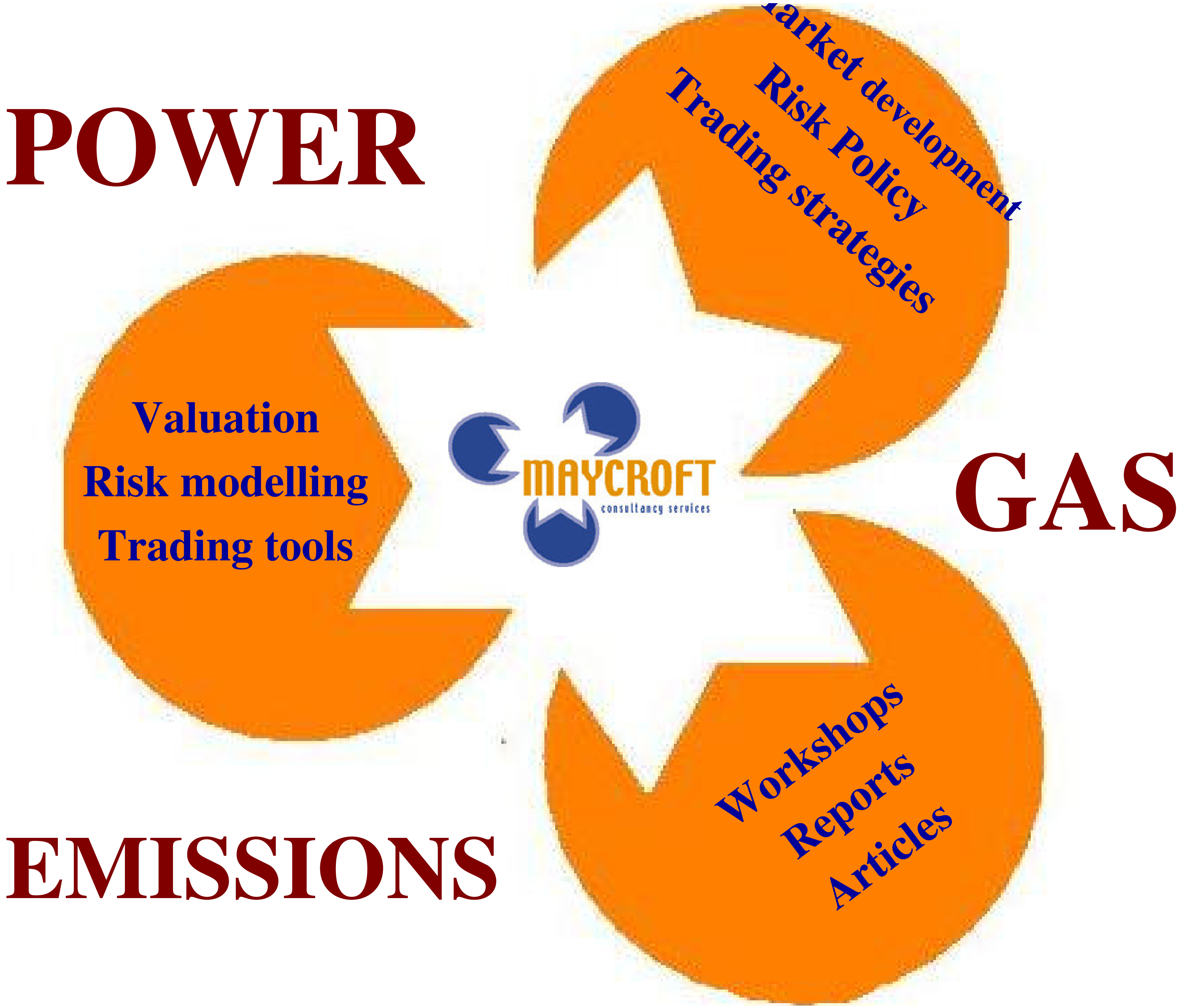
Gas Storage:
Valuation and Optimization

Operations Research Seminar

January 2008

Cyriel de Jong
Maycroft Consulting / Erasmus University Rotterdam

dejong@maycroft.com


POWER
GAS
EMISSIONS
Valuation
Risk modelling
Trading tools
arket development
Risk Policy
Trading strategies
Workshops
Reports
Articles
MAYCROFT
consultancy services

Overview

- Storage as portfolio tool or trading tool
- Market based valuation on spot and forward markets: different trading strategies and optimizations
- The least-squares Monte Carlo approach

Why real options?

- Fixed price scenarios do not correspond to real life
- Assets can be considered as an option to capture margins: dynamic prices
- Asset provides flexibility, which may create value: uncertainty > risk

Why storage?

