Optimal Commodity Trading with a Capacitated Storage Asset

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Commodity Asset Management/Optimization

Physical Control

Commercial Trading

Financial Trading

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

=> Interdisciplinary

Today’s Talk

Physical Control

Commercial Trading

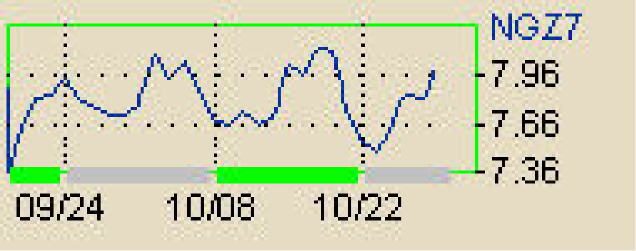
… mainly in the context of natural gas (NG) storage

NG Industry and the Economy

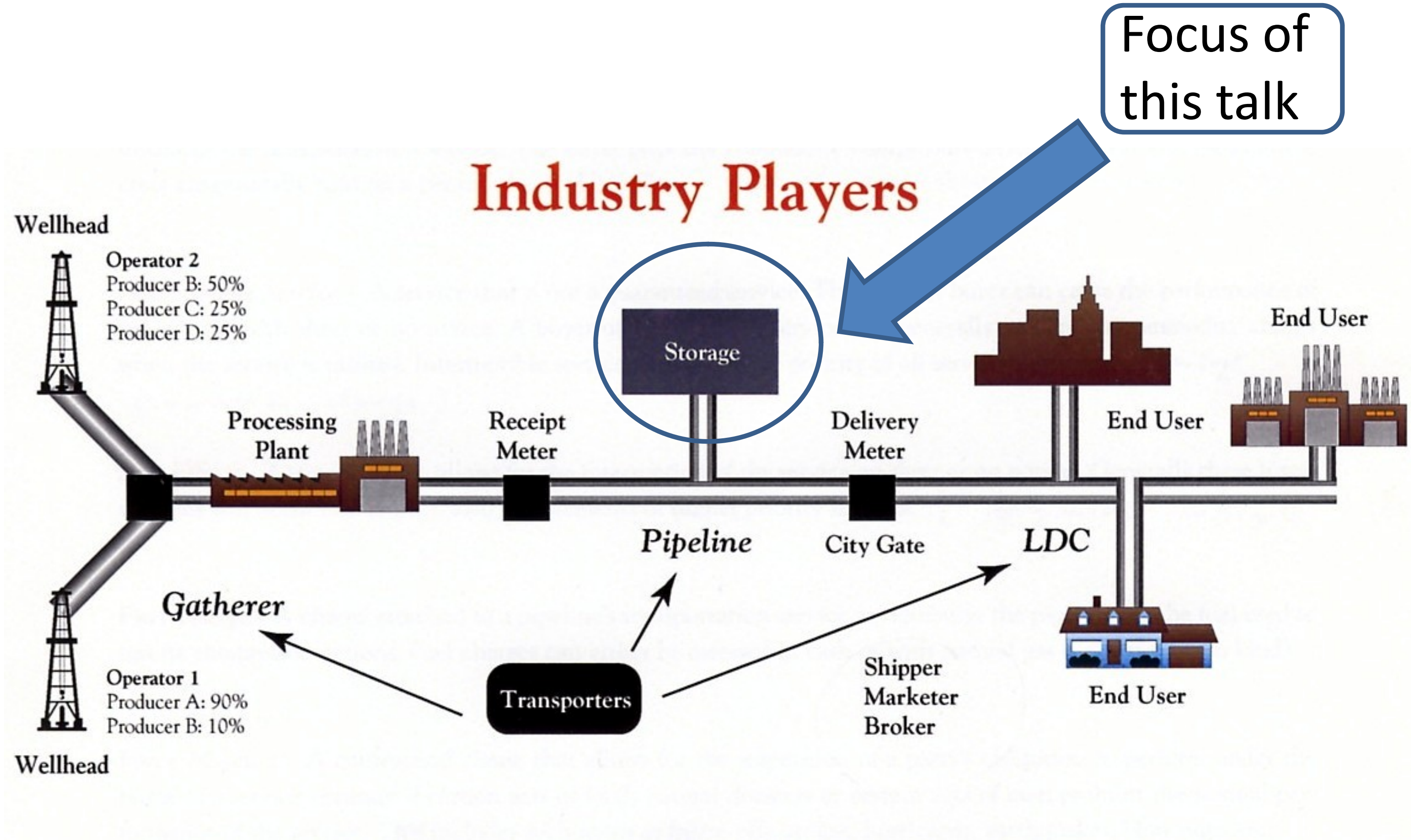
- The NG industry plays an important economic role
  - Annual 2006 worldwide NG production is valued at about 0.8 trillion U.S. dollars

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

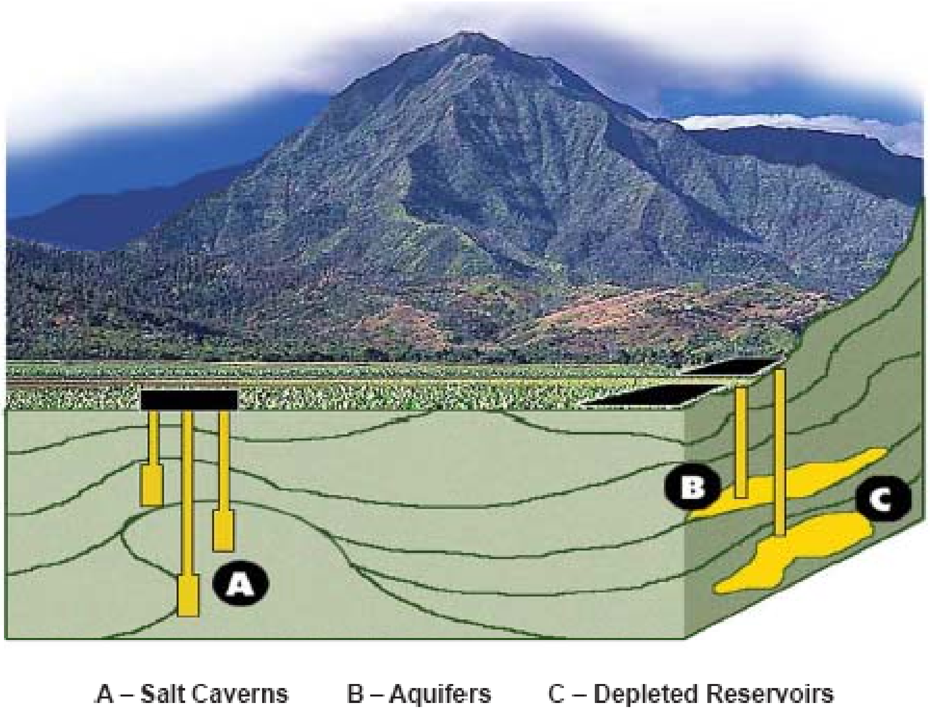
- The U.S. features a vibrant and fairly competitive wholesale NG **market**



The NG Industry Supply/Value Chain



NG Storage Assets
"Warehouses" or Contracts



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:

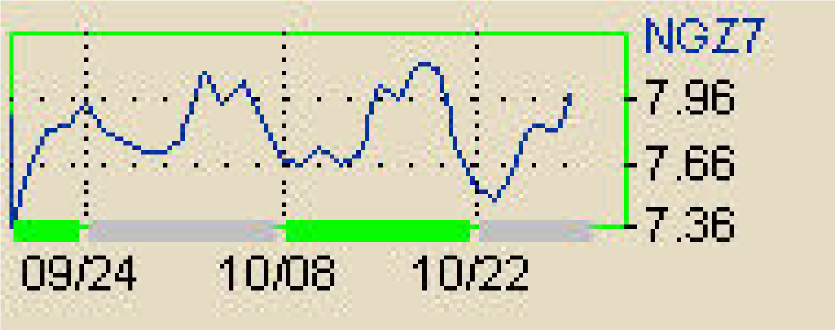
SERVICES AND RATES: Our rates are 'market based' meaning they are fully negotiable, but our 'rack rates' (suggested retail prices) are currently as follows:

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

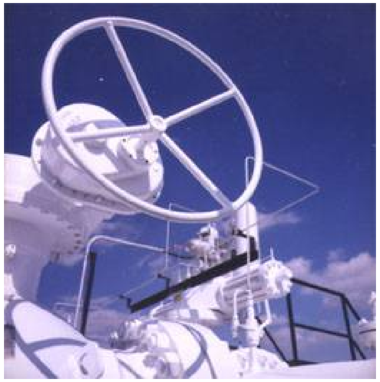
In principle, the idea is simple: Buy low, inject, store, withdraw, and sell high …



… but there are practical **difficulties**

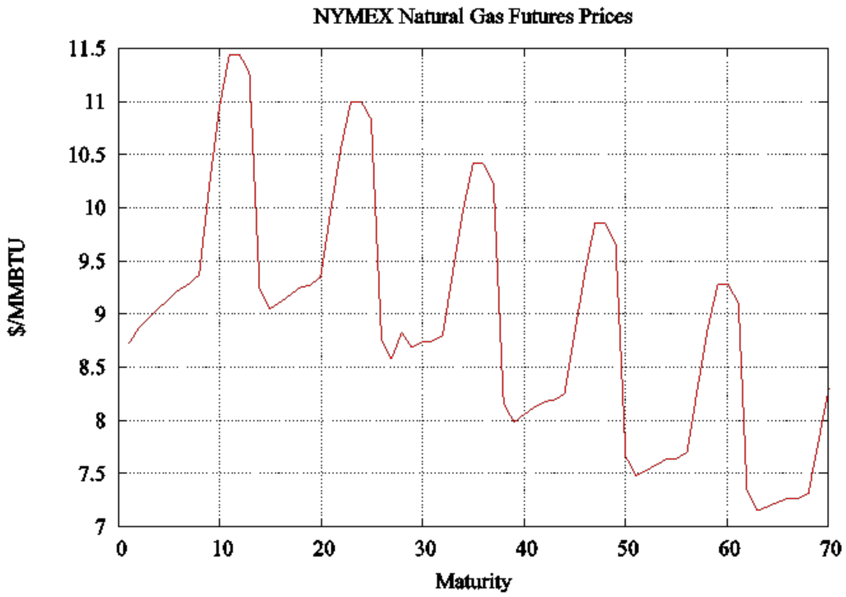
Modeling the **evolution** of NG **prices**

Constraints on minimum/maximum storage space and injection/withdrawal **capacity**



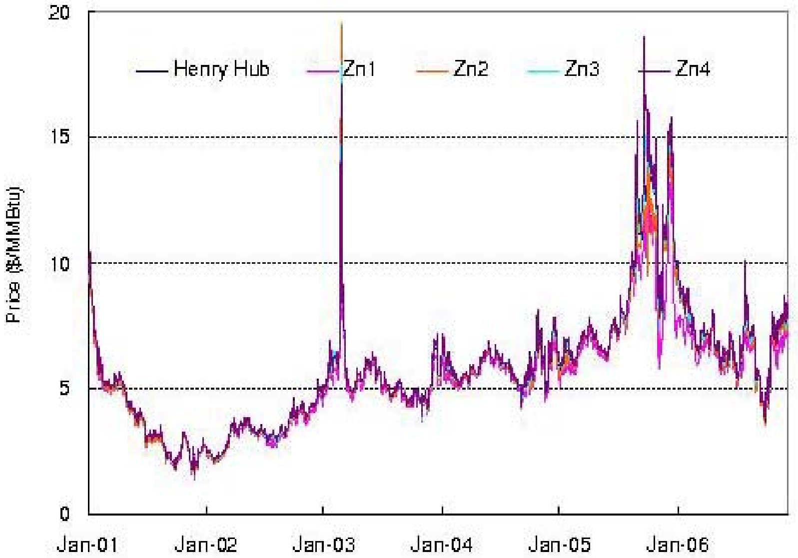
NG Prices and Variability

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



Monthly intervals – 72 months in the future

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



Daily intervals – 7 years

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

Type	Cushion to Working Gas Ratio	Injection Period (Days)	Withdrawal Period (Days)
Aquifer	Cushion 50% to 80%	200 to 250	100 to 150
Depleted Oil/Gas Reservoirs	Cushion 50%	200 to 250	100 to 150
Salt Cavern	Cushion 20% to 30%	20 to 40	10 to 20

Source: Analysis of FERC filings

"Slow" (Aquifer; Depleted Oil/Gas Reservoirs)

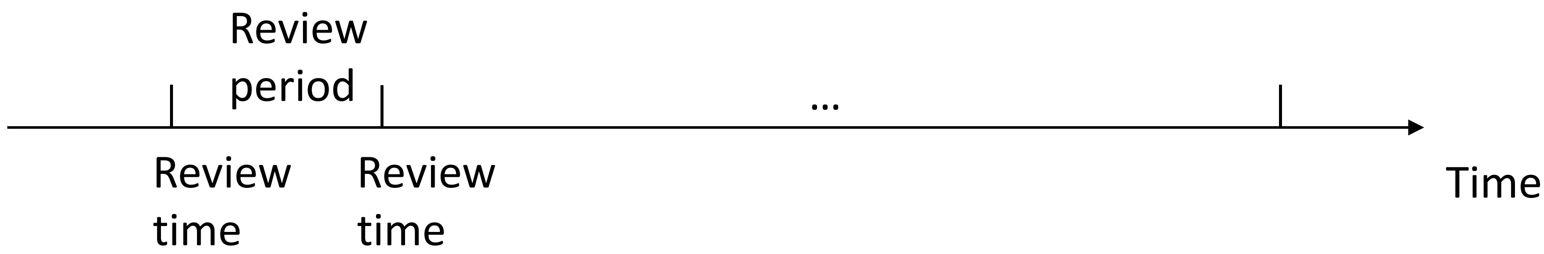
"Fast" (Salt Cavern)

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

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

$Stage$ (review time) is in $StageSet$

$Inventory$ is in $FeasibleInventorySet$ (closed convex subset of real line)

$SpotPrice$ is in $SpotPriceSet_{Stage}$ (subset of real line)

Bellman equations (there are also terminal boundary conditions):

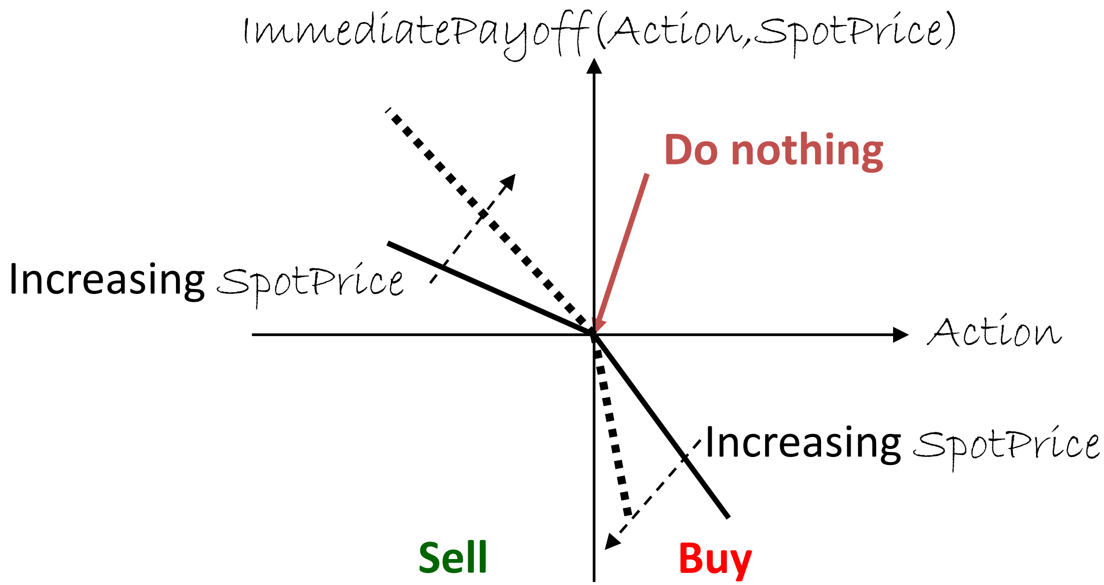
$$
\begin{aligned}
V_{Stage}(Inventory, SpotPrice) = \max_{Action} \{ & ImmediatePayoff(Action, SpotPrice) \\
& - HoldingCost \times Inventory \\
& + DiscountFactor \text{ (from NextStage back to Stage)} \\
& \quad \times E_{Stage}[V_{NextStage}(Inventory + Action, RandomSpotPrice)]\}
\end{aligned}
$$

s.t. Action belongs to FeasibleActionSet(Inventory)

for all Stage, Inventory, SpotPrice in their respective sets

E_{Stage} is conditional expectation in $Stage$ (given $SpotPrice$)

