Hydro Scheduling Powered by Derivatives

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Summary

- An empirical analysis of how commodity storage is operated for 13 hydropower producers
- Testing different hypotheses on inventory and operational policies
- Our results indicate:
  - A simple regression model can explain a significant part of the variation in the scheduling policies
  - Electricity forward prices are used in the optimization of hydro scheduling
  - Real option theory applies: The higher the price volatility, the lower the production

Outline

- Related literature
- Nordic electricity market
- Hydropower scheduling
- Empirical analysis

Related literature

- Theory of storage: Telser (1958), Williams & Wright (1991), Deaton & Laroque (1996)
- Hydropower scheduling
  - Many OR and engineering papers on methods, including stochastic programming: Wallace & Fleten (SP handbook, 2003)
  - Some econ papers, e.g., Førsund (2007)
  - Only few empirical studies. For instance, Tipping (2006) and Nasakkala & Keppo (2007)
- Related OR papers: Ding, Dong & Kouvelis (OR 2007), Caldentey & Haugh (MOR 2006), Birge (2006)
  - Imply that financial information should be used
- Empirical studies on nonfinancial firms: Guay & Kothari (JFE 2003), Bartram, Brown & Fehle (2006)
  - Nonfinancial firms don't trade much derivatives

Nordic electricity market

- All the time supply equals demand
  - National grid companies manage short term imbalances
- Spot market
  - Daily submission of supply and demand bids for the next 12-36 hours
- Forwards and futures
  - Traded on Nord Pool (exchange) and OTC/bilaterally

Electricity derivatives market

- Underlying asset
  - Elspot system price which is the average price of physical electricity in the whole Nord Pool area over the next 12-36 hours and calculated assuming no transmission bottlenecks
- Futures
  - Exchange-traded contract for delivery in a specified future time interval at an agreed price
  - Financially settled mark-to-market, week and month maturity lengths
- Forwards
  - Financially settled during maturity period, quarters and years maturity lengths, up to five years into the future