- Demand side very price inelastic and seasonal
  - ~ Heating
  - ~ Power production
  - ~ Industrial use

  E.g. UK: winter / summer demand = 5 / 1
- Supply more or less constant
- Storage needed to meet expected variations and back-up for unexpected variations

Storage need

	Working Volume 2000	Working Volume 2030
OECD North America	129	215
OECD Europe	61	138
OED Pacific	2	14
Transition Economies	132	266
Developing Countries	4	51
World	**328**	**685**

Source: IEA

Storage parameters

- Working gas: can be effectively used
  - ~ Gas in storage: the volume (out of the working gas) in store at any point in time
- Injection rate
- Withdrawal rate / Send-out rate / Deliverability
  - ~ May depend on storage level or season
- Cycling:
  - ~ Number of times the storage can be refilled in a year
  - ~ Combines Working Gas, Inj and Withdr rate

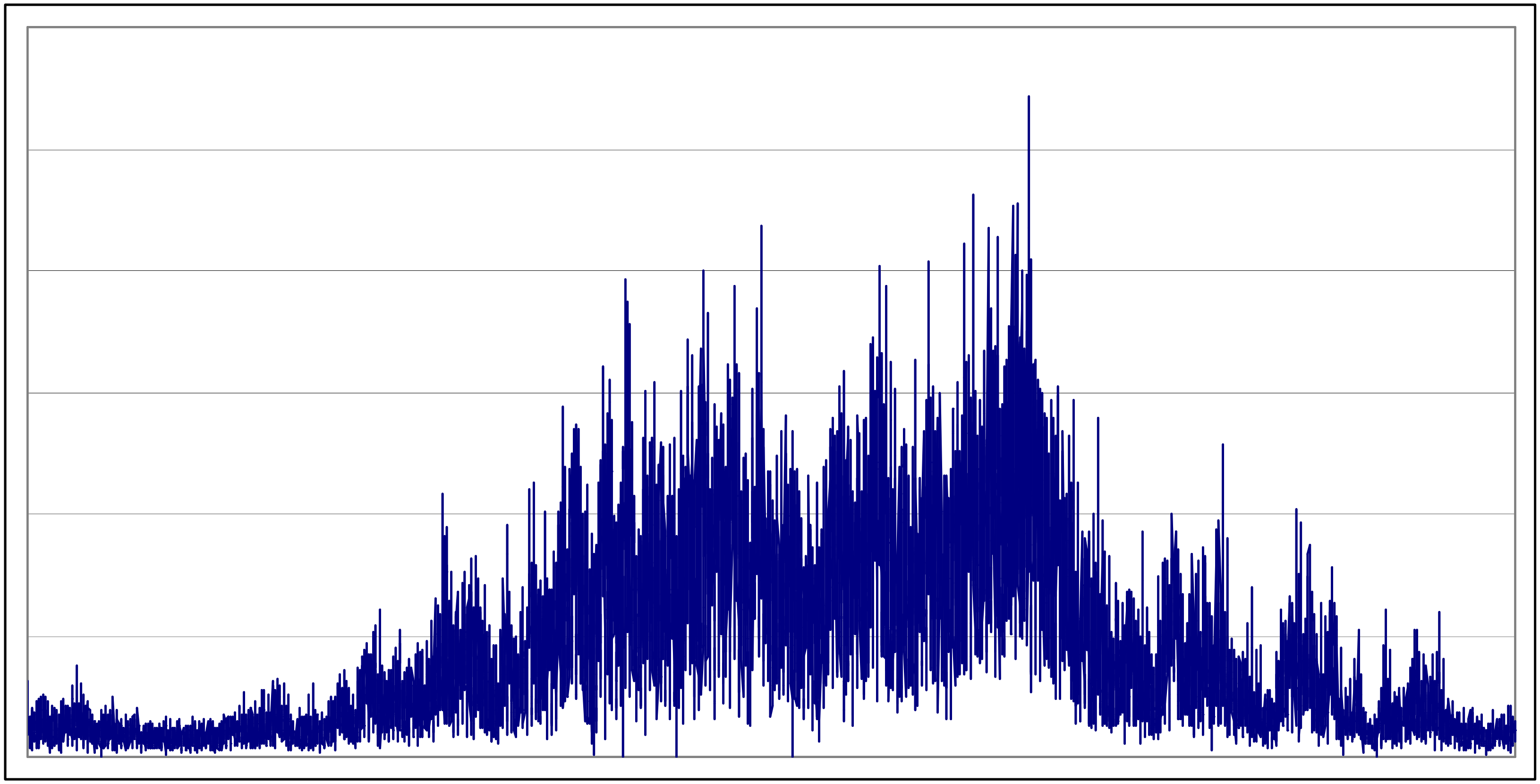
Types of storages

- LNG: small and high deliverability
- Depleted reservoirs:
  - ~ E.g. marginal reservoirs with cushion gas in place
  - ~ Mostly seasonal
- Aquifers: underground formations that are initially filled with water
  - ~ Intermediate deliverability
  - ~ Expensive to develop
- Salt caverns
  - ~ Small, high deliverability, quickly change flow direction

Application of storage

- Portfolio Peak-shaving / Supply security:
  - ~ Winter-summer variation
  - ~ Unexpected high demand days / hours in winter
    - * E.g. in the NL Gasunie pricing is based on maximum demand in any hour of a year
- Power plant optimization:
  - ~ Power plants often produce only in peak hours
  - ~ Hourly flexibility required: re-inject during night
- Trading:
  - ~ Season, Months, Days, Hours