Immediate Payoff

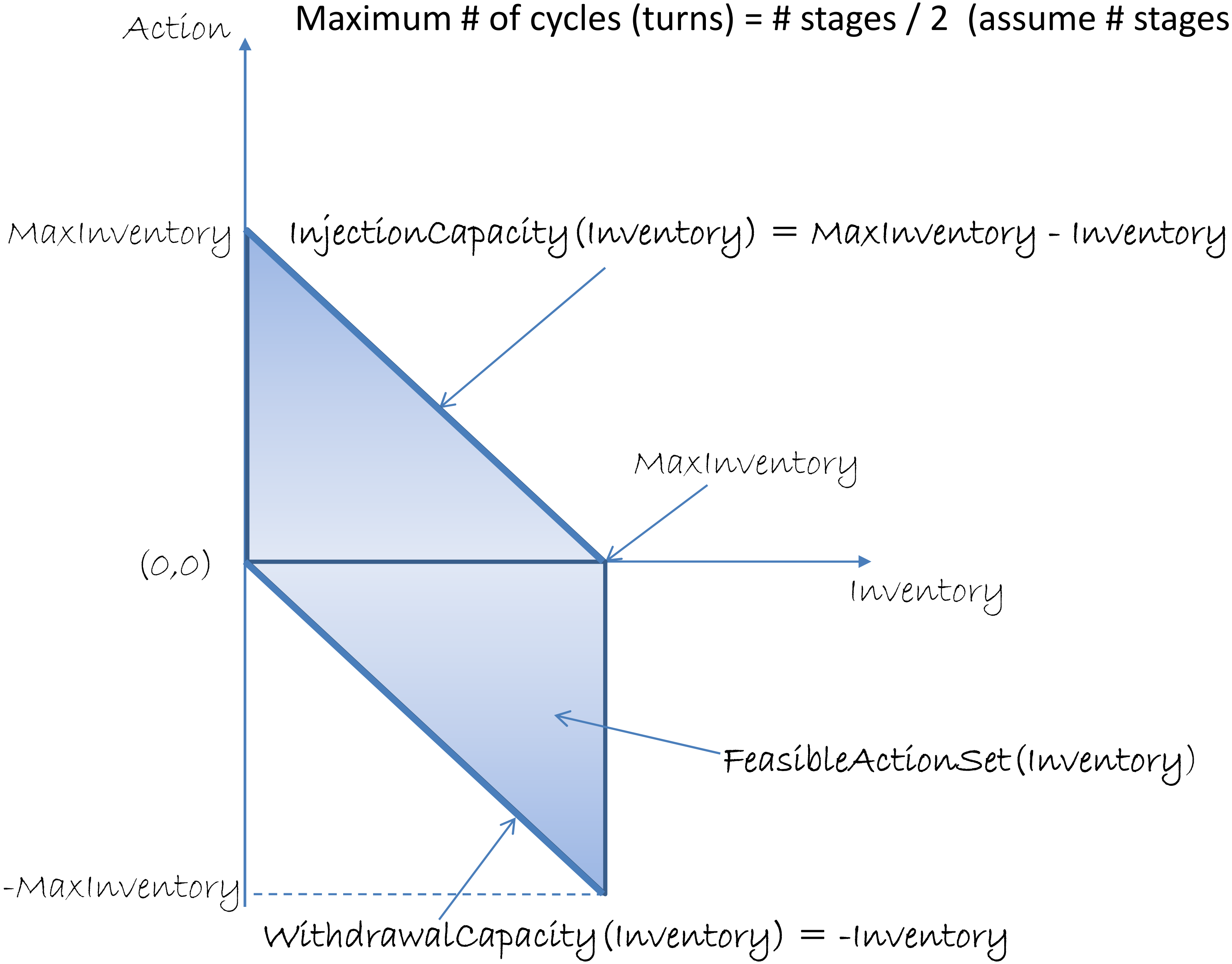


It never makes sense to buy and sell at the same time:
ImmediatePayoff(Action,SpotPrice) is **superadditive** with respect to two actions of opposite sign (consequence of concavity in the action)

“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)

