Generation Investments in Restructured Power Systems

Perspectives from the Nordic Power Market (Nord Pool)

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Outline of presentation

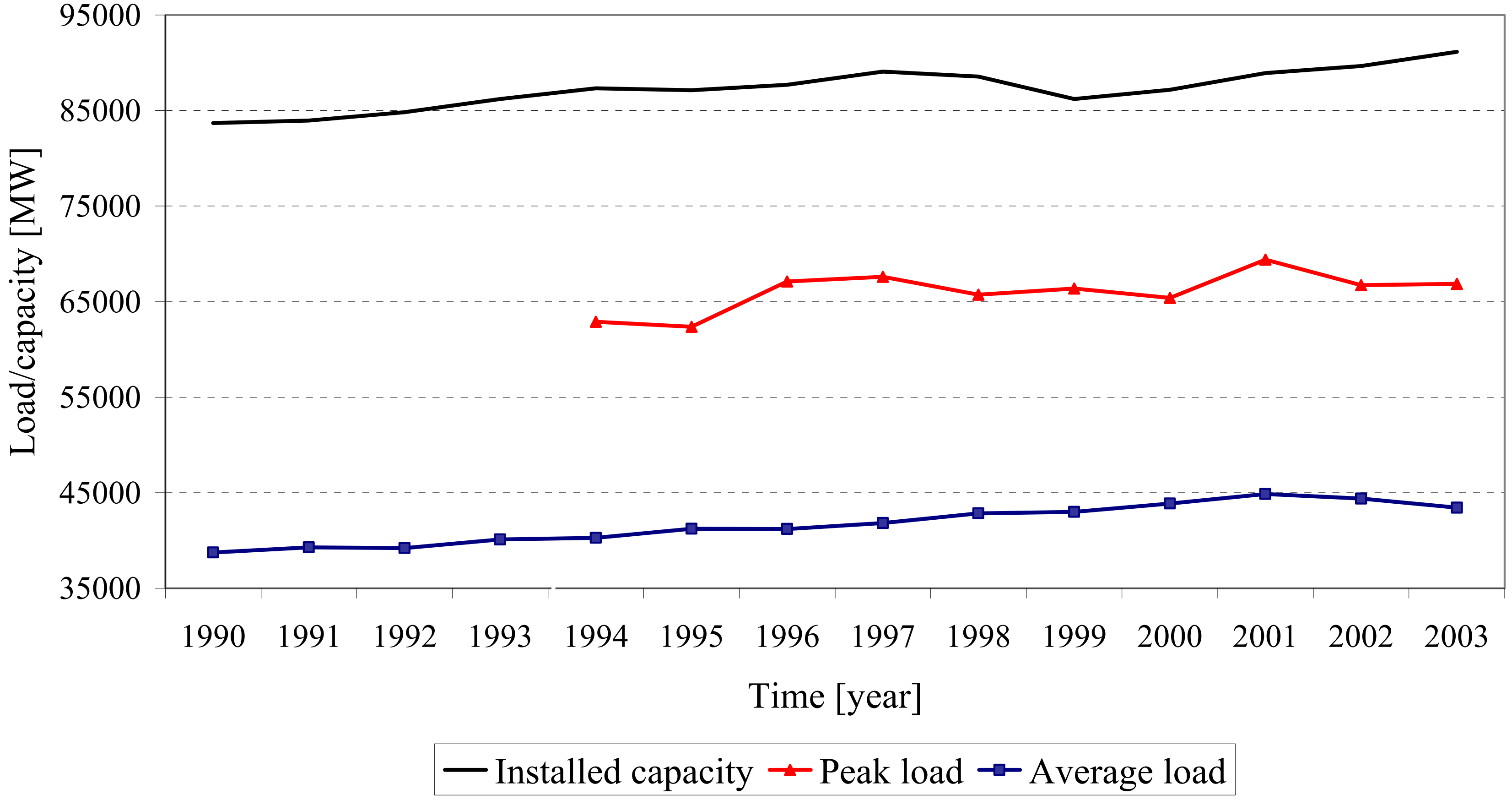
- Power generation investments after industry restructuring
  - Decentralized and profit-maximizing decision makers
  - Experiences from the Nordic Power market
- Optimal timing of new investments
  - A stochastic dynamic optimization model (real options approach)
  - Investment in new gas power generation in Norway
  - Effect of introducing a capacity payment
- Conclusions

Power generation investments after industry restructuring

Current situation in the Nordic power market

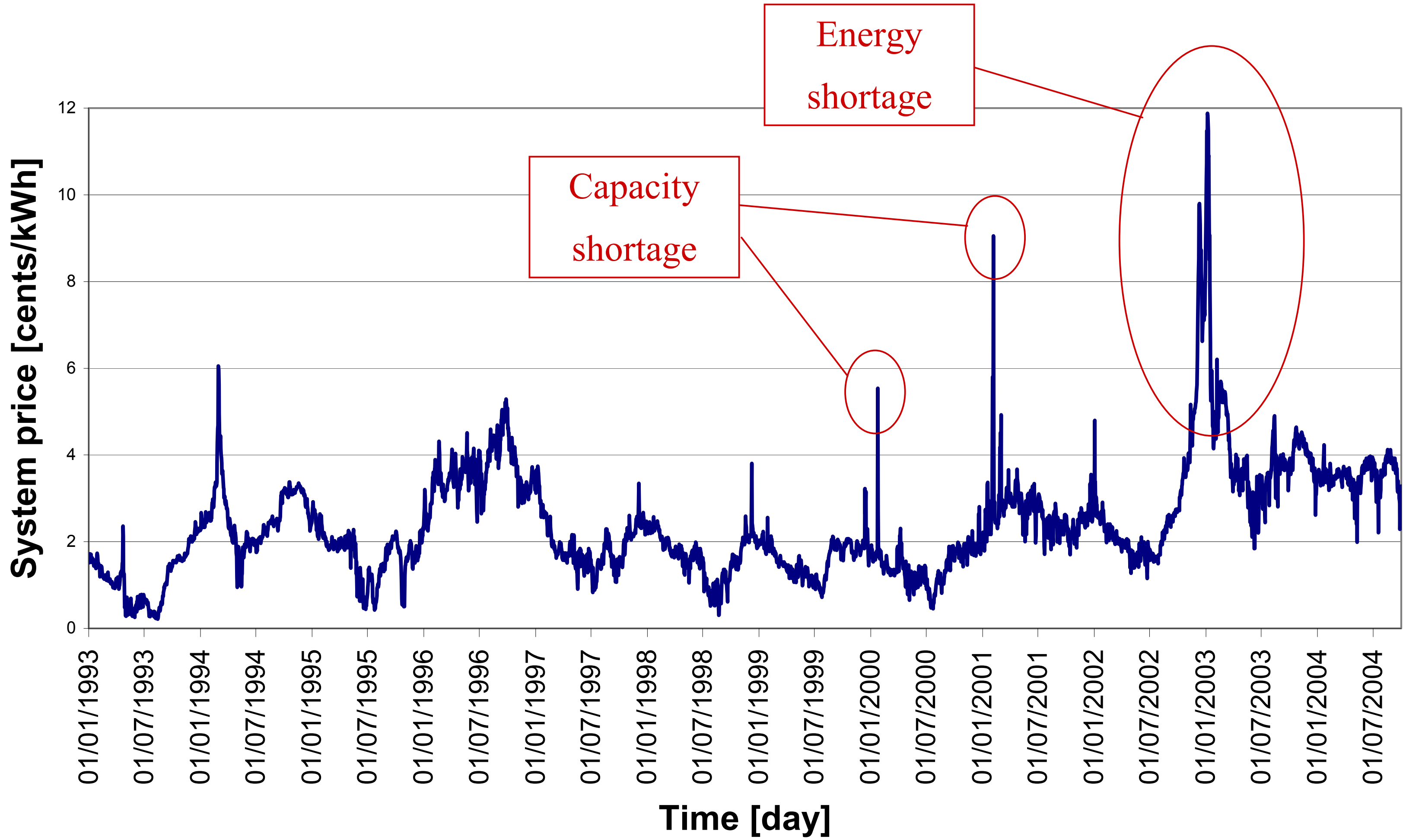
- Supply/demand balance
  - Surplus capacity from “pre-deregulation” disappearing
  - Increasing vulnerability to capacity and energy (hydro) shortages
  - Decentralized and profit-maximizing investors
- Capacity adequacy measures in Scandinavia
  - Increasing price flexibility on demand side
  - Markets for operating reserves
    - Real-time regulating market
    - “Option market” for provision of operating reserves (Norway)
    - Harmonization of rules between countries
  - Strategic reserves
- Alternative: explicit capacity mechanisms
  - Capacity payments
  - ICAP obligations

