Optimal Commodity Trading with a Capacitated Storage Asset

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EWO Seminar, CMU
April 9, 2008
Commodity Asset Management/Optimization

Relevant areas:
- Engineering
- Finance and Financial Engineering
- Marketing
- Operations Management
- Operations Research

=> Interdisciplinary
Today’s Talk

Physical Control  Commercial Trading

... mainly in the context of natural gas (NG) storage
NG Industry and the Economy

• The NG industry plays an important economic role
  – Annual 2006 worldwide NG production is valued at about 0.8 trillion U.S. dollars

• NG storage capacity accounts for about 20% of annual demand in the U.S.

• The U.S. features a vibrant and fairly competitive wholesale NG market
The NG Industry Supply/Value Chain

Focus of this talk
Types of storage facilities in the U.S.  
- 10% Aquifers  
- 86% Depleted reservoir  
- 4% Salt caverns

Wild Goose Storage, Northern California (depleted Wild Goose natural gas field)

The following was retrieved on 4/8/2008:

SERVICES AND RATES: Our rates are 'market based' meaning they are fully negotiable, but our 'rack rates' (suggested retail prices) are currently as follows:

Monthly Reservation Charges  
Inventory ($/Dth) 0.03  
Injection ($/Dth/day) 3.00  
Withdrawal ($/Dth/day) 2.00  
Variable Charges ($/Dth) 0.04  
Fuel (approximately) 1%
Valuing and Managing a NG Storage Asset

Merchants, e.g., Sempra Commodities, Merrill Lynch, value and manage natural gas storage facilities as real options on natural gas prices.

In principle, the idea is simple: Buy low, inject, store, withdraw, and sell high...

... but there are practical difficulties
Modeling the evolution of NG prices
Constraints on minimum/maximum storage space and injection/withdrawal capacity
NG Prices and Variability

**Predictable** (seasonal) variability
NYMEX NG Futures Prices as of 2/1/2006
(NYMEX: New York Mercantile Exchange)

**Unpredictable** (stochastic) variability
NG Spot Prices
Henry Hub is the NYMEX delivery point

Monthly intervals – 72 months in the future

Daily intervals – 7 years

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Operational Aspects

Times required to fill-up or empty a facility (They vary because they span facilities with different space availabilities)

### Gas Storage Facility Operations

<table>
<thead>
<tr>
<th>Type</th>
<th>Cushion to Working Gas Ratio</th>
<th>Injection Period (Days)</th>
<th>Withdrawal Period (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquifer</td>
<td>Cushion 50% to 80%</td>
<td>200 to 250</td>
<td>100 to 150</td>
</tr>
<tr>
<td>Depleted Oil/Gas Reservoirs</td>
<td>Cushion 50%</td>
<td>200 to 250</td>
<td>100 to 150</td>
</tr>
<tr>
<td>Salt Cavern</td>
<td>Cushion 20% to 30%</td>
<td>20 to 40</td>
<td>10 to 20</td>
</tr>
</tbody>
</table>

Source: Analysis of FERC filings

“Slow”

“Fast”
Outline of Remaining Part of this Talk

• Model

• Optimal policy structure
  – Meaning of high/low prices

• Numerical results
  – Value of coordinating operations-trading interface
  – Value of modeling price uncertainty
Model Set Up

Periodic review - Finite horizon

An action is taken at each review time and executed between two successive review times

- Action > 0: Buy and inject the commodity
- Action = 0: Do-nothing
- Action < 0: Withdraw and sell the commodity

The merchant is risk neutral and price-taker
Model

$V_{\text{Stage}}(\text{Inventory, SpotPrice})$: Optimal value function

- Stage (review time) is in $\text{StageSet}$
- Inventory is in $\text{FeasibleInventorySet}$ (closed convex subset of real line)
- SpotPrice is in $\text{SpotPriceSet}_{\text{Stage}}$ (subset of real line)

Bellman equations (there are also terminal boundary conditions):

$V_{\text{Stage}}(\text{Inventory, SpotPrice}) = \max_{\text{Action}} \{\text{ImmediatePayoff}(\text{Action, SpotPrice})$

- $- \text{HoldingCost} \times \text{Inventory}$

+ $\text{DiscountFactor}$ (from NextStage back to Stage)

$\times \mathbb{E}_{\text{Stage}} [V_{\text{NextStage}}(\text{Inventory + Action, RandomSpotPrice})] \}$

s.t. Action belongs to $\text{FeasibleActionSet}(\text{Inventory})$

for all Stage, Inventory, SpotPrice in their respective sets

$\mathbb{E}_{\text{Stage}}$ is conditional expectation in Stage (given SpotPrice)
Immediate Payoff

ImmediatePayoff(Action, SpotPrice)

It never makes sense to buy and sell at the same time: ImmediatePayoff(Action, SpotPrice) is superadditive with respect to two actions of opposite sign (consequence of concavity in the action)

“Attractiveness” of selling/buying increases/decreases in price: Decreasing vertical differences in Action or ImmediatePayoff(Action, SpotPrice) is submodular in (Action, SpotPrice) or supermodular in (-Action, SpotPrice)
Capacity Functions: Fast Asset