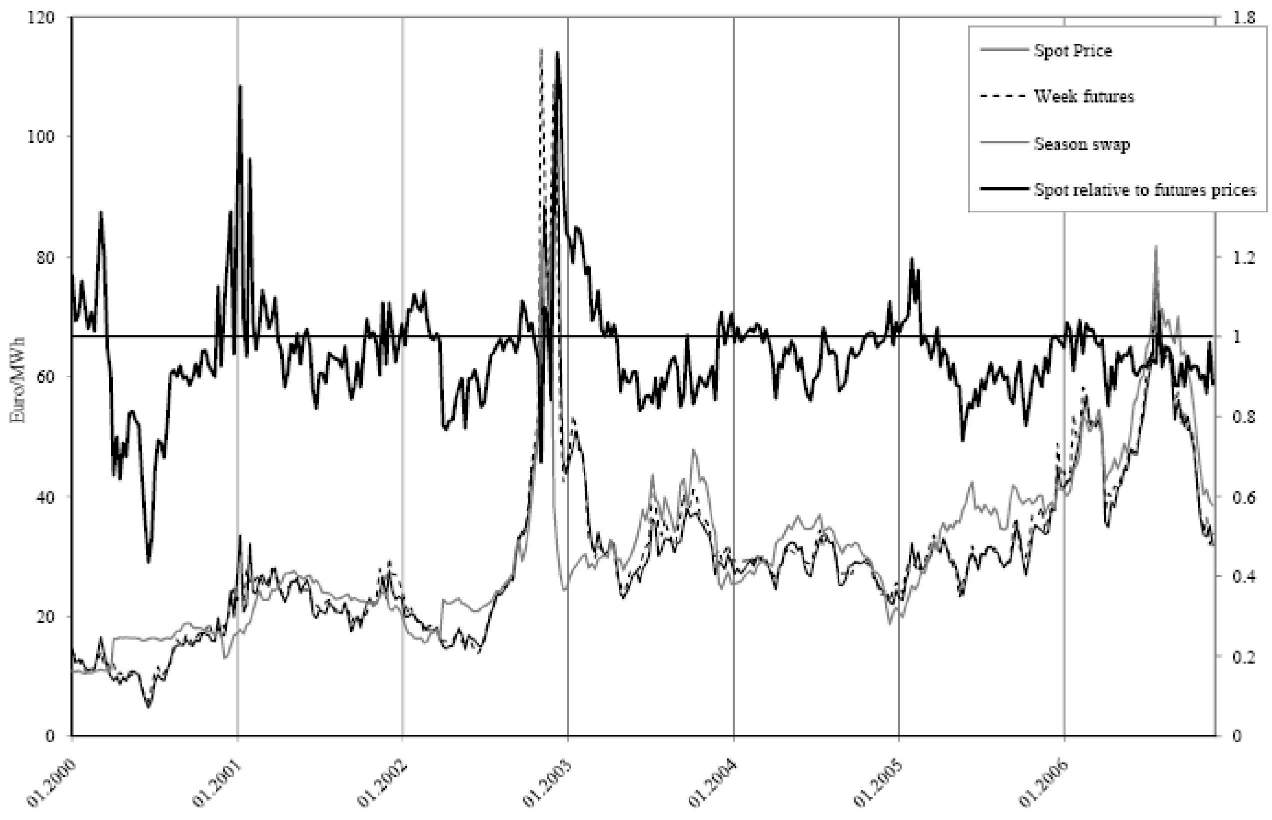
Nord Pool prices

- Descriptive statistics for spot prices, weekly futures, seasonal forwards, and spot price relative to the futures prices. All prices are in Euro/MWh. ADF is the Augmented-Dickey-Fuller stationary test statistic which has a critical value of -2.87 at a 5% significance level.
- An average of 0.96 indicates that forward prices above the spot price, i.e., risk premium

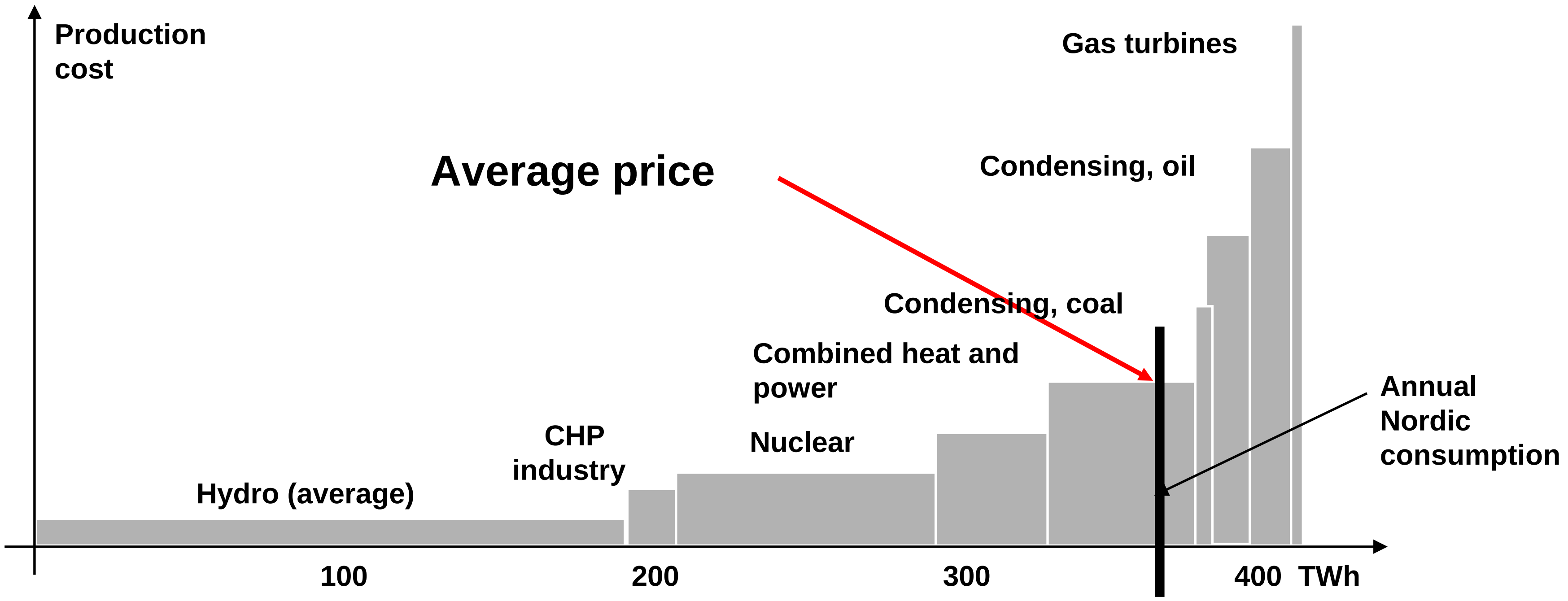
	Mean	*Min*	*Max*	*Std. dev*	*ADF*
Spot Price	29.63	4.78	103.65	14.01	-2.928
Weekly futures	30.44	5.70	114.56	14.89	-3.446
Seasonal forwards	31.16	10.48	83.25	13.56	-2.890
Spot relative to futures prices	0.958	0.435	1.71	0.136	

