life of the resource, and
- in some cases, reduce recoverable reserves of the resource.

End result: higher natural gas prices
Coordinated Markets

• Changing the natural gas spot market?

• Changing the regulations for natural gas production?

• What are the tradeoffs?
  - Sub-optimal production?
  - Market power?
  - Both?
Conclusions and Ongoing Research

- Peak-load demand for natural gas for generation is not always met
- Electricity generation and natural gas production markets distinctly different
- At the optimum, the sum of the marginal cost of producing gas plus the shadow value of the gas is equal to the value of the marginal product of gas
- Downstream efficiency may be at the expense of upstream efficiency
- The key to efficient operation of gas production and electricity production with gas may be the development of optimal storage at strategic locations. This is the focus of ongoing research
- What is the design of market rules for improved efficiency upstream and downstream? Also the focus of ongoing research...
Thank you.
Questions, comments and suggestions welcome
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