Maximum # of cycles (turns) = # stages / 2 (assume # stages is even)

InjectionCapacity(Inventory) = MaxInventory - Inventory

WithdrawalCapacity(Inventory) = -Inventory

FeasibleActionSet(Inventory)

Maximum # of cycles (turns) = # stages / 2 (assume # stages is even)
Capacity Functions: Slow Asset

**Injection Capacity**

$$\text{InjectionCapacity}(\text{Inventory}) = \min\{IC, \text{MaxInventory} - \text{Inventory}\}$$

**Withdrawal Capacity**

$$\text{WithdrawalCapacity}(\text{Inventory}) = \max\{WC, -\text{Inventory}\}$$

These kinks play a key role in determining the parameters of the optimal policy structure.

Maximum # of cycles (turns) < # stages / 2
Basestock Target Optimal Policy

These targets are functions of the SpotPrice.
Optimal Basestock Targets and SpotPrice

Under mild assumption on the distribution of RandomSpotPrice in the next stage conditional on SpotPrice in the current stage (stochastically increasing in SpotPrice)

**Complementarity** relationship between inventory and spot price

\[ V_{stage}(Inventory, SpotPrice) \text{ supermodular in } (Inventory, SpotPrice) \]
High & Low Spot Prices with a Fast Asset

These spot prices are high at all inventory levels

These spot prices are low at all inventory levels

Decoupled optimal trading and operational decisions: “buy low” and “sell high”
High & Low Spot Prices with a Slow Asset

This spot price is both low and high at different inventory levels.

This structure cannot be fully characterized as “buy low” and “sell high”.

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Numerical Results: Policies

(1) Fast Capacity Optimal Policy (FCOP): Fast asset

(2) Slow Capacity Optimal Policy (SCOP): Slow asset

(3) Decoupled Operations Trading Policy (DOTP): buy/sell as in FCOP but inject/withdraw taking capacity functions into account.

In the slow case the injection/withdrawal capacities (per stage) vary between 10%, 20%, ..., 100% of maximum allowed inventory.

Stage length = 1 month
Numerical Results: Price Modeling

The **seasonal** component of the average spot price is given by the NYMEX forward curve

*Stochastic variations* around the deseasonalized average profile follow a mean reverting one-factor model

Price evolution is modeled using a trinomial lattice (Jaillet et al. 2004, MS)

Policies are computed using standard backward dynamic programming (DP)

Source: Smith and McCardle (1999)
Effect of Decoupling Trading and Operational Choices

DOTP Vs SCOP Total Value Losses (Percent)

ICSF: Injection Capacity Scaling Factor
WCSF: Withdrawal Capacity Scaling Factor

ICSF increases
Slow asset: ~ 110-120%

“Almost” fast asset: ~ 10%
Effect of “Slow” Capacity Functions

FCOP Vs SCOP Total Value Gains (Percent)

- ICSF increases
- Slow asset: 30-60%
- “Almost” fast asset: ~1%

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Flow Rate and Capacity Functions

FCOP Vs SCOP Flow Rate Gains (Percent)

ICSF increases

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**SCOP Relative Value of Price Uncertainty**

**Total** value = **Intrinsic** value
(Value of Price Seasonality)
+ **Extrinsic** Value
(Value of Price Uncertainty)

Average Extrinsic Value = 21%

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25
SCOP Absolute Value of Price Uncertainty

SCOP Extrinsic Value ($/MMBTU)
The total and intrinsic values increase at different rates

=> The extrinsic value is not monotonic in ICSF or WCSF
Capturing the SCOP Extrinsic Value

• **Reoptimized Intrinsic Value Policy (RIVP):**
  - Optimize using seasonal price component only
  - Implement current optimal action
  - Execute it
  - Observe newly realized forward curve
  - Repeat

• RIVP captures 99.81% of the average total asset value of SCOP across all I/WCSF values
  - min is 96%
  - max is 100%

• Modeling price uncertainty is important but can be done in a reactive fashion
  - Seasonal component is sufficient to make the right *initial* choice
  - Initial choice is always updated ...
Conclusions

• Optimally management of a capacitated storage asset is nontrivial
  – Operational and trading choices should not be decoupled with a slow asset

• Modeling price uncertainty is important in natural gas storage

• In this setting, this value can be captured (on average) without directly considering price uncertainty it the optimization

• However, asset valuation must take price uncertainty into account, directly or indirectly
Ongoing and Future Work

• Optimization with multifactor price models: DP curse of dimensionality
  – Currently working on approximation methods (w/ F. Margot, A. Scheller-Wolf, D. Seppi)

• “Uncontrollable” injections: storage downstream of a production/shipping process
  – Worked on a liquefied NG application where the shipping process is modeled as a closed queuing network (w/ M. Wang, S. Kekre, A. Scheller-Wolf)

• Multiple inventories and blending/refining (“assembly/disassembly”) systems: DP Curse of dimensionality, again
  – Petrochemical/process industries