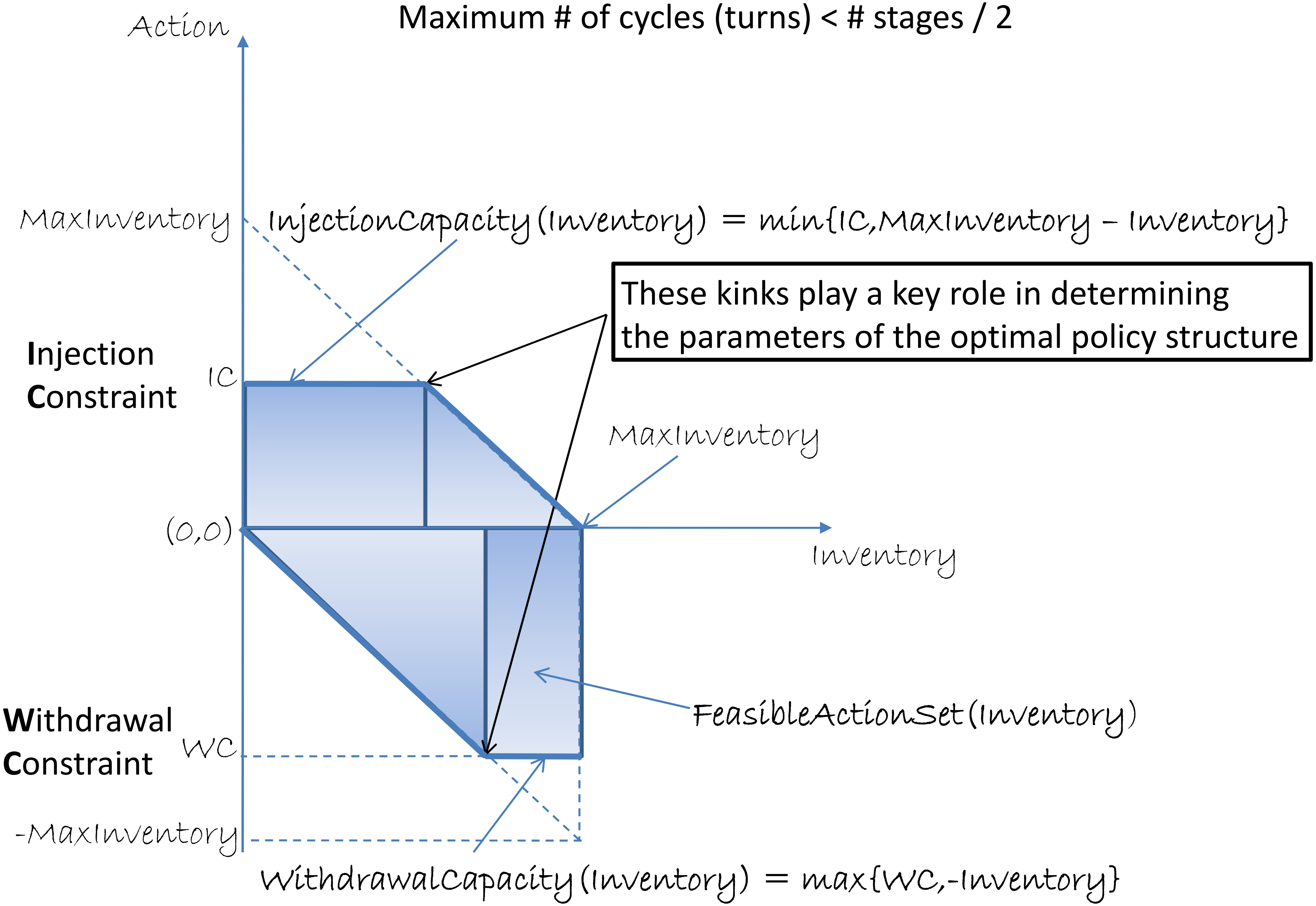
Capacity Functions: Fast Asset

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

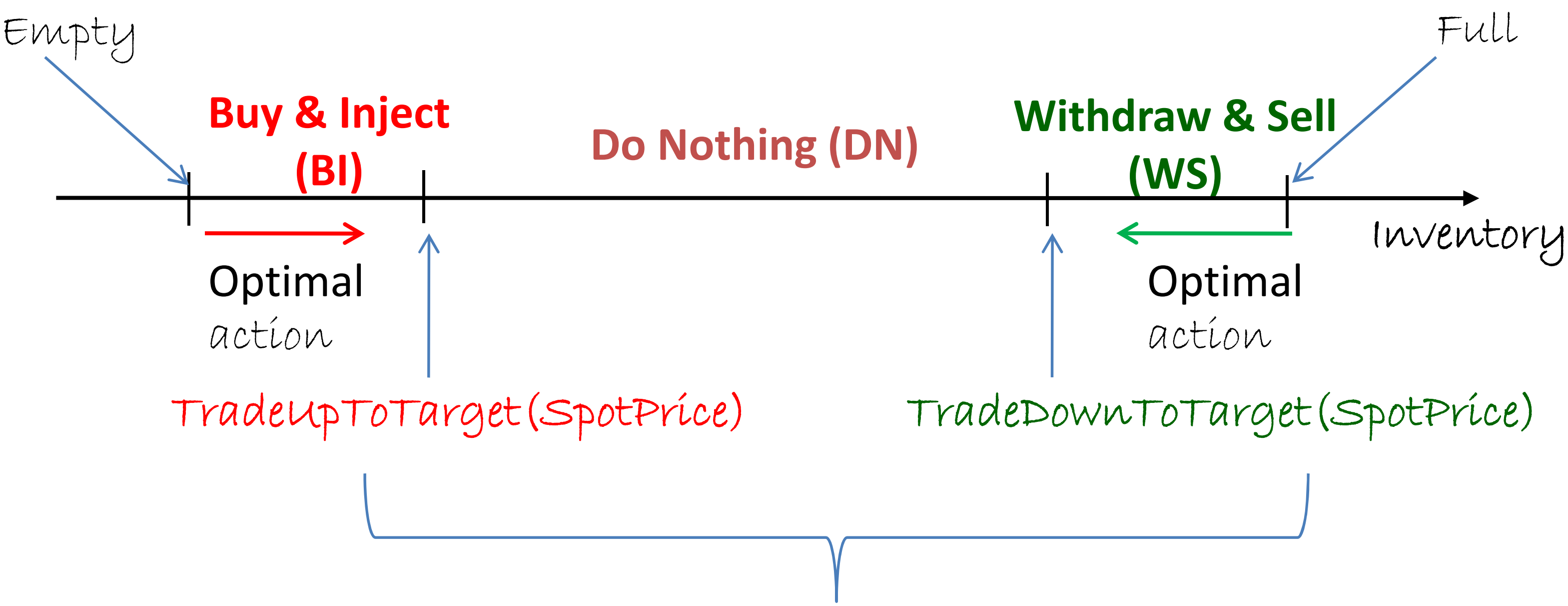


Capacity Functions: Slow Asset

Maximum # of cycles (turns) < # stages / 2

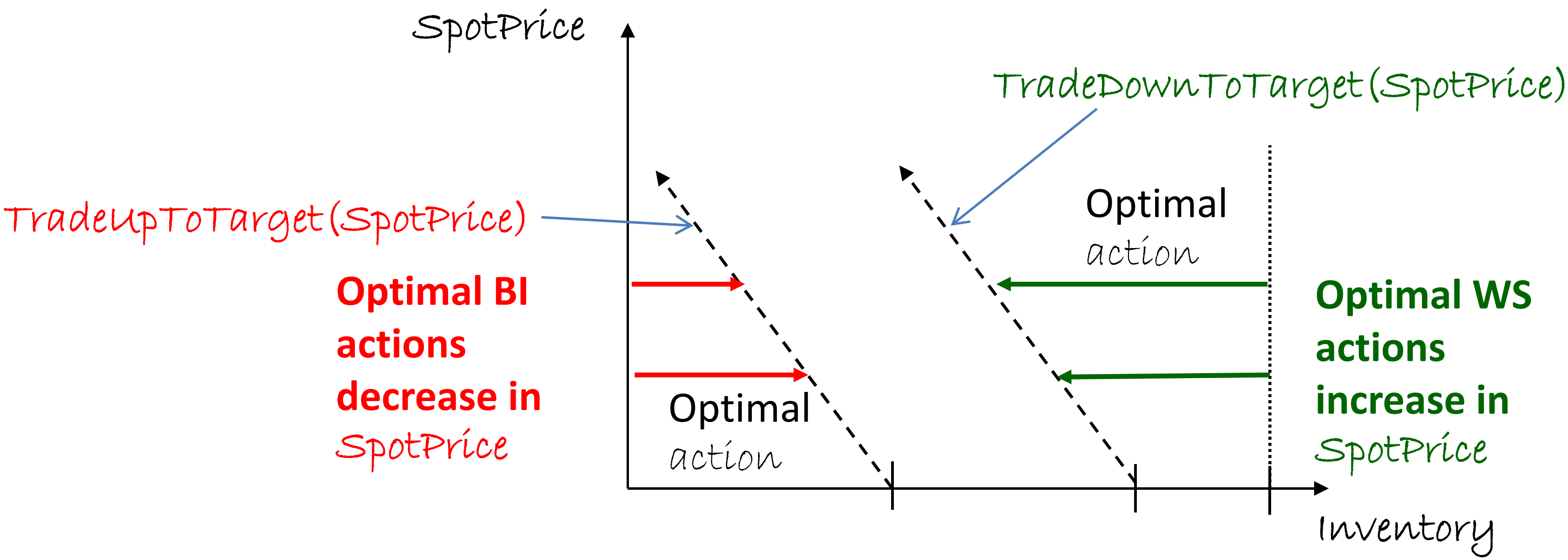


Basestock Target Optimal Policy



These targets are functions of the *SpotPrice*

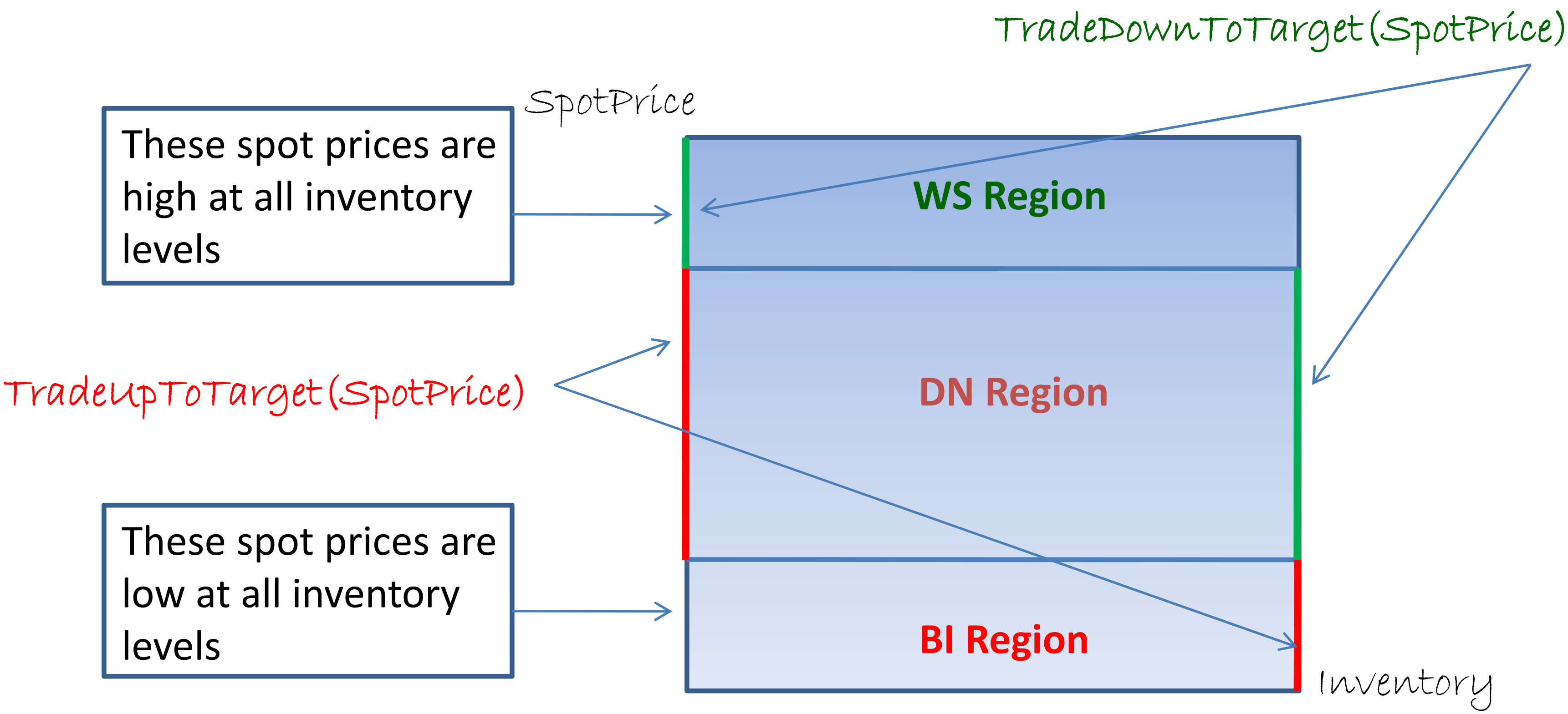
Optimal Basestock Targets and SpotPrice



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

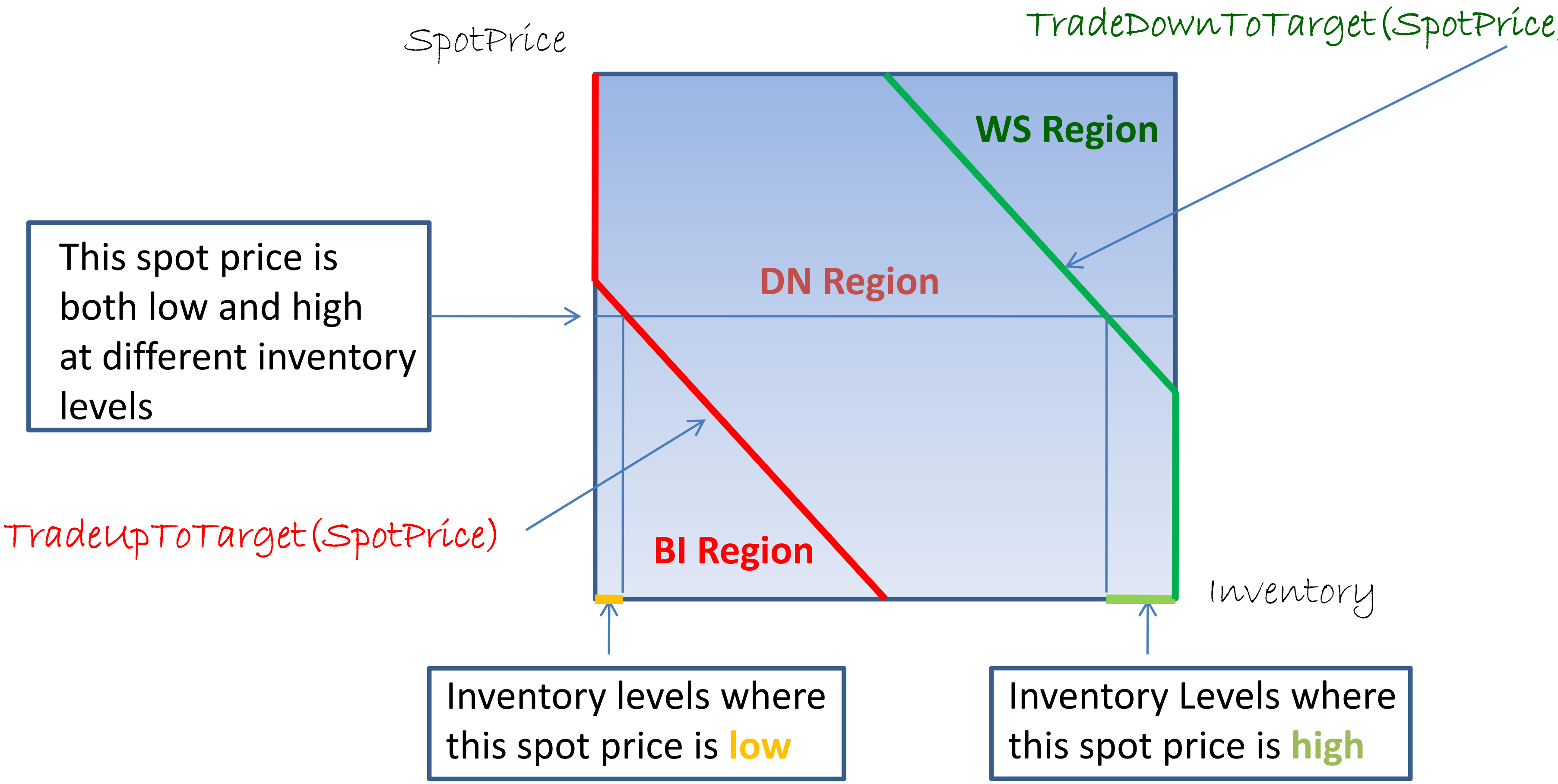
Complementarity relationship between **inventory** and **spot price** (V_{Stage}(Inventory,SpotPrice) supermodular in (Inventory,SpotPrice))