Capacity balance in Nordic power system



Source: Nordel

Daily spot prices in the Nord Pool market



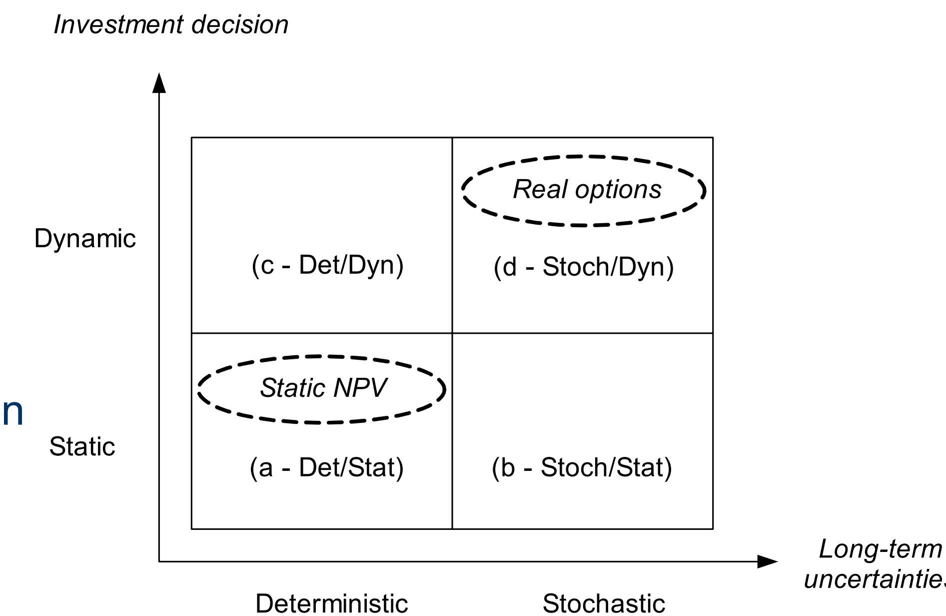
Source: Nord Pool

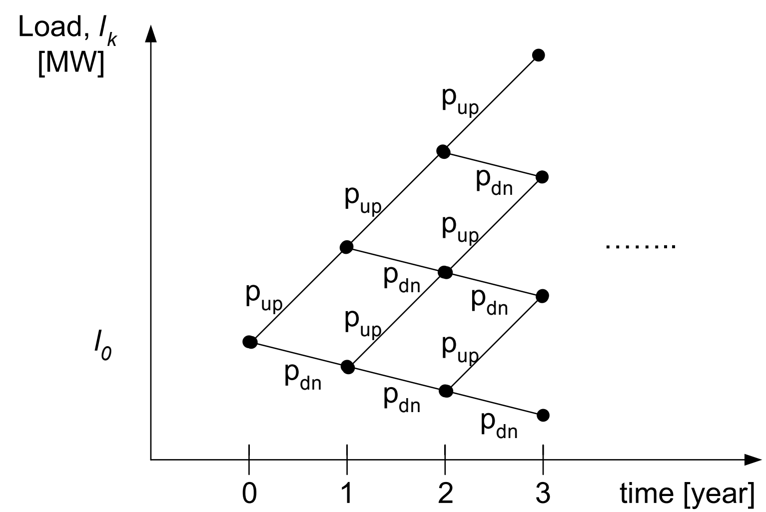
Optimal timing of investments in new power generation

A model for optimal investment timing

- One profit maximizing investor
  - New entrant
  - Permit to build obtained
  - Flexible timing of investment
- A real options approach
  - Stochastic dynamic optimization
  - Uncertainty in load growth
- Investor profit
  - Electricity spot market
  - Capacity payment
  - Functions of load and installed generation capacity
- Full model description:

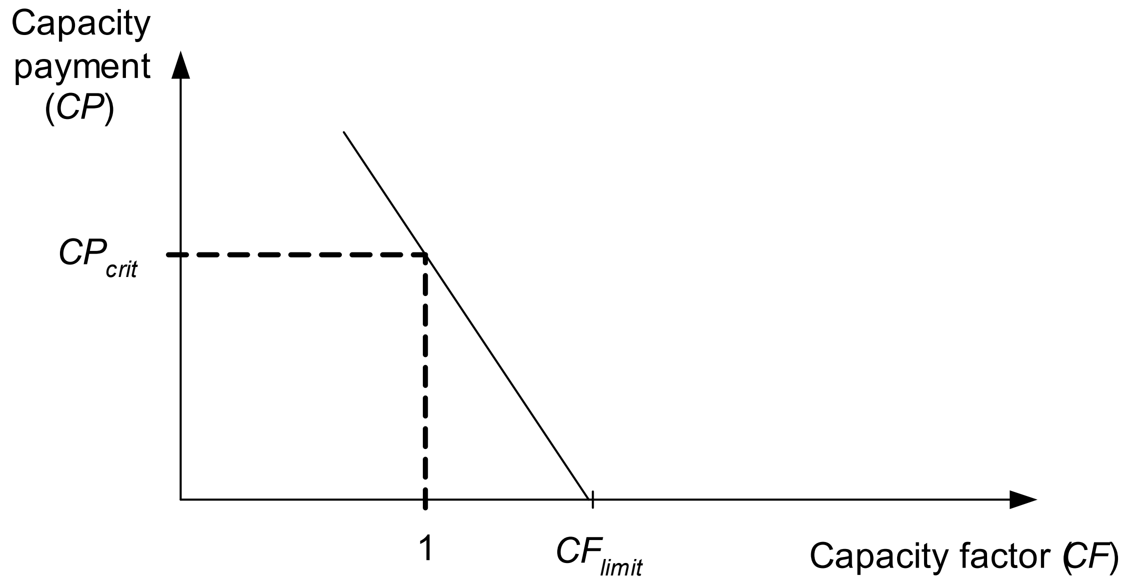
Botterud A. and M. Korpås (2004), "Modelling of power generation investment incentives under uncertainty in liberalised electricity markets", Proceedings 6th IAEE European Conference, Zurich. [Online]: http://www.saee.ch/saee2004/botterud.pdf