Nord Pool prices, Cont'd

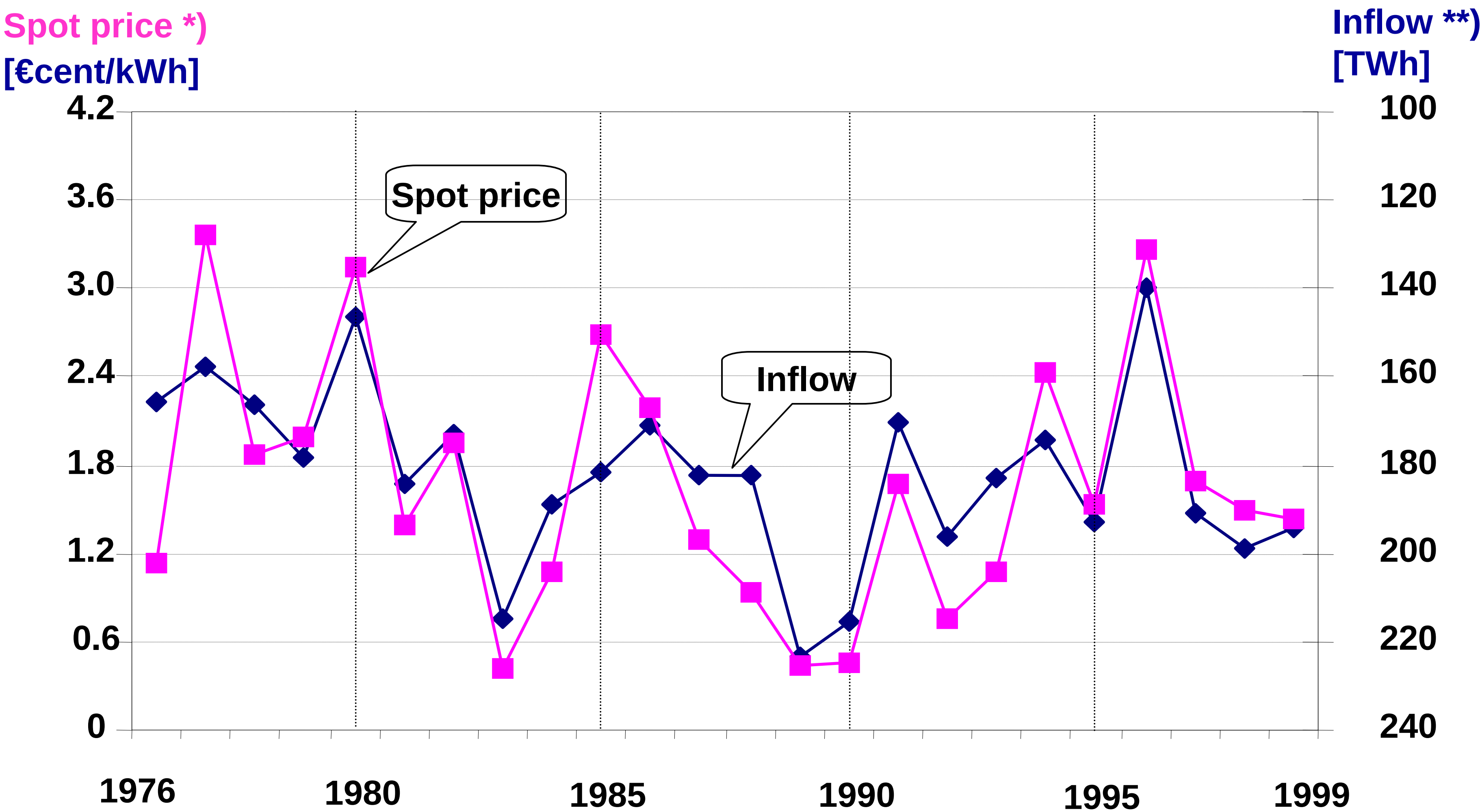
- Spot and selected futures and forward prices between February 2000 and December 2006.
- Timing matters!