High & Low Spot Prices with a Fast Asset



Decoupled optimal trading and operational decisions: "buy low" and "sell high"

High & Low Spot Prices with a Slow Asset



This structure cannot be fully characterized as "buy low" and "sell high"

Numerical Results: Policies

(1) Fast **C**apacity **O**ptimal **P**olicy (**FCOP**): Fast asset

(2) Slow **C**apacity **O**ptimal **P**olicy (**SCOP**): Slow asset

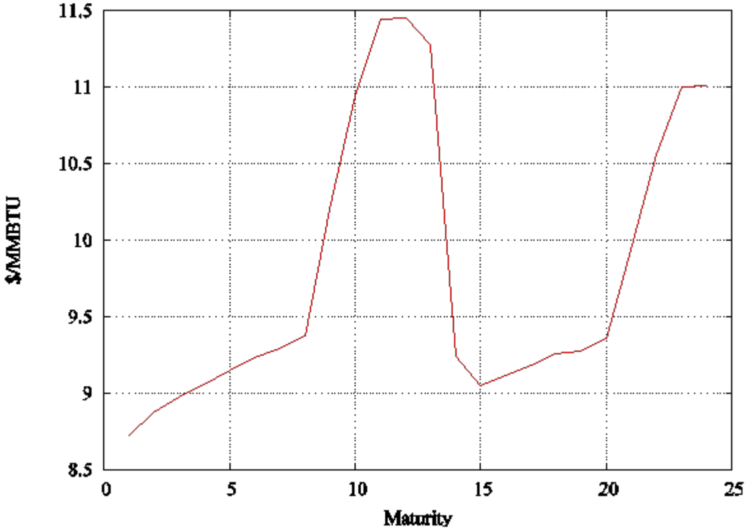
(3) Decoupled **O**perations **T**rading **P**olicy (**DOTP**) : buy/sell as in FCOP but inject/withdraw taking capacity functions into account