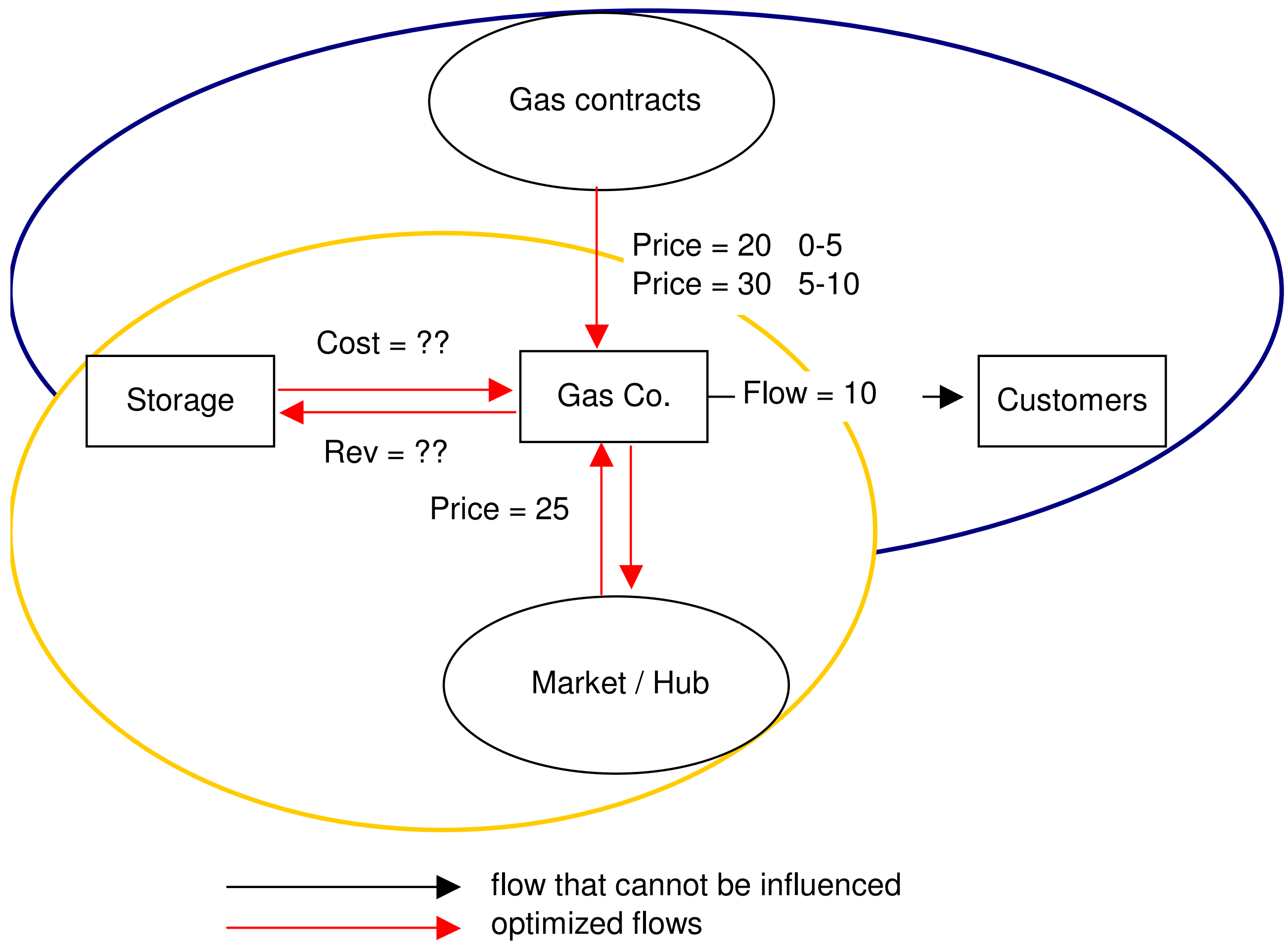
Example load development



Trading Valuation

- Increasingly possible
- Optimal operation depends on the development of market prices and the ability to trade
- A user can benefit from:
  - ~ Long-term price movements (stable):
    - * Forward curve
    - * Yielding an intrinsic value
  - ~ Short-term price movements (volatile):
    - * Spot dynamics
    - * Adding an extra option/extrinsic value

Integrated storage management



Q: What is the “cost” and “revenue” of using gas from storage?