Supply curve



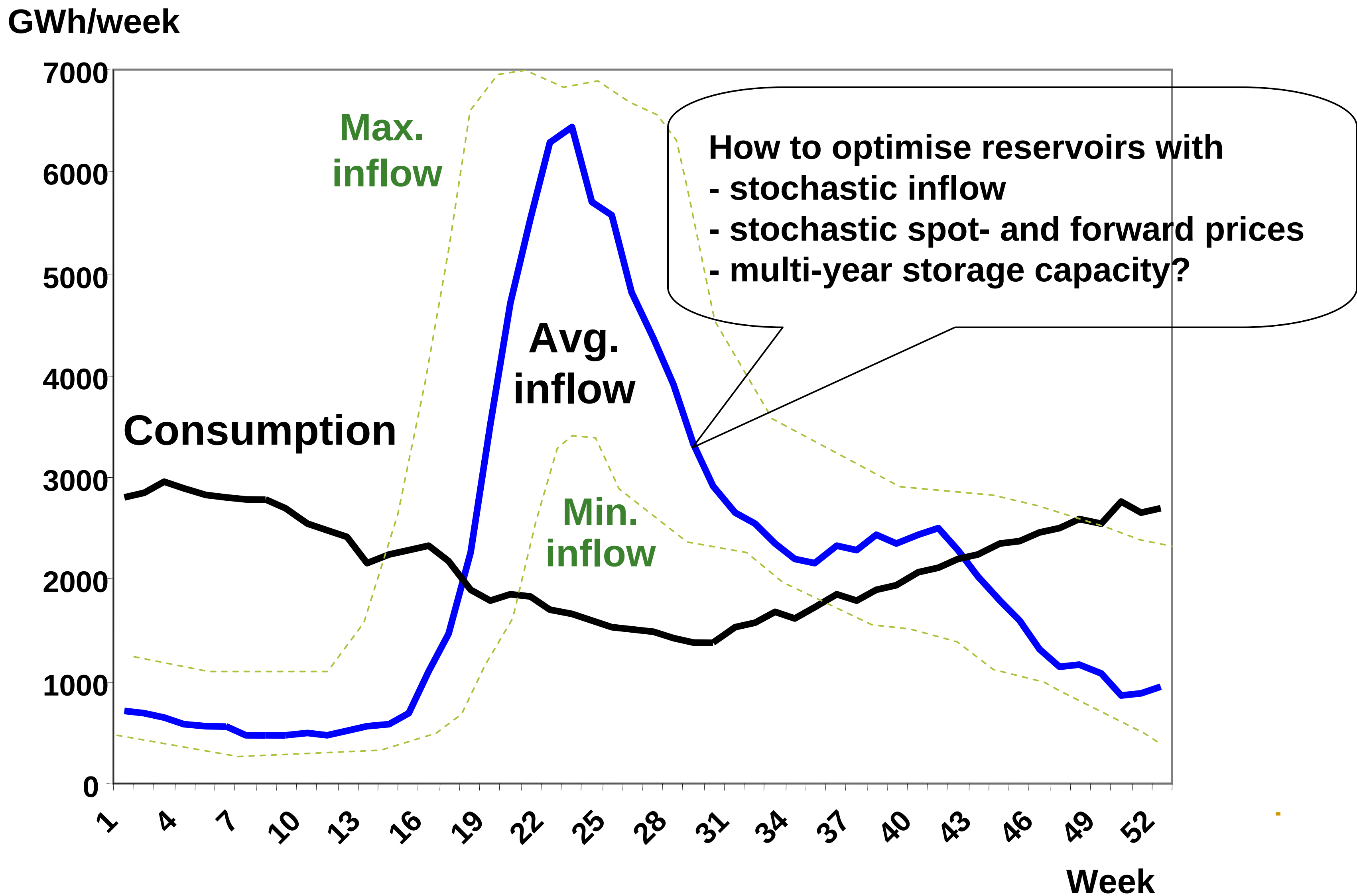
Key characteristic: Inflow uncertainty



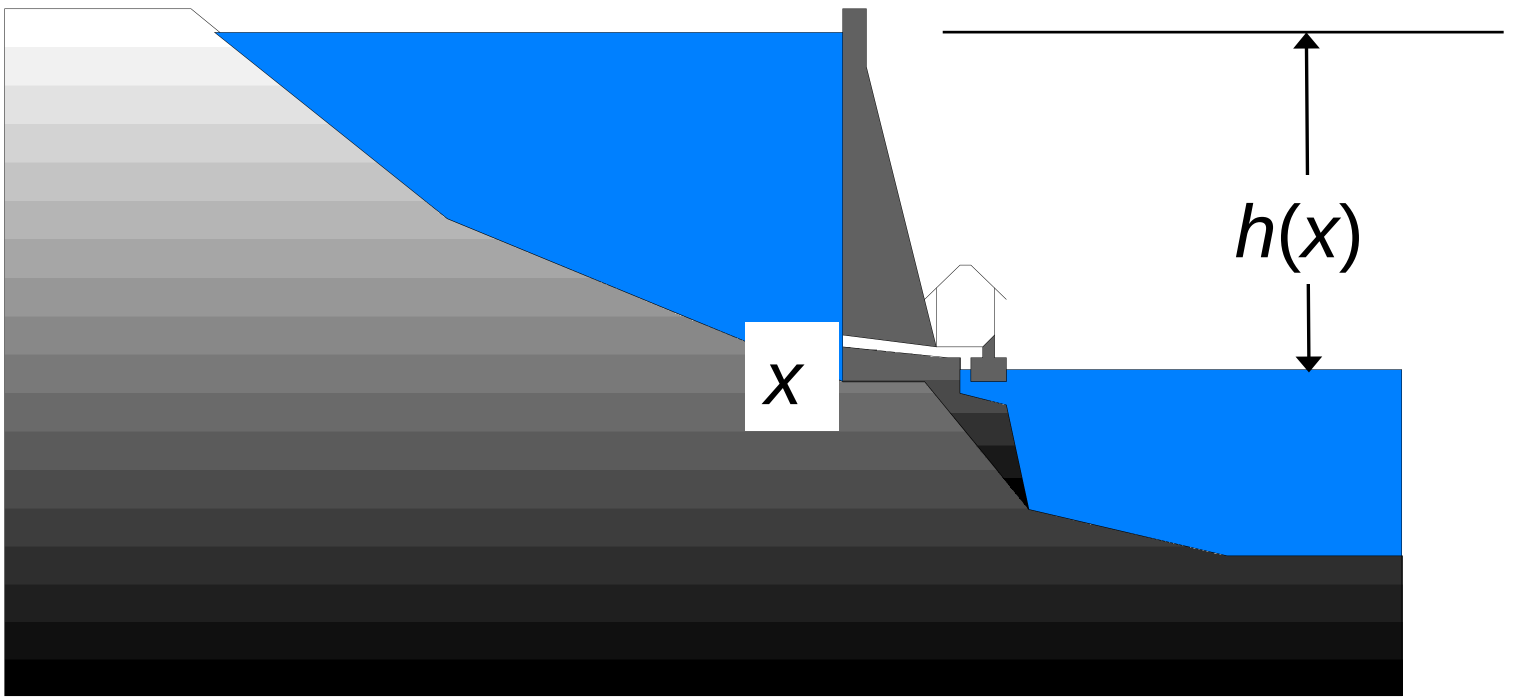
*) Average spot price in 1999-prices

**) Annual inflow Norway and Sweden

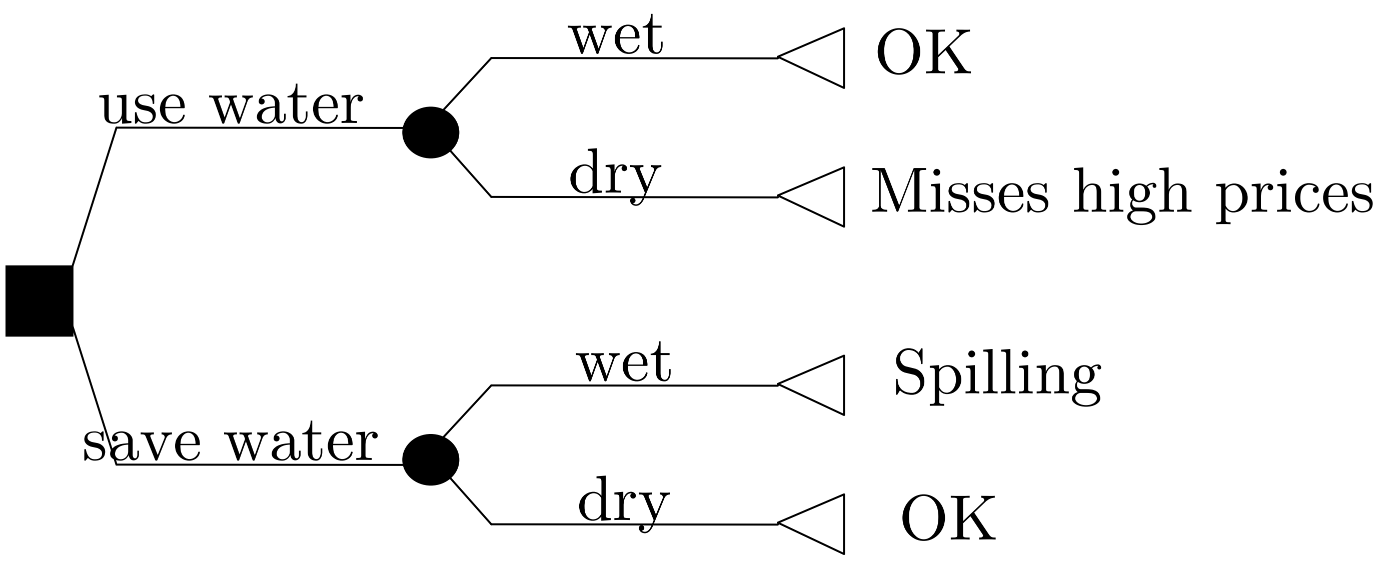
Inflow and hydro scheduling



Power station and reservoir



Scheduling problem



- "Marginal costs" are opportunity costs of discharging water
- Avoid spilling, discharge when prices are high

Scheduling problem

How to calculate the expectations? Forecasts or forward curve?

$$\max E_{\pi,p}\left[\sum_{t=1}^{T}\frac{\pi_t p_t}{(1+k)^t}+\frac{V(l_T,\pi_T)}{(1+k)^T}\right]$$

subject to

hydro balance

lower and upper bounds on reservoir and discharge