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

Stage length = 1 month

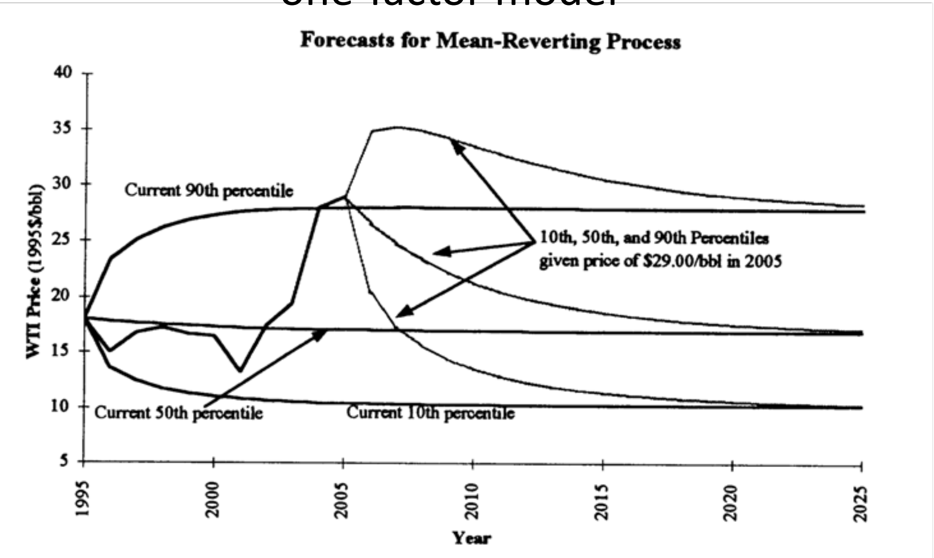
Numerical Results: Price Modeling

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



24 months in the future

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

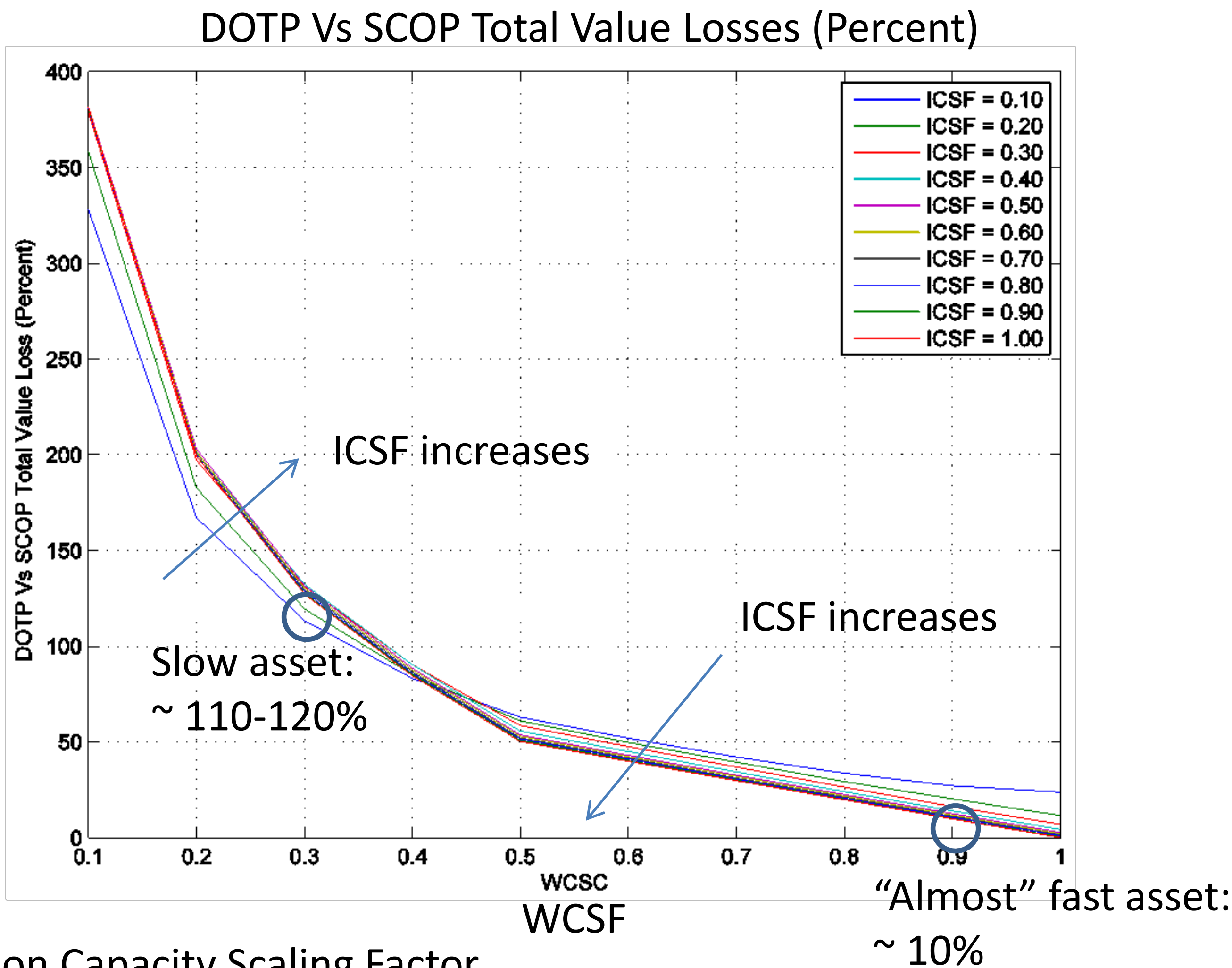


Source: Smith and McCardle (1999)

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

Policies are computed using standard backward dynamic programming (DP)

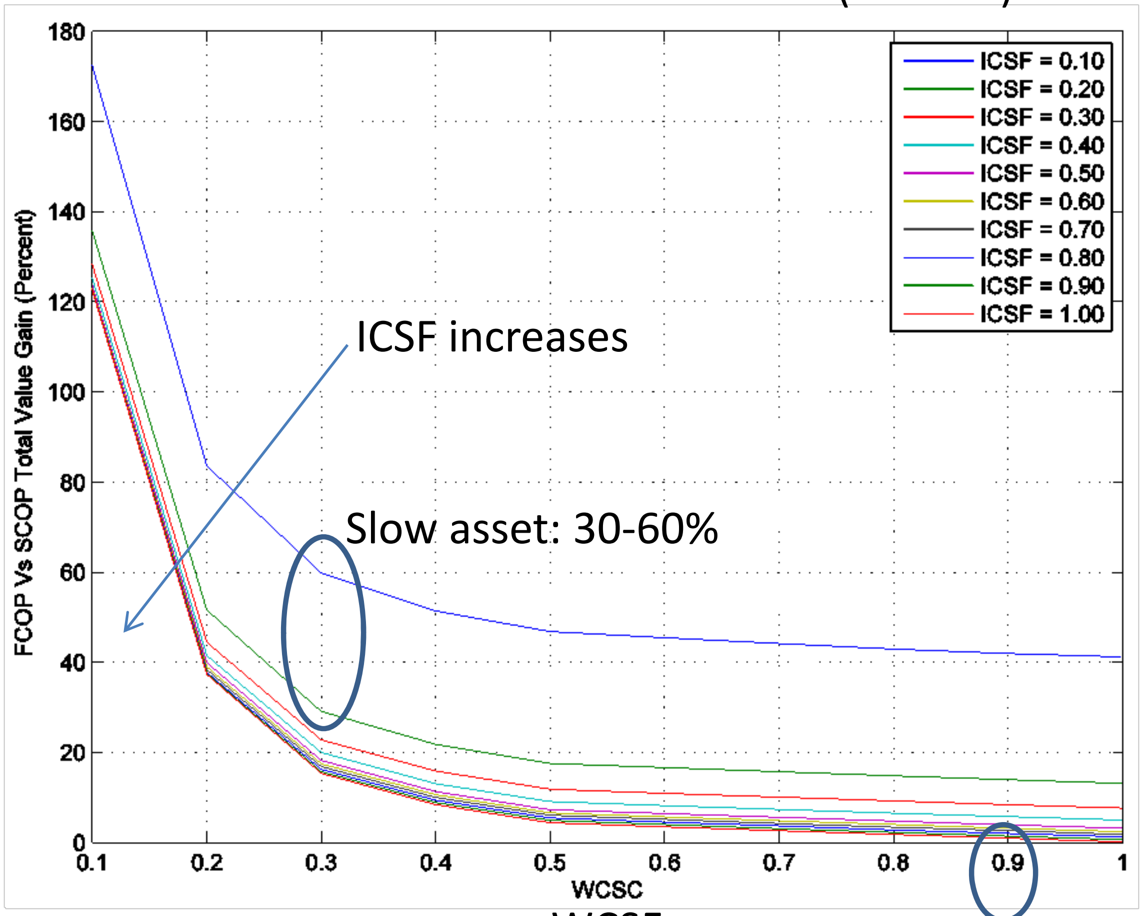
Effect of Decoupling Trading and Operational Choices