Capacity mechanism

- Monthly capacity payments: function of installed capacity and load level
  - Administrative payment
  - Capacity demand in a system with ICAP obligation



Capacity factor, CF = Available capacity/peak load

Investment in a new gas power plant

- 800 MW CCGT plant
- Spot price model based on historical Nord Pool data
  - 1997-2003
- Fixed growth in renewable generation
  - Covers half of the expected growth in demand
- Three scenarios
  - 1. Energy only
  - 2. Fixed capacity payment
  - 3. Variable capacity payment

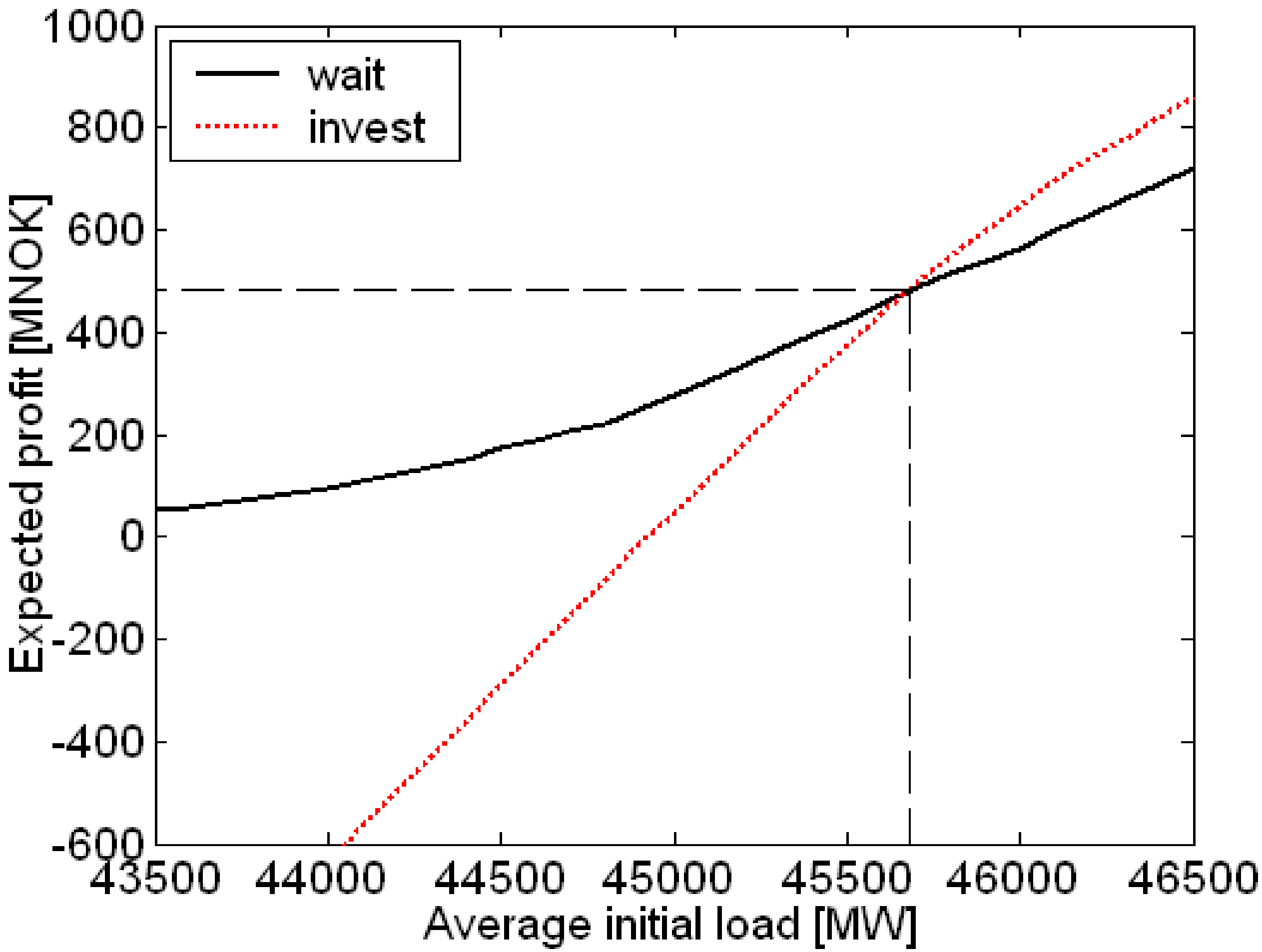
Parameter	*Value*	*Unit*
Installed capacity	800	MW
Electric efficiency	0.58	
Average availability	0.9	
Investment cost	714	$/kW
Variable costs (fuel + O&M)	2.33	cents/kWh
Construction time	3	years
Life time	30	years
Risk-adjusted discount rate	8	% pa