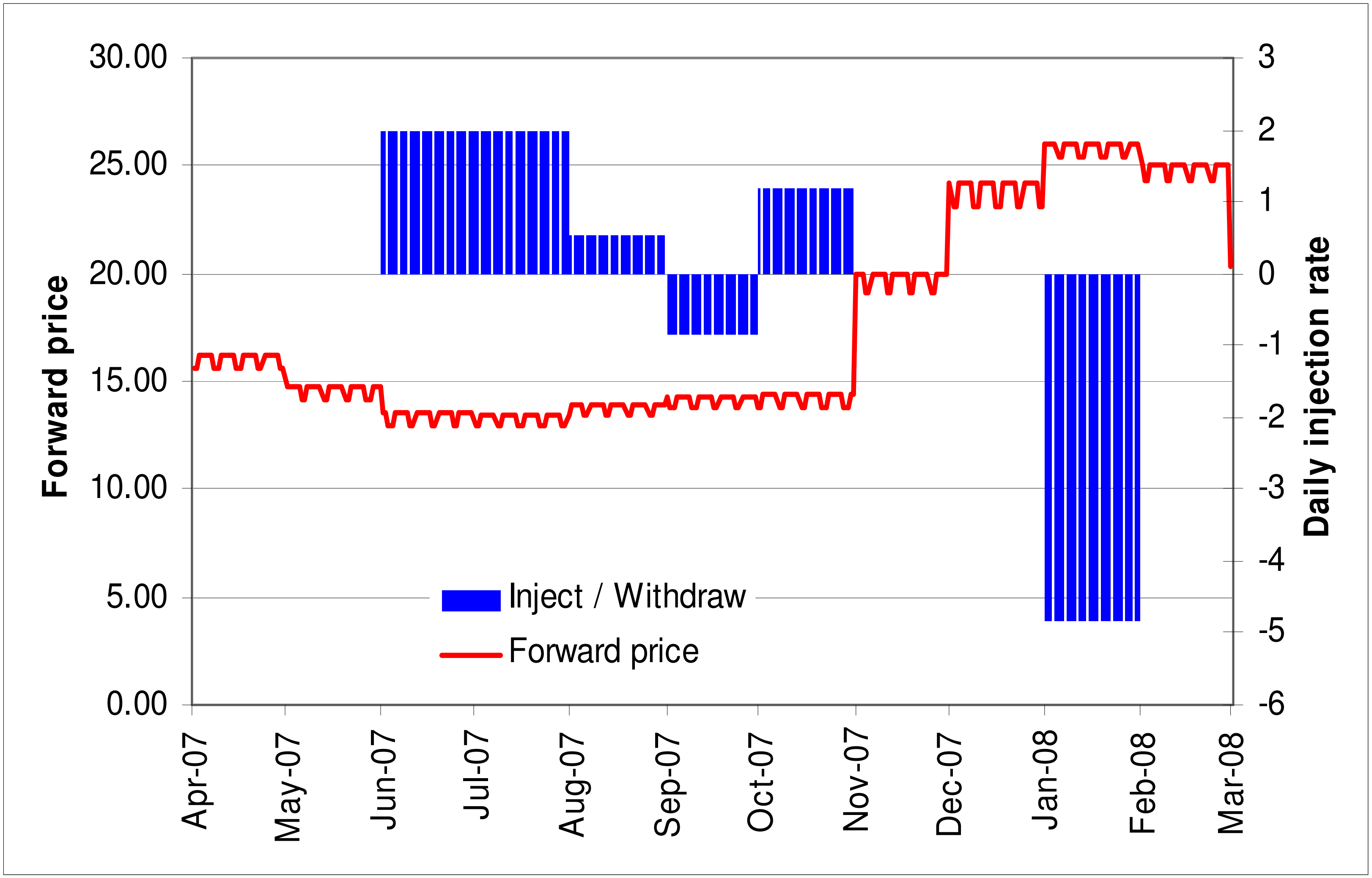
Opportunity cost = option value

I. Intrinsic Strategy

- Source of revenue:
  - ~ Seasonality = intrinsic value
- Intrinsic value strategy:

  Static strategy, entered into at the start of storage contract:
  - ~ Inject in cheapest expected periods
  - ~ Withdraw in most expensive expected periods
  - ~ Take into account technical constraints and costs
  - ~ Use forward curve to lock in value = capture time spreads

Example Intrinsic Value



II. (Full) Real Option Strategy

- Forward strategy ignores daily asset flexibility and daily market volatility
- Trading decisions on day-to-day basis
- Exploit unexpectedly low prices to inject and unexpectedly high prices to withdraw
- May be combined with (rolling) intrinsic
- 50-200% extra value on NBP, ZB and TTF
- Practical limitation: spot liquidity

Least-squares Monte Carlo

- Carriere (IME, 1996), Longstaff and Schwartz (RFS 2001, Risklab 2001 presentation)
- Breakthrough in convergence speed
- Applied to American-style financial (put) options
- Idea:
  - ~ Avoid the problem of forward-looking nature of simulations
  - ~ OLS regressions to calculate ‘expected continuation value’ and thus the optimal exercise strategy

Example

- Suppose we have an American style option:
  - ~ Exercise price € 20
  - ~ Time-to-maturity 2 days
  - ~ No dividends, no interest
- We compare a ‘traditional’ tree to ‘LSMC’
- Central to both valuation is the comparison at time t=0 and t=1 of the:
  - ~ Direct pay-off = P(t) – 20
  - ~ Expected continuation value = E[CV]
    - * Tree approach: E[CV(t)] = (CV(t+1,up) + CV(t+1,down))/2
    - * Simulation approach: E[CV(t)] = fitted value of regression

TREE APPROACH

Market price

26.00
24.20
22.00 22.00
20.00
18.00

Direct pay-off

6.00
4.20
2.00 2.00
0.00
-2.00

Expected continuation value

0.00
4.00
2.60 0.00
1.00
0.00

Option value = maximum of
a) direct pay-off OR 0
b) exp. cont. value

6.00
4.20
2.60 2.00
1.00
0.00

Strategy

exerc
exerc
wait exerc
wait
none

SIMULATION APPROACH

Market price

22.00	25.00	24.00
22.00	23.00	26.00
22.00	22.00	19.00
22.00	21.00	21.00
22.00	19.00	17.50