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

Effect of “Slow” Capacity Functions

FCOP Vs SCOP Total Value Gains (Percent)

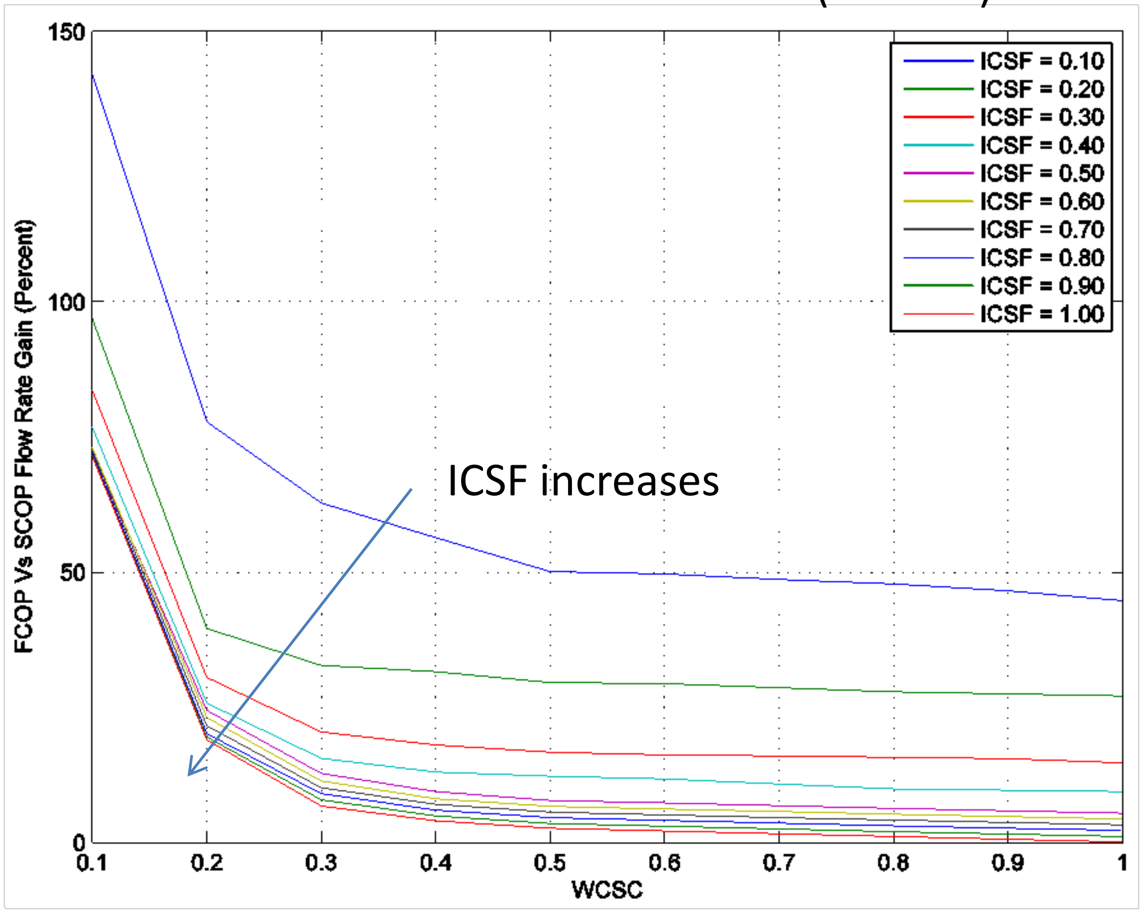


WCSF

“Almost” fast asset: ~1%

Flow Rate and Capacity Functions

FCOP Vs SCOP Flow Rate Gains (Percent)