Levelized unit cost: 3.17 cents/kWh

Net expected load growth: 180 MW

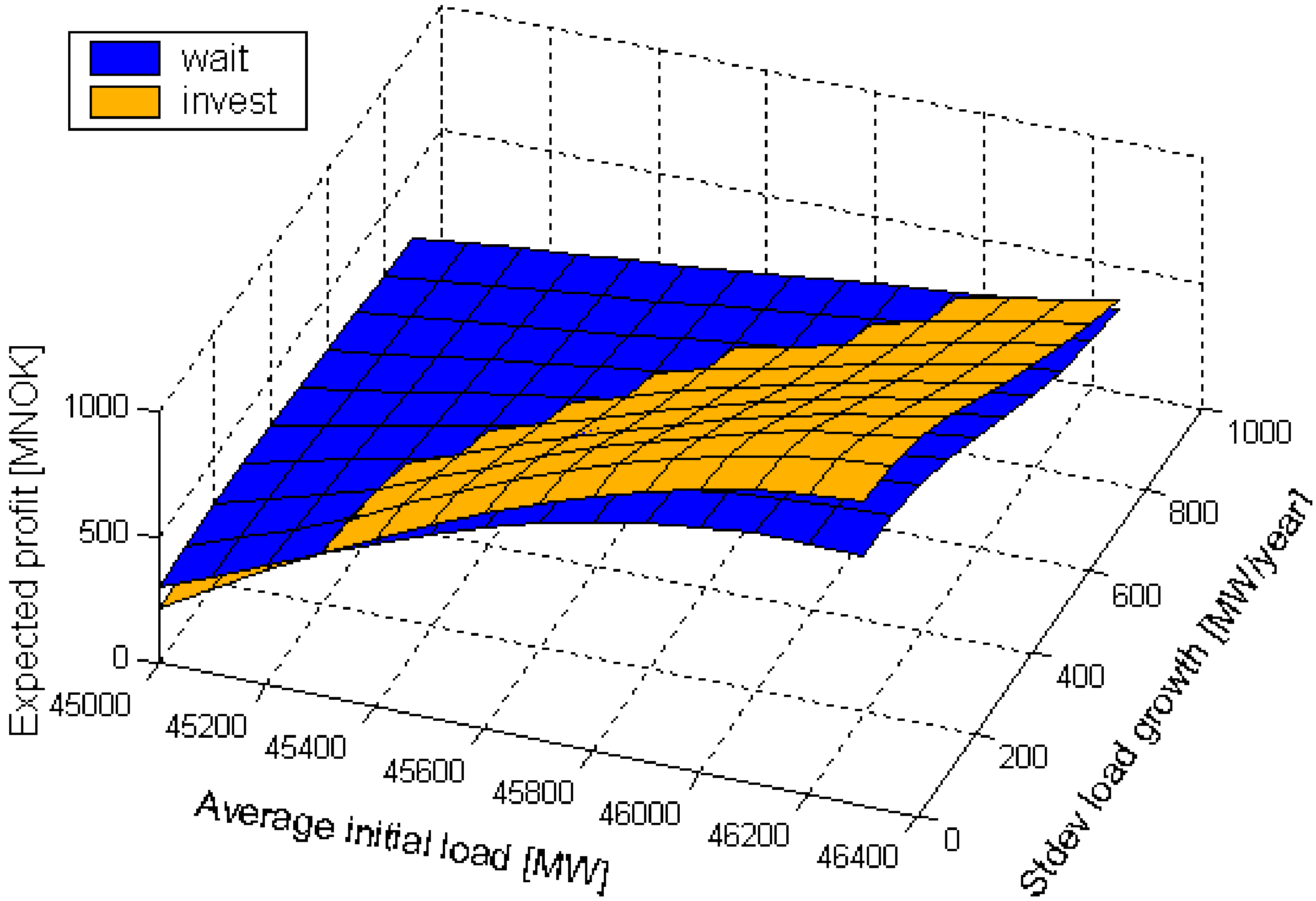
St.Dev. in load growth: 600 MW

Scenario 1: Energy only

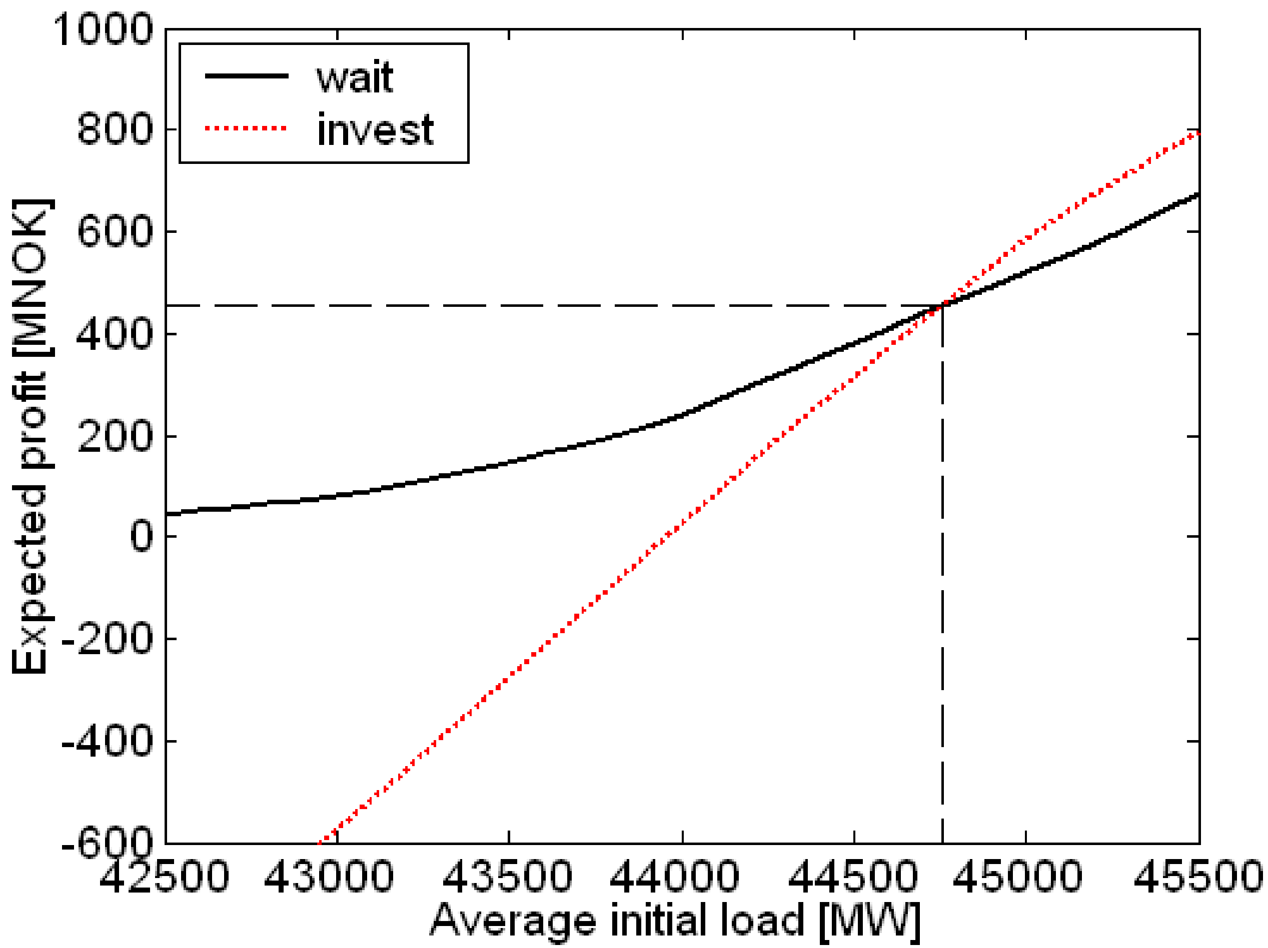


$1 million ≈ 7 MNOK

Scenario 1: effect of uncertainty

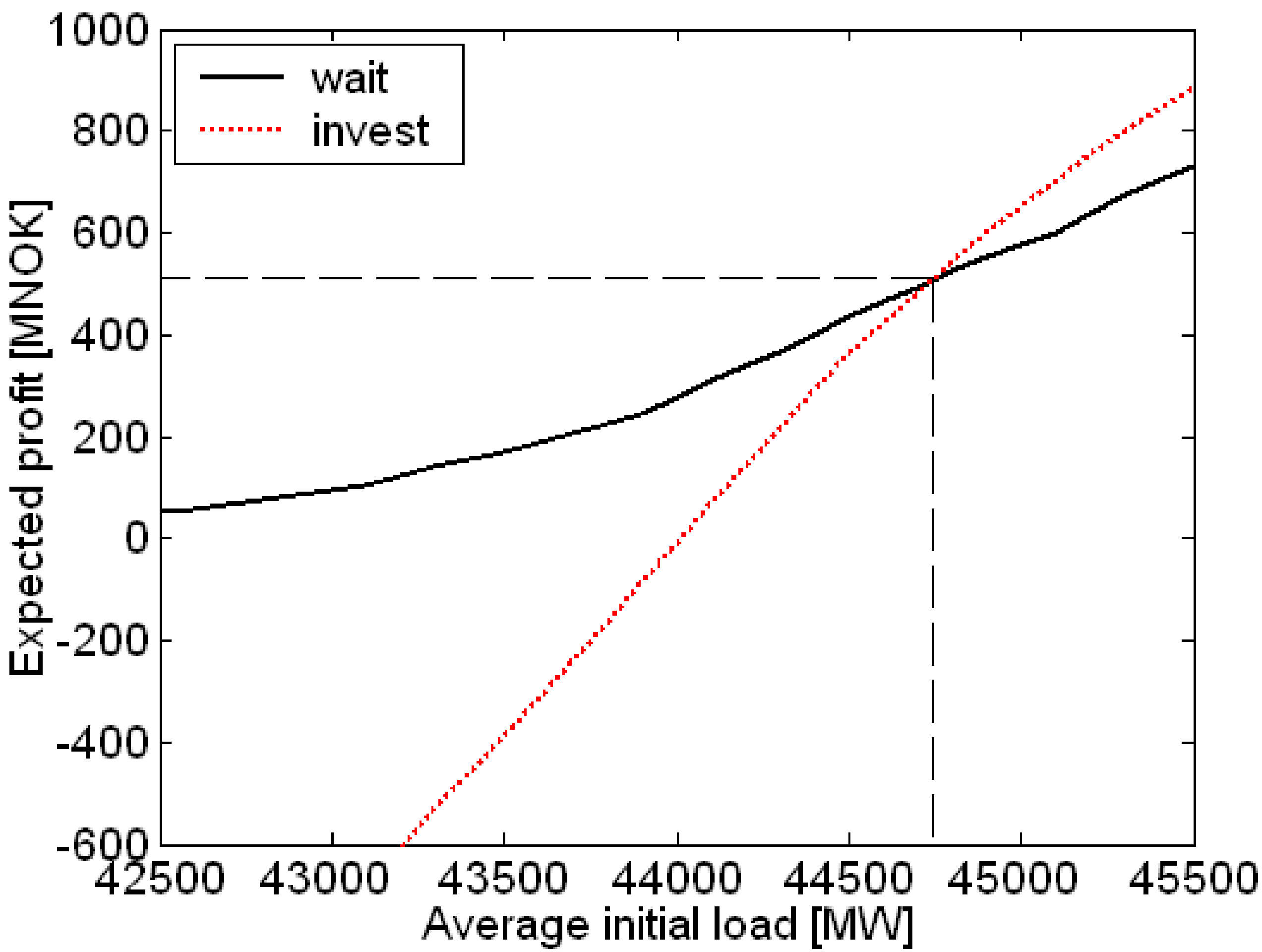


Scenario 2: Fixed capacity payment



$\boldsymbol{CP}$ = 0.43 cents/kWh for all $\boldsymbol{CF}$

Scenario 3: Variable capacity payment



$$CP_{crit} = 5.57 \text{ cents/kWh}, \quad CF_{limit} = 1.1$$

Comparison of results

Scenario	Investment threshold				*Total exp. profit* [$ million]
	Load [MW]	*Price* [cents/kWh]	*Cap payment* [cents/kWh]	*Total price* [cents/kWh]	
1 - inflex	45650	3.43	0	3.43	67.1
2 - inflex	44750	2.93	0.43	3.36	65.0