Direct pay-off

2.00	5.00	4.00
2.00	3.00	6.00
2.00	2.00	-1.00
2.00	1.00	1.00
2.00	-1.00	-2.50

Regression at t = 1:
Regress CV(2) on P(1)
CV = -16.5 + 0.85*P + e

Expected continuation value

2.32	4.75	0.00
2.32	3.05	0.00
2.32	2.20	0.00
2.32	1.35	0.00
2.32	0.00	0.00

Option value = maximum of
a) direct pay-off OR 0
b) exp. cont. value

2.32	5.00	4.00
2.32	3.05	6.00
2.32	2.20	0.00
2.32	1.35	1.00
2.32	0.00	0.00
	2.32	

Strategy

wait	exerc	exerc
wait	wait	exerc
wait	wait	none
wait	wait	exerc
wait	wait	none

Application to gas storage

"Gas storage valuation using a Monte Carlo method"
Alexander Boogert and Cyriel de Jong
To appear in *Journal of Derivatives*

Decision

- At time t, for given price S(t) and volume v(t), storage operator has to optimally select:
  - ~ The value of doing nothing:
    - * Expected value of having v(t) also at time t+1
  - ~ The value of injecting:
    - * Expected value of having v(t) + Inj at time t+1
    - * Minus injection costs (market)
  - ~ The value of withdrawing:
    - * Expected value of having v(t) - Wd at time t+1
    - * Plus withdrawal revenues (market)

Mathematical Formulation

$$v(t) := v(0) + \sum_{i=1}^{t} \Delta v(i-1)$$

Inventory level

$$h(S(t), \Delta v(t)) := \begin{cases} -c(S(t))\Delta v(t) & \text{inject at day } t \\ 0 & \text{do nothing at day } t \\ -p(S(t))\Delta v(t) & \text{withdraw at day } t \end{cases}$$

Cash-flows

$$\sup_{\pi} \mathbf{E}\left[\sum_{t=0}^{T} e^{-\delta t} h(S(t), \Delta v(t)) + e^{-\delta(T+1)} q(S(T+1), v(T+1))\right]$$

Optimal strategy (π): maximize discounted cash-flows, including termination value (q)

Mathematical Formulation

$U(t, S(t), v(t))$ Storage value

$$C(t, S(t), v(t), \Delta v) := \mathbf{E}\left[e^{-\delta} U(t+1, S(t+1), v(t) + \Delta v)\right]$$

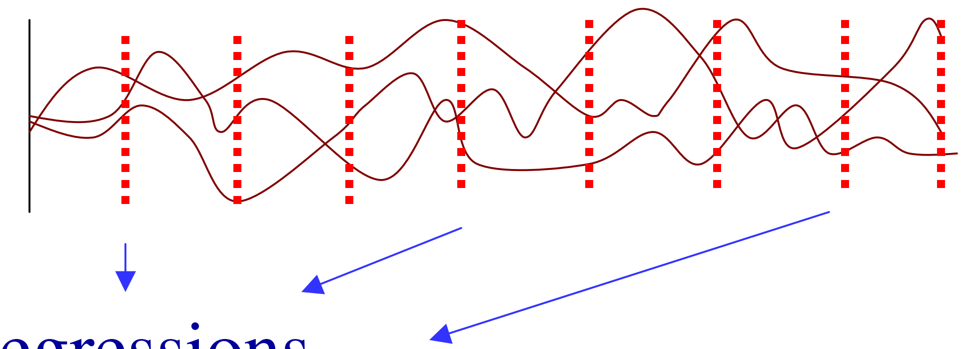
Continuation value

$$U(t, S(t), v(t)) = \max_{\Delta v \in \mathcal{D}(t, v(t))} \{h(S(t), \Delta v) + C(t, S(t), v(t), \Delta v)\}$$

Storage value under optimal action Δv on day t, for set of allowed actions D

Least-squares Monte Carlo

1.Simulation set A



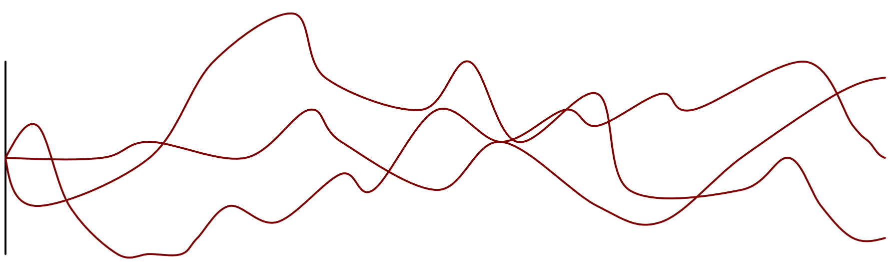
2. Regressions

3. Exercise strategy

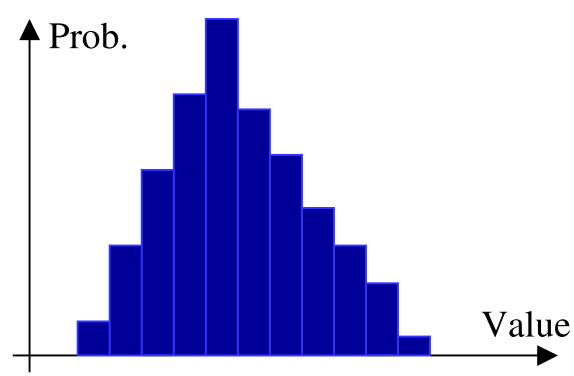
Day t
Inv. level v
Price S

Inject?
Do nothing?
Withdraw?