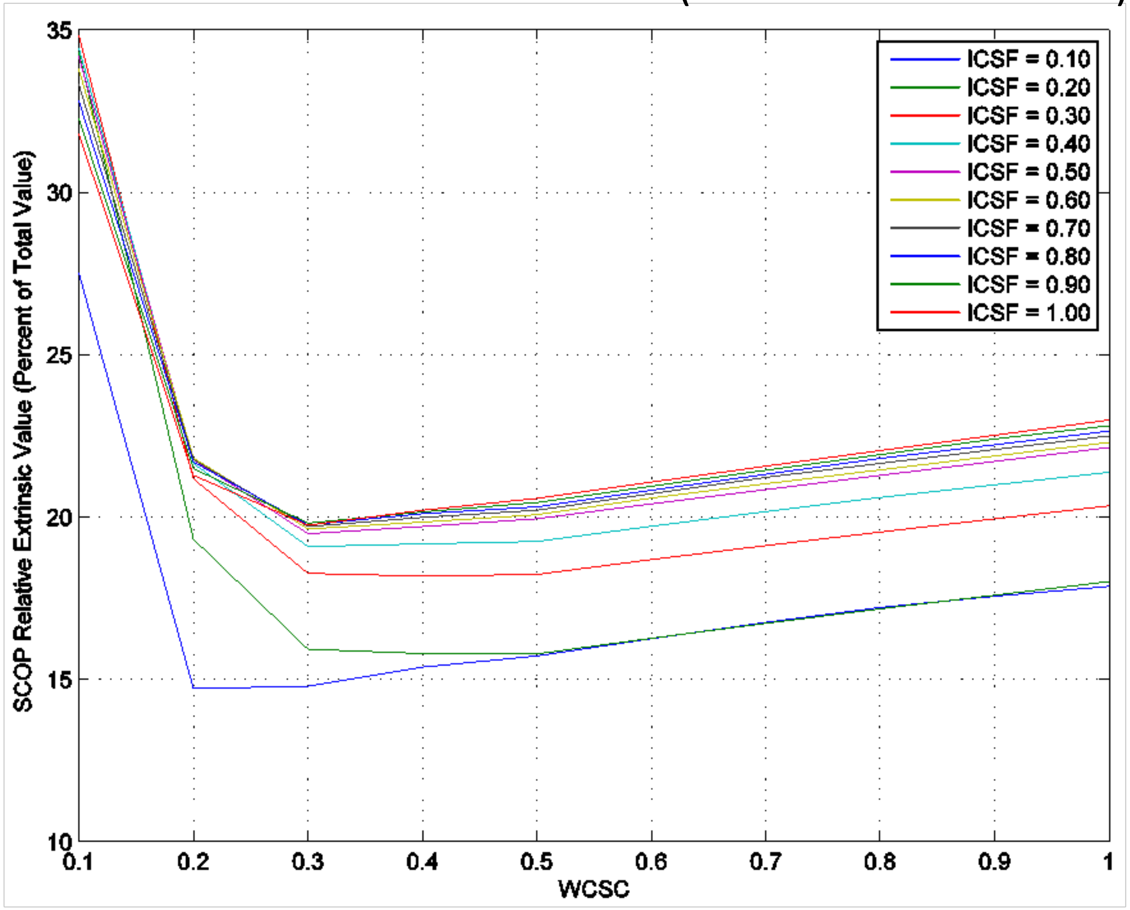
WCSF

SCOP Relative Value of Price Uncertainty

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

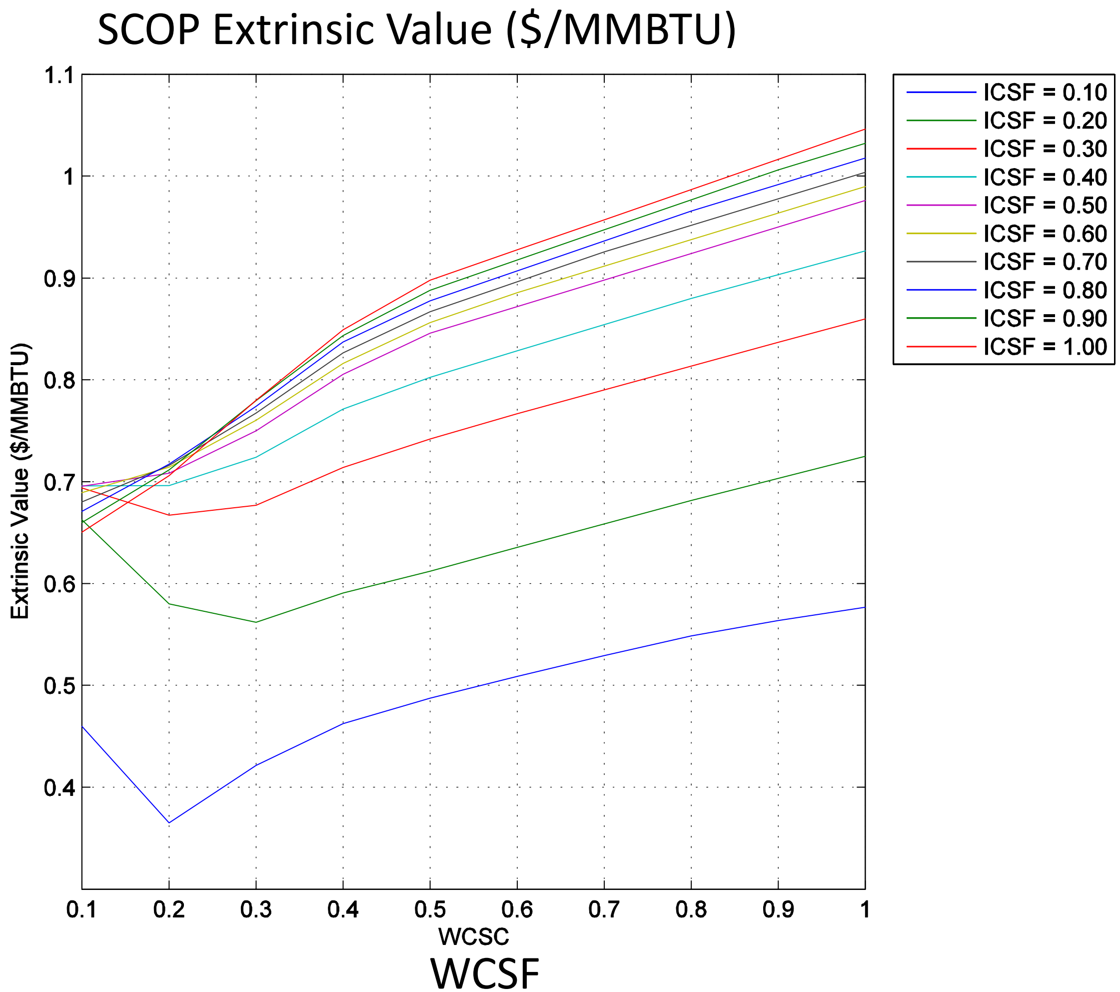
Average Extrinsic Value = 21%

SCOP Relative Extrinsic Value (Percent of Total Value)



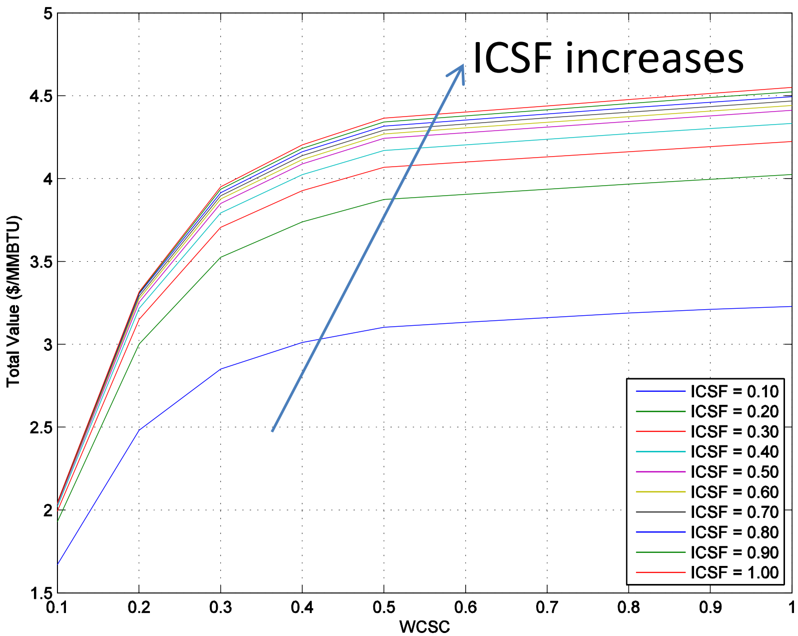
WCSF

SCOP Absolute Value of Price Uncertainty



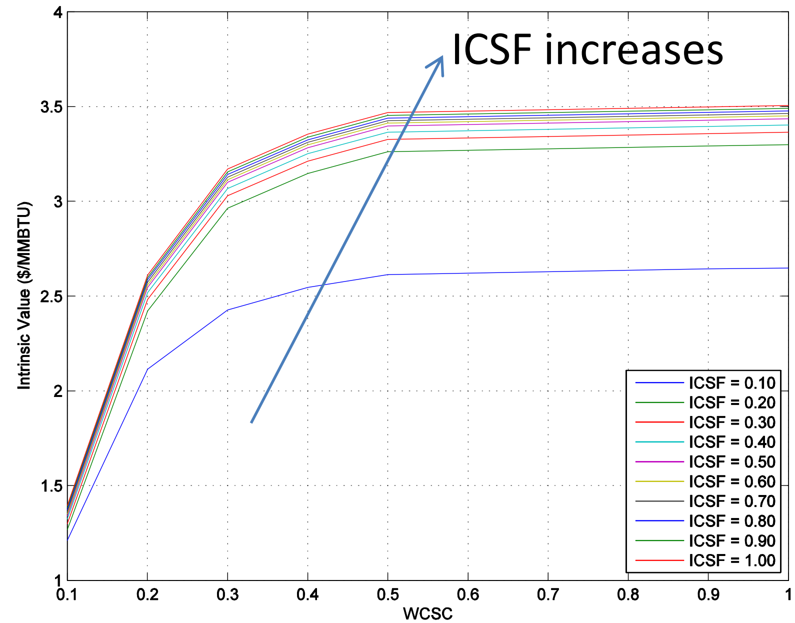
SCOP Total Value of the Asset

SCOP Total Value ($/MMBTU)



WCSF

SCOP Intrinsic Value ($/MMBTU)



WCSF

The total and intrinsic values increase at different rates
=> The extrinsic value is not monotonic in ICSF or WCSF

Capturing the SCOP Extrinsic Value

- **R**eoptimized **I**ntrinsic **V**alue **P**olicy (**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 <u>initial</u> 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