3 - inflex	44750	2.93	0.63	3.56	73.3

Historical average load levels:

2001 (max): 44864 MW

2003: 43425 MW

Variable capacity payment adds growth and uncertainty to investors' profit

→ Increases the value of waiting

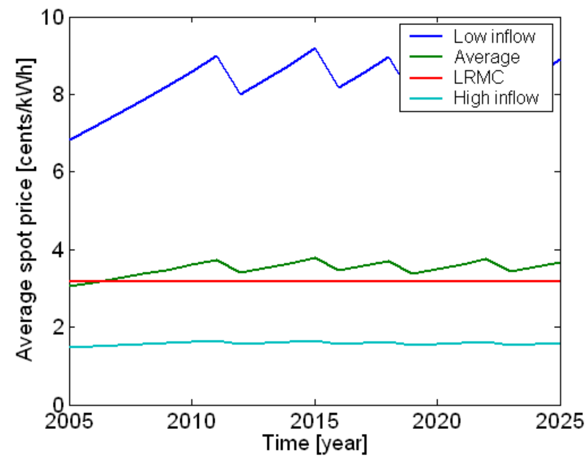
System consequences

Conditions 2 years after investment decision with expected load growth:

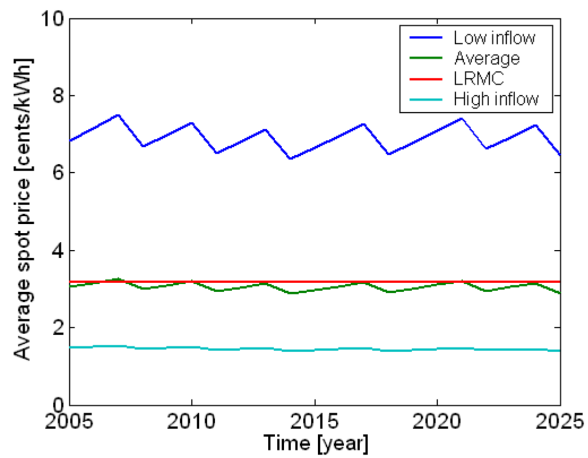
- Average spot price over the year
  - Scenario 1: **3.67** cents/kWh
  - Scenario 2/3: **3.11** cents/kWh
- Monthly price, lowest inflow realization
  - Scenario 1: **20.3** cents/kWh
  - Scenario 2/3: **15.7** cents/kWh
- Capacity reserve
  - Scenario 1: **580** MW
  - Scenario 2/3: **1795** MW

Simulated prices:

Scenario 1:



Scenario 2:



Summary/conclusion

Summary/conclusion

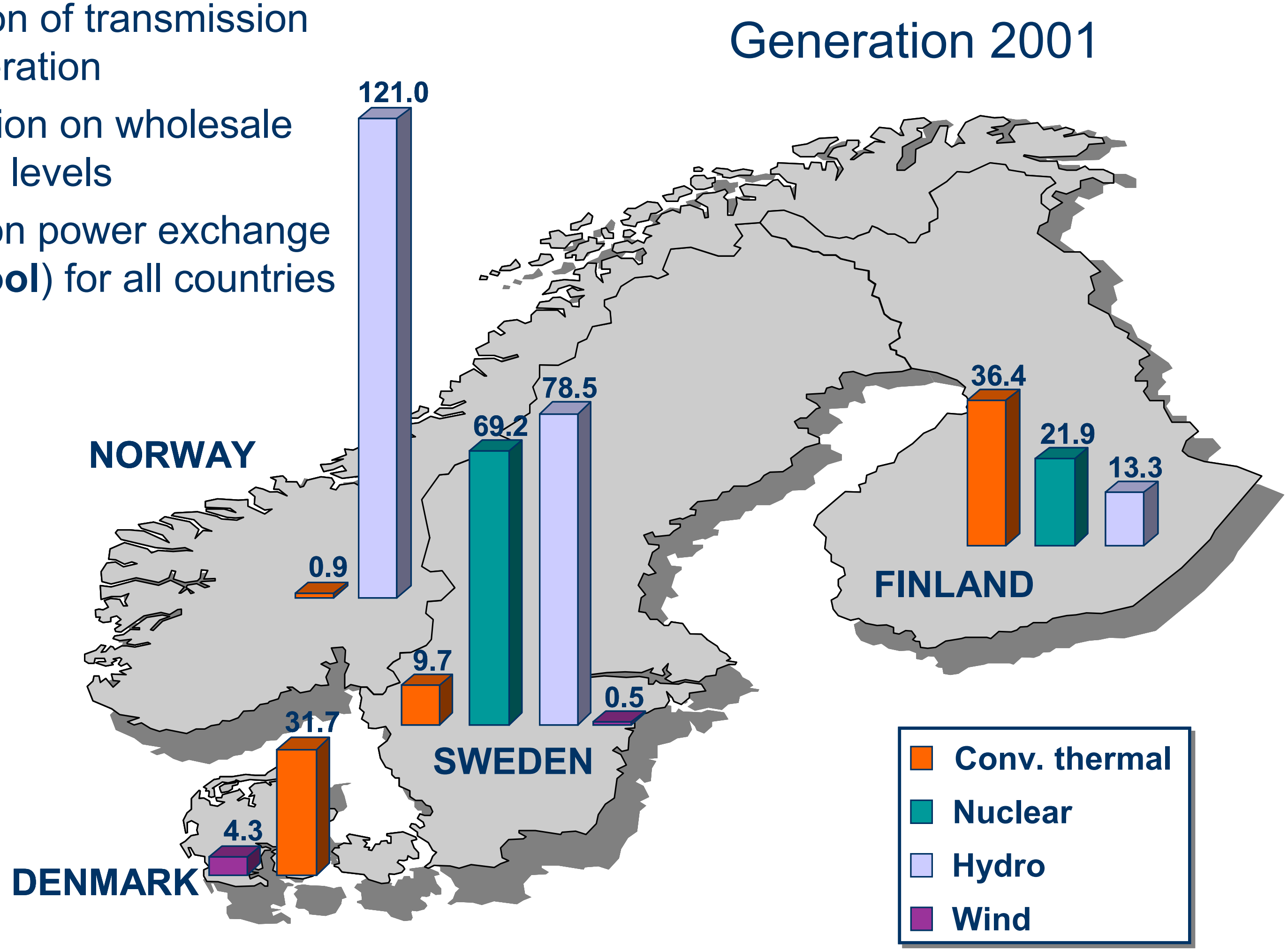
- Generation investments in a restructured system
  - Decentralized and profit-maximizing investors
  - Transfer of risk to the supply side
  - Limited possibilities for long-term hedging
  - Several factors can distort the market prices
- Current situation in the Nord Pool market
  - Tighter capacity and energy balances
  - Will the market pass the long-run “investment test”?
  - Policy focus: reserves and demand side flexibility
- Effect of capacity payments
  - Interrelated dynamics of capacity and energy prices
  - Increases investor’s profit and triggers earlier investments
  - A variable payment will also add uncertainty to investor’s income

Appendices

The Nordic power market (Nord Pool)

Current status

- Separation of transmission and generation
- Competition on wholesale and retail levels
- A common power exchange (**Nord Pool**) for all countries



The decentralized investors' perspective

- Objective: Maximize profits
- Long-term uncertainties
  - *Demand growth*
  - *Fuel prices*
  - *Regulations*
  - *Cost of capital*

Price ← *Decisions by other market participants*

- Investors are exposed to the uncertain prices
  → increased investment risk
  → more important to make prudent investment decisions
  → increased need for long-term hedging

The system perspective

In a perfect market optimal investments should emerge from price signals. However:

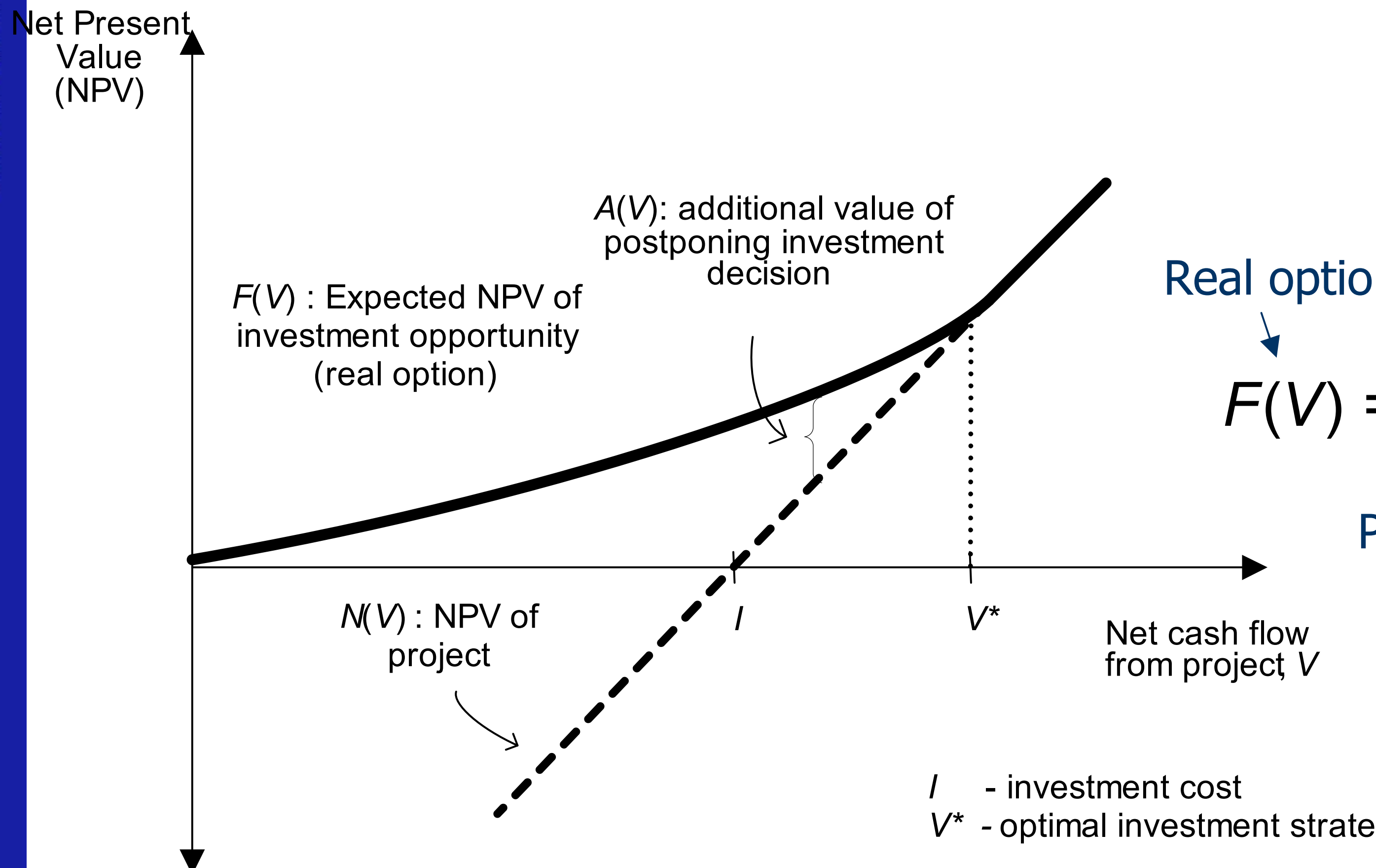
- Low price elasticity of demand
  - End-users willingness to pay not reflected in the spot price
  - Possible that supply does not mean demand