4. Simulation set B: Evaluate strategy

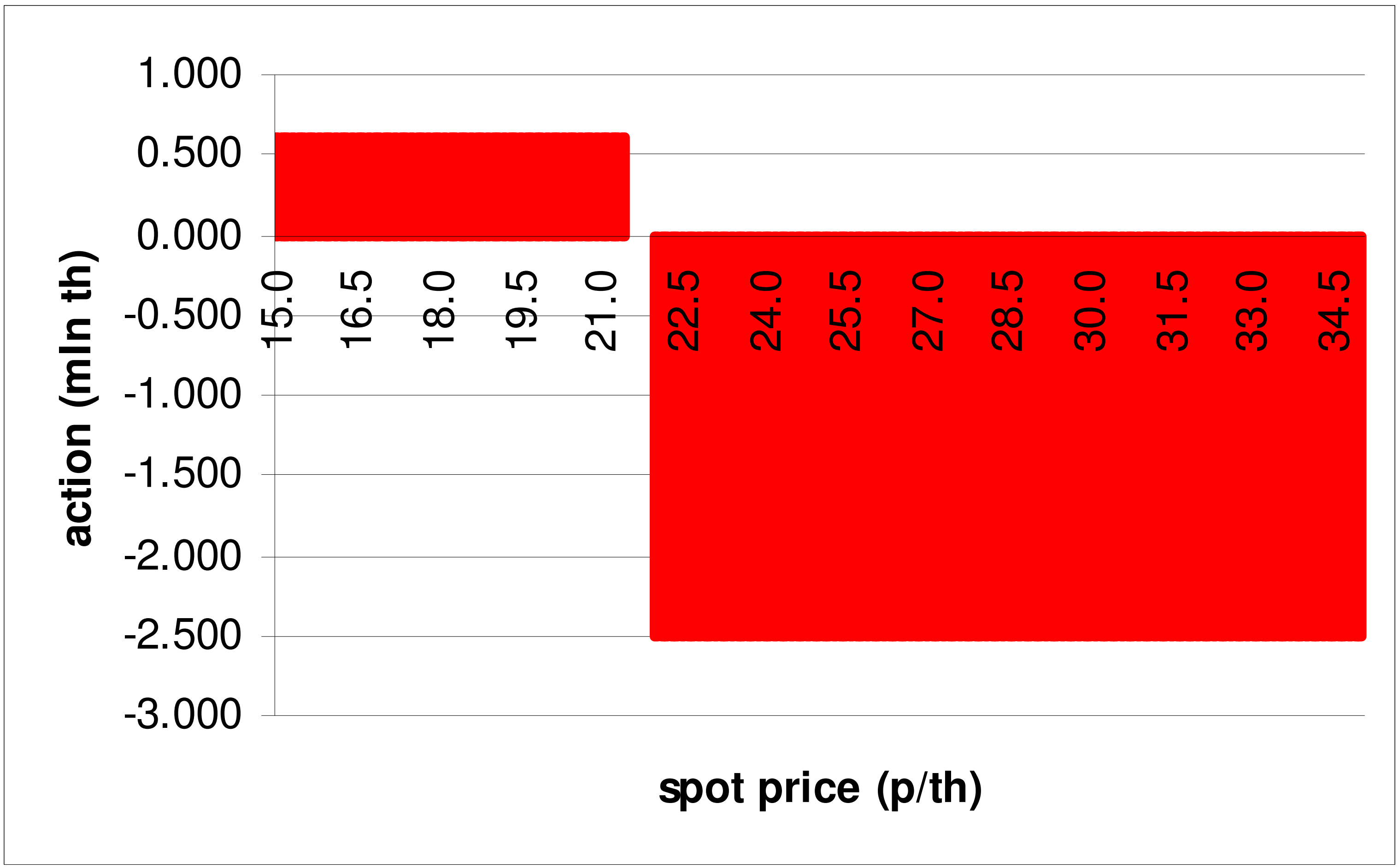


Value = 9
Value = 11
Value = 10