Notation:

$\pi =$ price
$p =$ generation
$k =$ discount interest rate
$V =$ value at end of horizon
$l =$ reservoir volume

Hydro scheduling – hierarchy (Fosso et al., 1999)

Reservoir management
Horizon: 2-3 years

Time step: 1 week

- Scheduling discharges
- The horizon depends on the size of the reservoir compared to the annual inflow
- There may also be a medium term model

Short term planning

Horizon: 24-168 h

Time step: 1 h

- Detailed generation allocation with signals from the long term models
- Bidding into the physical day-ahead market

Production and information

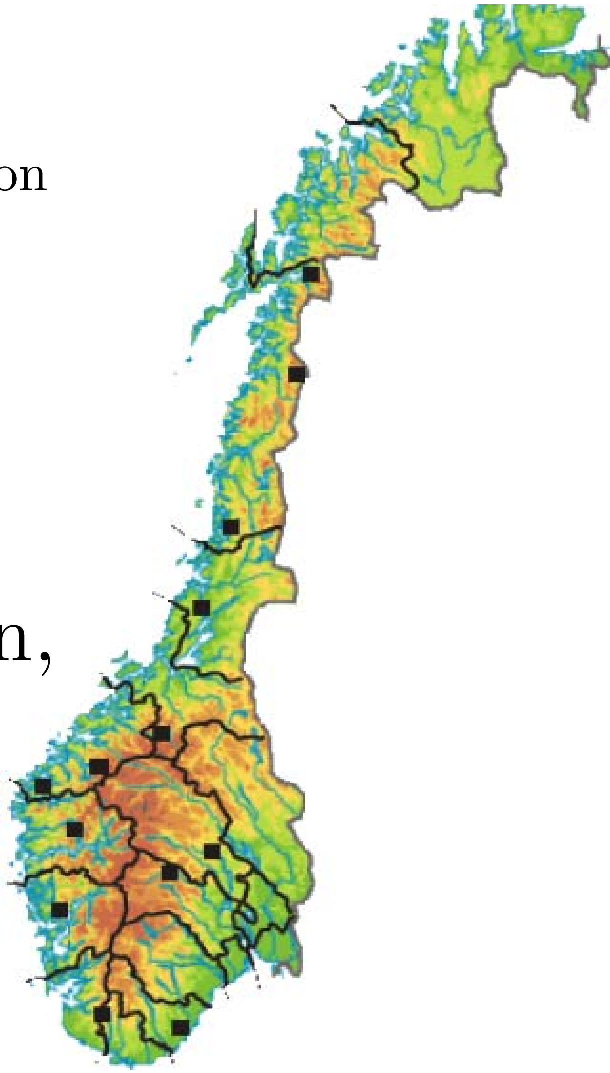
- Hydropower producer should consider
  (i) current spot price and expected future prices
  (ii) water reservoir level and expected inflow
  (iii) production constraints
- For instance,
  - The higher the forward prices the more should be produced later
  - The higher the water level the more should be produced now
- Producers have continuous access to spot and forward price information
  - Inflow forecasts are not reliable beyond one week ahead
  - Daily inflow forecasting, price forecasting, bidding

Empirical questions

- Is derivative price information used in hydropower scheduling?
  - Do forward prices explain realized production schedules?
  - Does it help to use forward prices?
- Which factors drive generation scheduling?
  - Prices, inflow, reservoir levels, ...