- High risk involved in investing in new power generation
  - Volatile spot prices
  - Long expansion delays: permitting and construction
  - Difficult to hedge long-term positions

- Market power
  - High barriers for new entrants
  - Incumbents can postpone investments to increase prices

- Procurement of operating reserves
  - Can distort prices in the spot market

The real options principle



Real option — Additional value

$$F(V) = N(V) + A(V)$$

Project

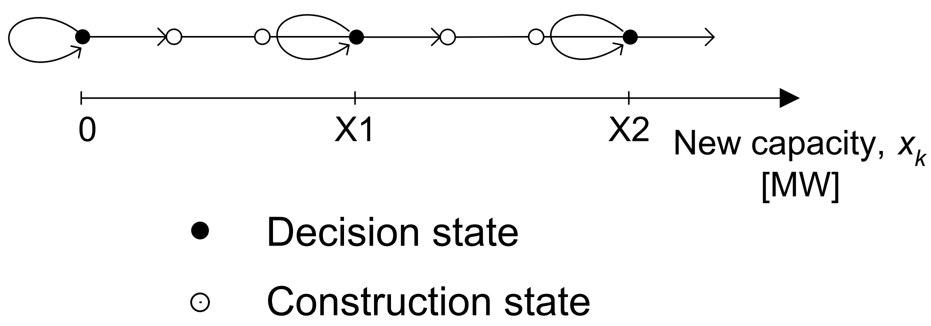
Ref. Dixit/Pindyck 1994

Solving the model

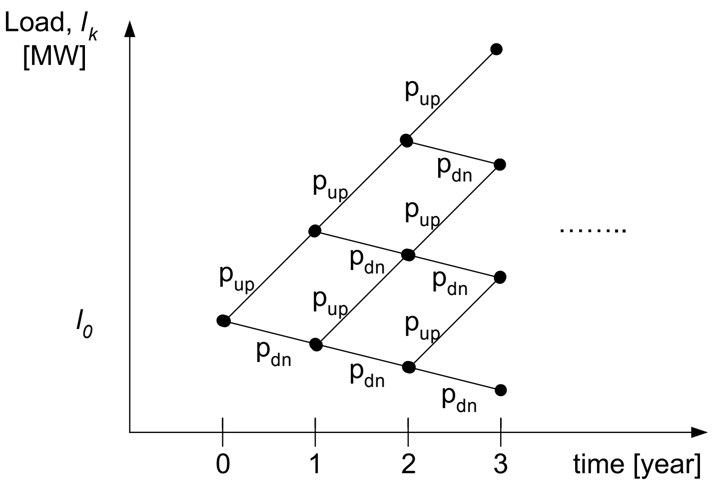
- A dynamic optimization problem with sequential decision making
- Objective: maximize total profits in the planning period
  - (income from electricity sales) + (income from capacity mechanism) – (investment and operating costs)
- Uncertainties
  - Long-term: demand (discrete Markov chain)
  - Short-term: availability of renewable generation (discrete probability distribution)
- Stochastic dynamic programming (SDP)
  - Discrete time
  - Discrete state variables

Solving the model (II)

Discrete states for new capacity, x_k:



A binomial tree for load, l_k:



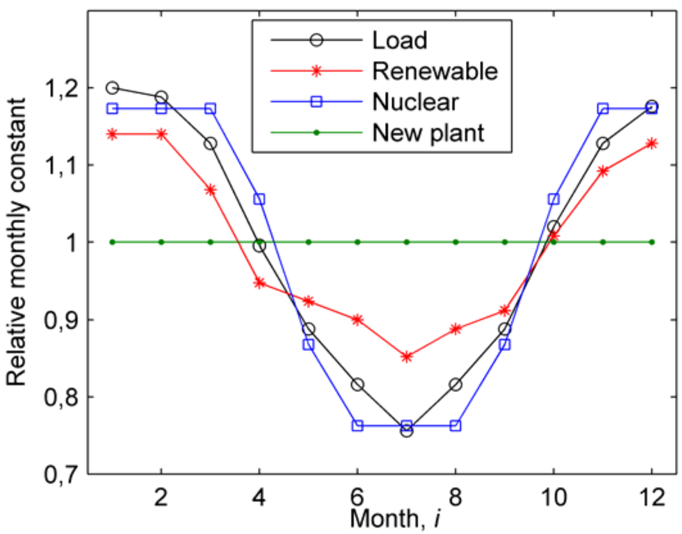
- Problem solved by backwards SDP:

$$J_k(x_k,l_k) = \max_{u_k \in \Omega_{u,k}} \underset{\omega_s,\omega_l}{E} \left\{ g_k(x_k,l_k,u_k,\omega_s) + (1+r)^{-1} \cdot J_{k+1}(f(x_k,l_k,u_k,\omega_{l,k})) \right\}$$