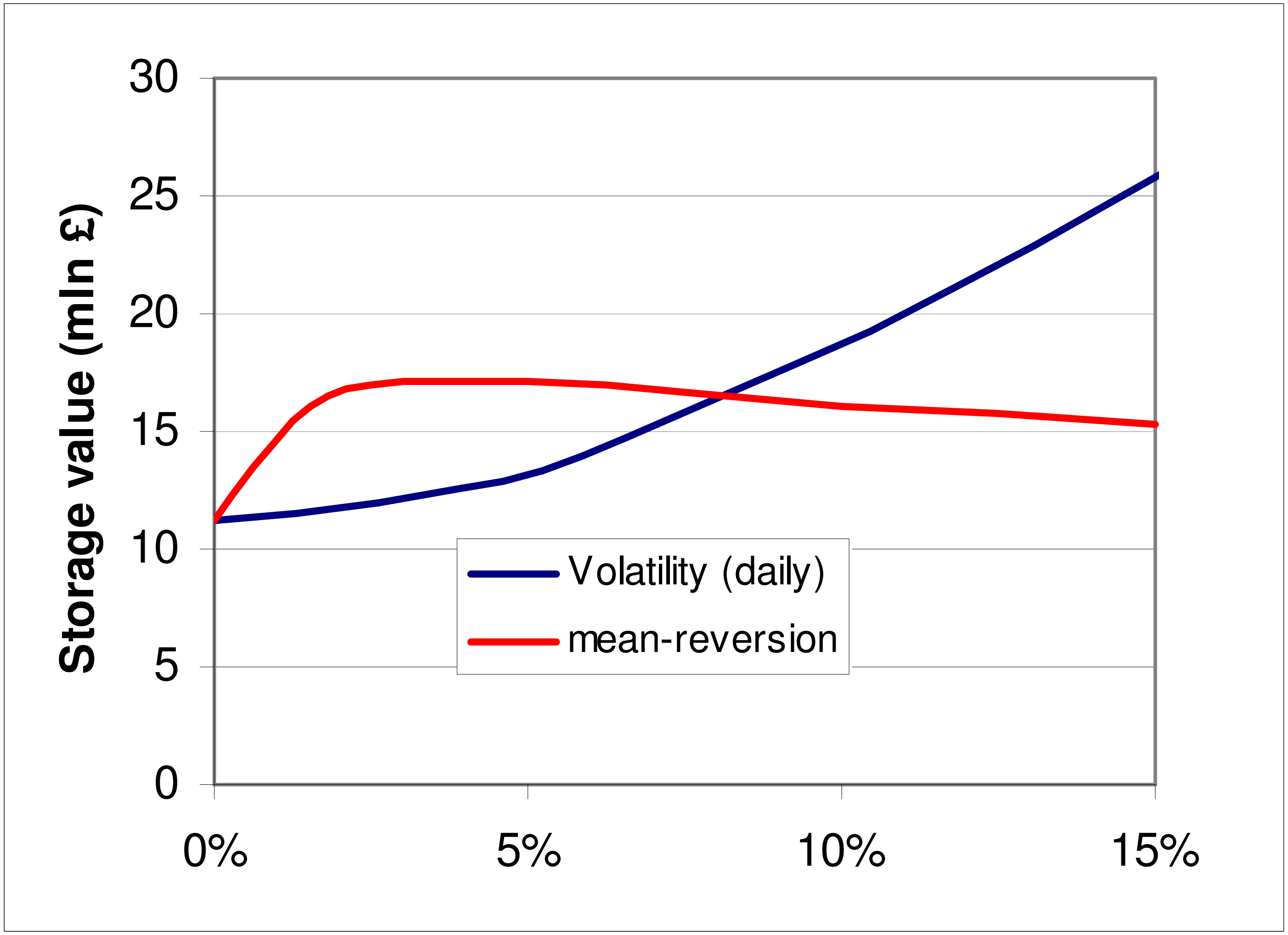


Exercise frontier example

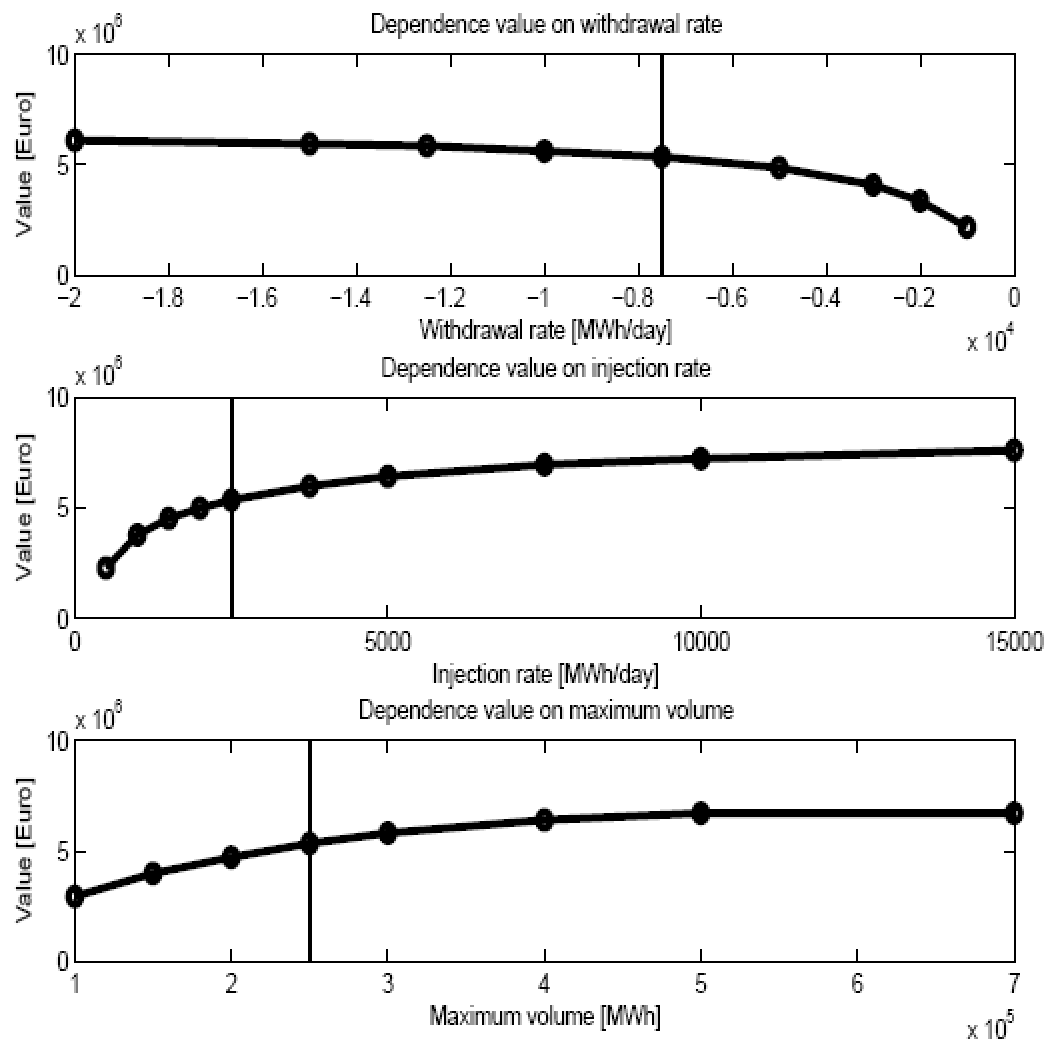
(for a day t and inventory level L)