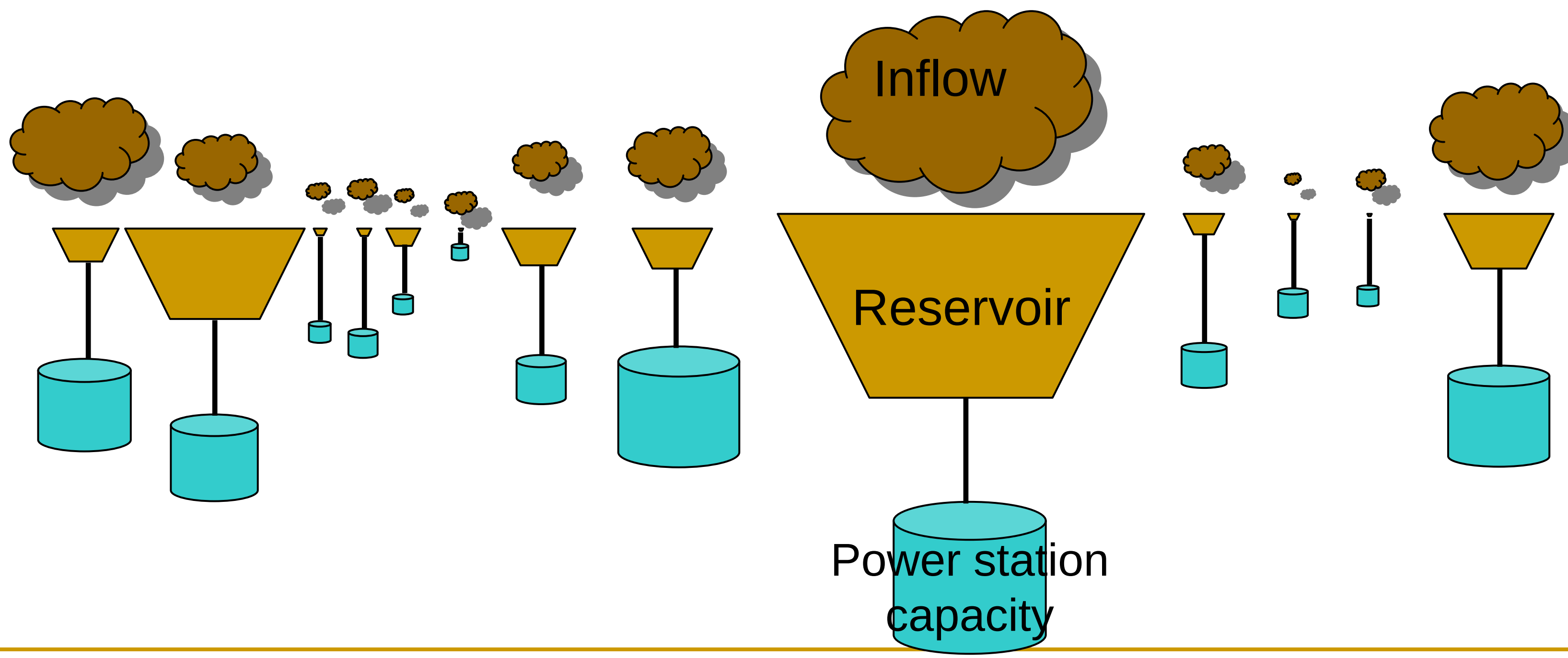
Data

- 13 Norwegian plants, having one main reservoir
  - 9 producers say that they use forward information
  - 4 producers use their own forecasts
- The largest producers (Statkraft, Hydro) are not represented
  - We consider only price takers
- Weekly data 2000-2006: generation, reservoir level, inflow
- Nord Pool prices
  - Elspot (day ahead) and Eltermin (futures and forwards)



Producers

	1	2	3	4	5	6	7	8	9	10	11	12	13
Capacity MW	128	120	30	40	28	23	68	167	210	62.1	41	29	140
kWh/m3	1.16	1.32	1.15	1.27	0.67	0.16	1.25	1.09	1.46	1.5	0.95	0.91	1.36
Reservoir GWh	228.1	624.4	47.1	51.8	118.9	14	255	272.5	1270	142	42.6	12.4	380.8
Inflow GWh/y	641.2	380.8	106.6	139.9	87.8	153	272.3	414.4	1250.5	231.8	81.3	147.2	662.9
Relative reservoir	0.356	1.64	0.442	0.37	1.35	0.092	0.937	0.642	1.015	0.613	0.953	0.084	0.574
Capacity factor %	57.2	36.2	40.5	39.9	35.8	76	45.7	28.3	68	42.6	22.6	57.9	54