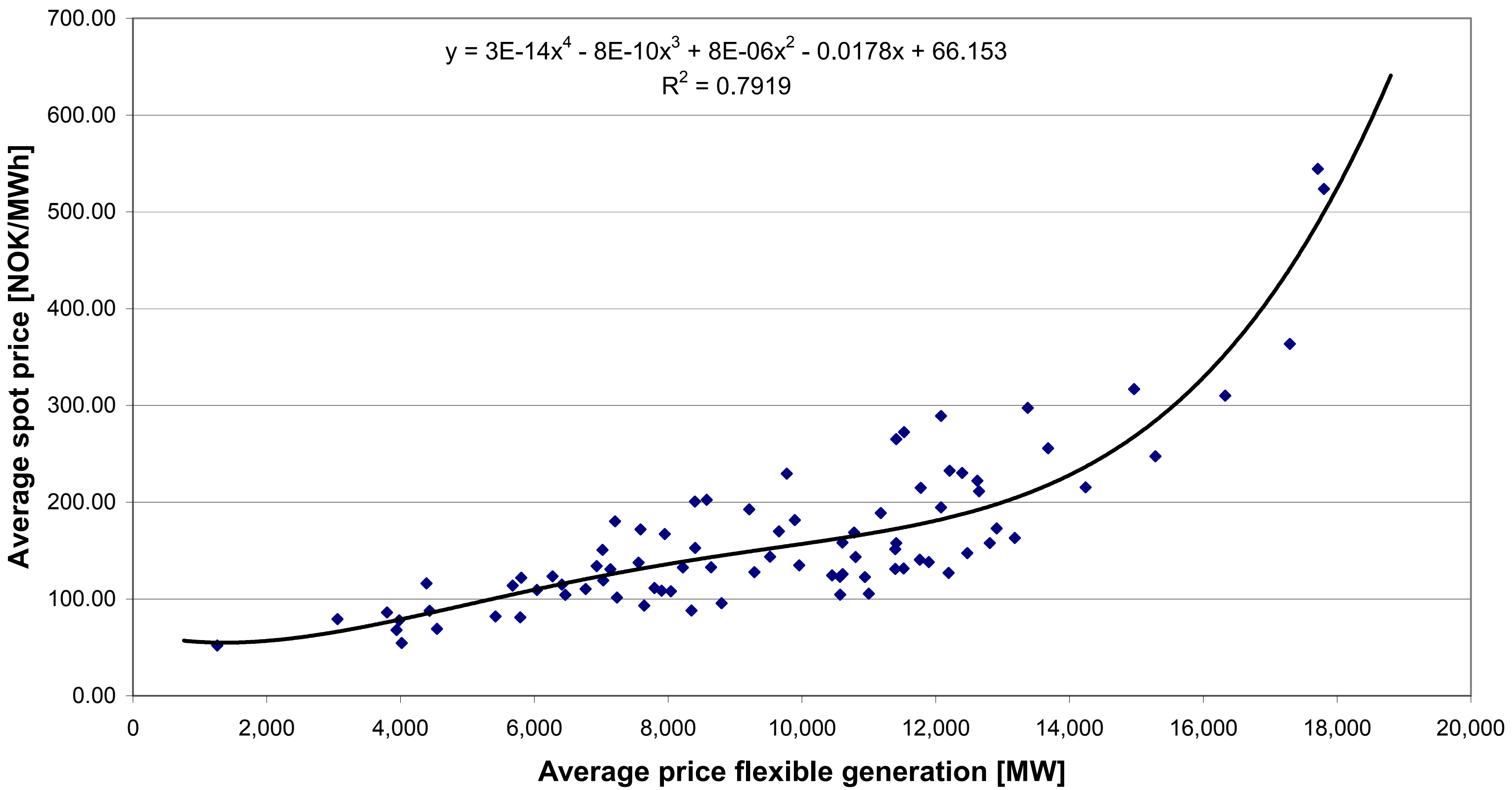
J_k	– aggregate profit	u_k	– investment in new capacity
g_k	– profit in period k	ω_s	– short-term uncertainty
r	– risk adjusted discount rate	ω_l	– long-term uncertainty

Representation of the spot price

- Spot market model for Nord Pool
  - Supply/demand balance
  - Uncertain renewable generation
  - Short-term (hourly) fluctuations
- Three generation technologies in existing system
  - Nuclear generation (fixed)
  - Renewable generation (stochastic)
  - Other thermal generation (price flexible)
- Time resolution
  - Monthly average prices
  - Hourly spot prices represented as probability distribution

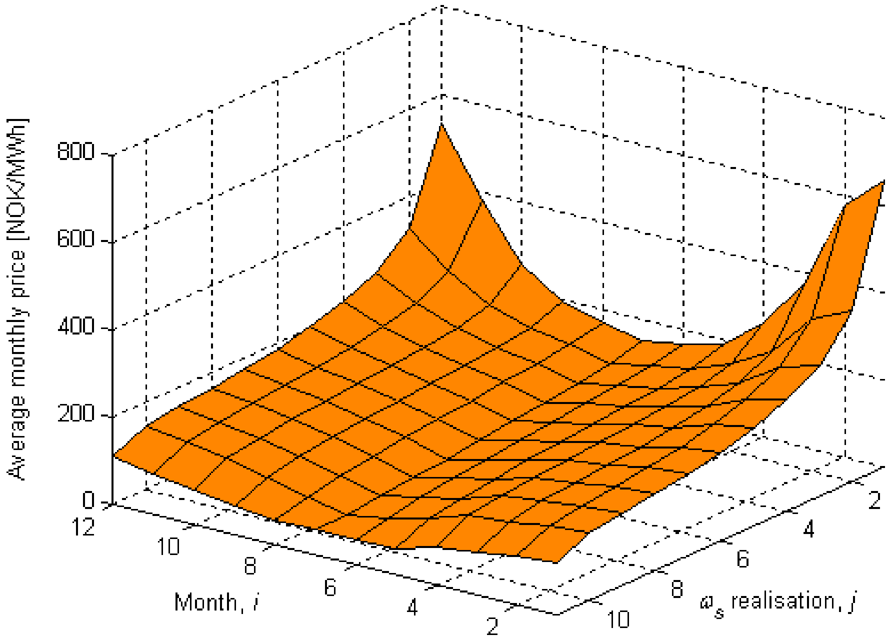


Supply curve for initial thermal generation

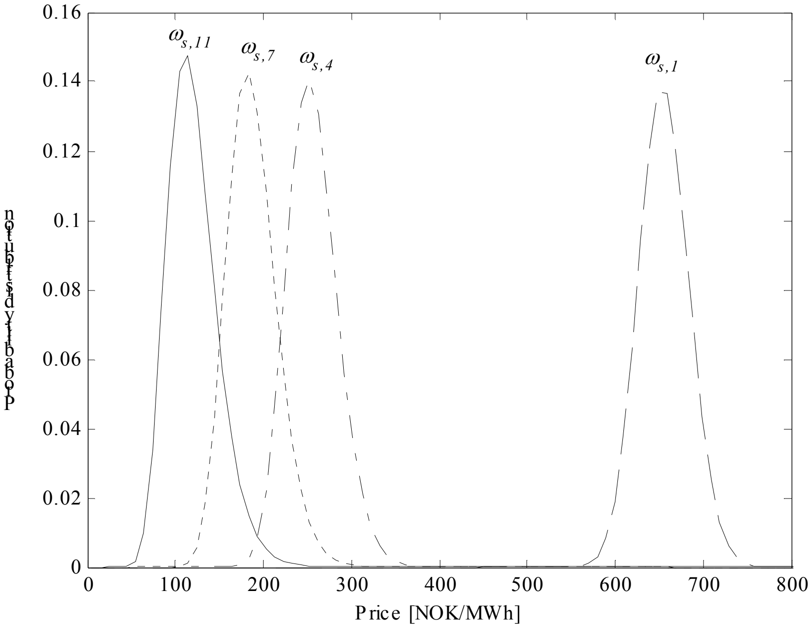


Spot price distributions in initial system

Monthly average price



Spot price



$\omega_{s,j}$ – renewable generation