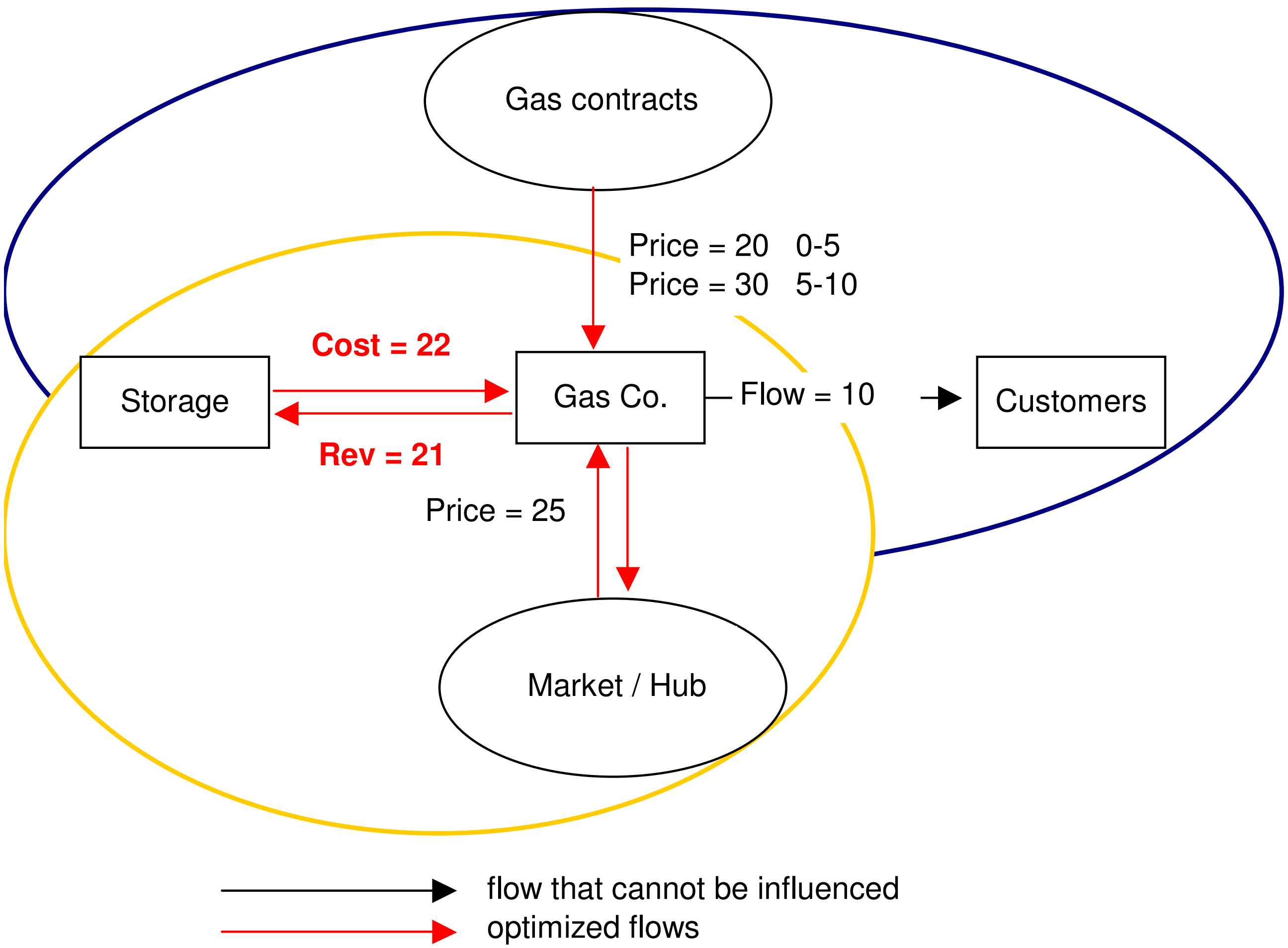
Value drivers



Storage Design



Storage cost & revenue



Conclusion

- Simulation-based storage model may be used for valuation and day-to-day management of storage
- Major advantages: accuracy and flexibility
- Simulations should contain long-term and seasonal uncertainty
- Provides benchmark to which portfolio decisions can be compared
- Major challenge: incorporate other portfolio parts
  - ~ Customer load / demand
  - ~ Multiple sources of supply and flexibility