Regression model variables

- Dependent variable is weekly production relative to the capacity
- Main explanatory variables:
  - Inflow relative to capacity
  - Spot price relative to forward price (nearest season or quarter), we call this as Basis
  - Seasonality dummies: months and filling season (weeks 18-39)
  - Relative production in the previous week
- Additional effects through dummy variables:
  - Reservoir level > average level: Production should be higher.
  - Reservoir level is high or low (over/below 90%/10% of the max level): Production should depend less on the market prices.
  - Reservoir level > 90% of the max level: Production should depend more on inflow.
  - Spot price > 95% of the max price: Production should be high.
  - Spot price volatility > 95% of the max volatility: Production should be low.
  - Producer claims to use forward prices in the scheduling: Production should depend more on the market price.

Regression model

- Granger causality test:
  - Controlling for seasonality
  - Basis Granger causes aggregate production of the 13 power plants
  - The aggregate production does not Granger cause Basis
- OLS estimation procedure
  - Fixed effects: A dummy on the intercept for each producer
  - Lagged production as a covariate, all the other covariates are assumed to be strictly exogenous
  - Each producer in the model is allowed to have its own sensitivity towards inflow, seasonal inflow, and lagged production (only own lagged production)
- In-sample period: week 5, 2000 – week 52, 2004;
  out-of-sample period: week 1, 2005 – week 52, 2006
  - Out-of-sample R^2 is used as criterion
- Typical model:

Production week t = constant + dummies + inflow + spot price relative to forward price + lagged production

Best model

- Best out-of-sample model for the relative production (producer i and week t):

$$p_{i,t} = \alpha_i + \underset{(0.025)}{0.084} \cdot Basis_t + \beta_{1,i} inflow_{i,t} + \beta_{2,i} S_t inflow_{i,t} + \beta_{3,i} p_{i,t-1}$$

$$+ \sum_{k=2}^{12} \hat{\beta}_k M_{k,t} + \sum_{k=1}^{6} \tilde{\beta}_k H_{k,i,t} + \varepsilon_{i,t}$$

  where S_t, $M_{k,t}$, and $H_{k,t}$ are the filling season, month, and the hypothesis dummies

- Out-of-sample R^2 is 78%

Best model, Cont'd

- The higher the spot price relative to the forward prices, the higher the production
- The higher the inflow the higher the production
  - Less so in the filling season (if S_t=1)

Additional effects

- A higher reservoir than normal increases production (confirmed)
- When reservoirs are nearly full or nearly empty, market prices are less important (confirmed)
- Inflow is more important when reservoirs are nearly full (confirmed)
- Production is high at the highest prices (opposite is found – they had low reservoir levels)
- Production decreases when spot price volatility is very high (confirmed)
- Producers that claim to use forward price information are more sensitive against market price changes (confirmed)

Production changes

- Best out-of-sample model:

$$\Delta \mathrm{p}_{\mathrm{i,t}} = 6.05 + 0.03\ \Delta inflow_{i,t} + 5152.68\ \Delta Basis_{i,t}$$

  and its R^2 is 3%.
- The R^2 is consistent with the best empirical work in financial time series (see, e.g., Campbell and Thompson (2008))
  - R^2 is lower since we model differences
- The forward price is also in this model

More on the use of forwards

- 4/13 of the producers report that they do not use forward prices to guide scheduling
  - They instead use their own forecasts
- This is confirmed by the data:
  - This difference is significant: The four use significantly less forward information than the nine
- The group which uses forwards have significantly higher production volatility (608% vs. 575%, annualized)

More on the use, Cont'd

- Cash flows normalized wrt production capacity are not significantly different:
  - With forward information: average = 10.78, standard deviation = 10.09
  - Without forward information: average = 12.24, standard deviation = 12.67
  - Performance measures that avoid valuation of water may be hard to come by
- Does it really help using forward price information?
  - Data indicates the case is not clear

Conclusion

- Forward prices are significant in driving production scheduling
  - Our model simplifies hydro scheduling in practice
- 4/13 do not use forward information, the rest say they use
  - Forward prices explain significantly more the production of the nine companies
  - Those using forward info are not performing significantly better than those who use own forecasts
- Large variance in spot prices decreases production
  - This is due to the value of waiting