# Co-movements between forward prices and resource availability in hydro-dominated electricity markets

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# Seasonal hydropower production planning

- Hydropower producers with reservoirs can decide when to release water
- Release now to reduce spillage risk or if expecting lower prices in near future
- Release later if expecting higher prices in near future
- **We study how a negative price-inflow relationship affect release decisions (water values) for a price-taking hydro producer**

# Common business practice

- Common to use stochastic dual dynamic programming (SDDP) to estimate water values
- Scenarios, e.g. historical price-inflow years, used in the forward simulation
- Stochastic model used in the backward recursion, assuming that price and inflow are independent variables

# Two illustrative examples

Run-of-the-river with unlimited generation capacity

Reservoir with unlimited generation and storage capacity

# Example 1: Run-of-the-river (ROR)

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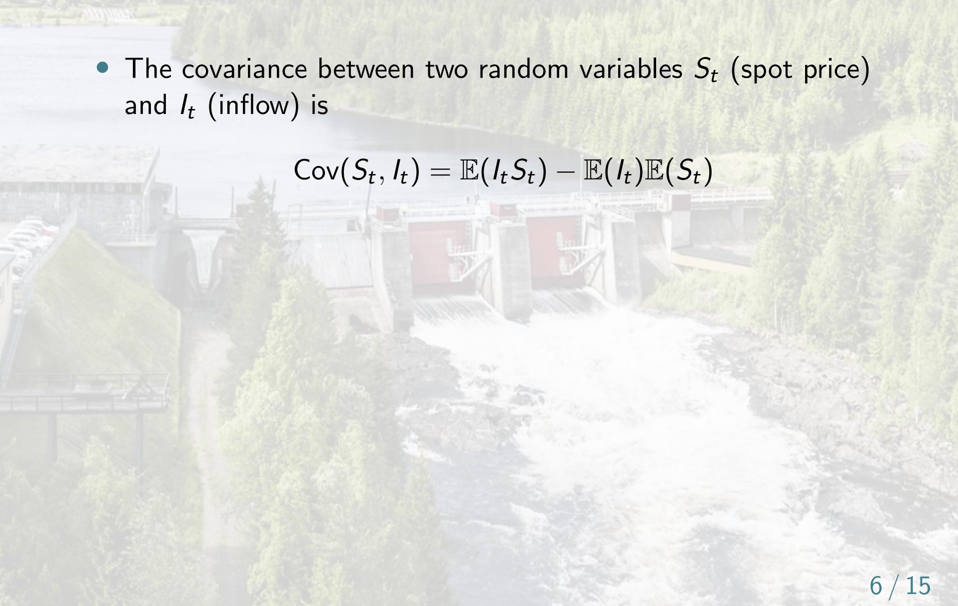

- The covariance between two random variables $S_t$ (spot price) and $I_t$ (inflow) is

$$\mathrm{Cov}(S_t, I_t) = \mathbb{E}(I_t S_t) - \mathbb{E}(I_t)\mathbb{E}(S_t)$$

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- Total expected profit can be written as expected spot price times expected production minus expected shortfall

$$V^{\mathrm{ROR}} = \sum_t \mathbb{E}(I_t S_t) = \sum_t \Big( \mathbb{E}(I_t)\mathbb{E}(S_t) + \mathrm{Cov}(S_t, I_t) \Big)$$

$$= \sum_t \mathbb{E}(I_t)\mathbb{E}(S_t) - \lambda$$

# Example 2: Reservoir with unlimited capacity

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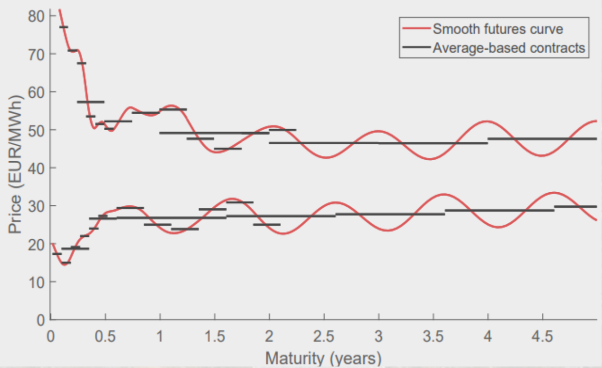
- If there exists a futures market, a producer with unlimited storage (but finite planning horizon), can sell the expected production today $t = 0$ at the most expensive hour $T$ at price $F_{0,T}$



# Example 2: Reservoir with unlimited capacity

- Total expected profit can be written as

$$
\begin{aligned}
V^{\mathrm{UNLIMITED}} &= F_{0,T}\sum_t \mathbb{E}(I_t) + \mathbb{E}\left[\sum_t S_t(I_t - \mathbb{E}(I_t))\right] + \omega \\
&= F_{0,T}\sum_t \mathbb{E}(I_t) + \sum_t (\mathbb{E}(I_t S_t) - \mathbb{E}(S_t)\mathbb{E}(I_t)) + \omega \\
&= F_{0,T}\sum_t \mathbb{E}(I_t) + \sum_t \mathrm{Cov}(S_t, I_t) + \omega \\
&= {\color{blue}F_{0,T}\sum_t \mathbb{E}(I_t)} {\color{red}-\lambda} + \omega
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&= F_{0,T} \sum_t \mathbb{E}(I_t) + \sum_t \mathrm{Cov}(S_t, I_t) + \omega \\
&= F_{0,T} \sum_t \mathbb{E}(I_t) - \lambda + \omega
\end{aligned}
$$

- Expected spot price times expected production minus expected shortfall plus extrinsic value

# Water values

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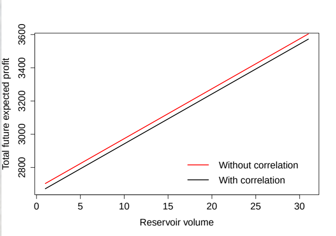
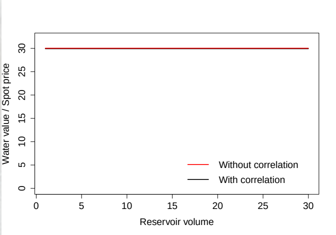
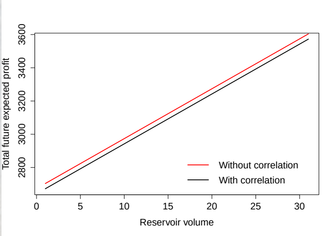
## Unlimited reservoir

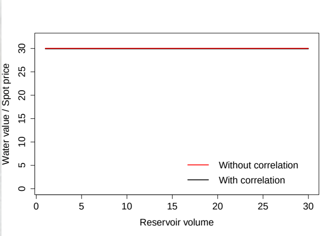


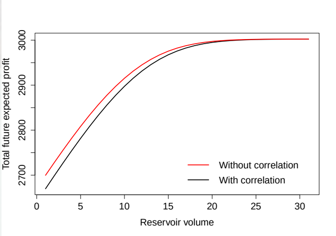
# Water values

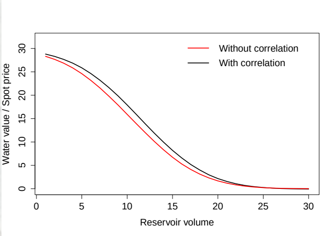
## Unlimited reservoir




## Limited reservoir



**Take-away so far**

Ignoring correlations between price and inflow underestimates the water value. What is the potential loss?

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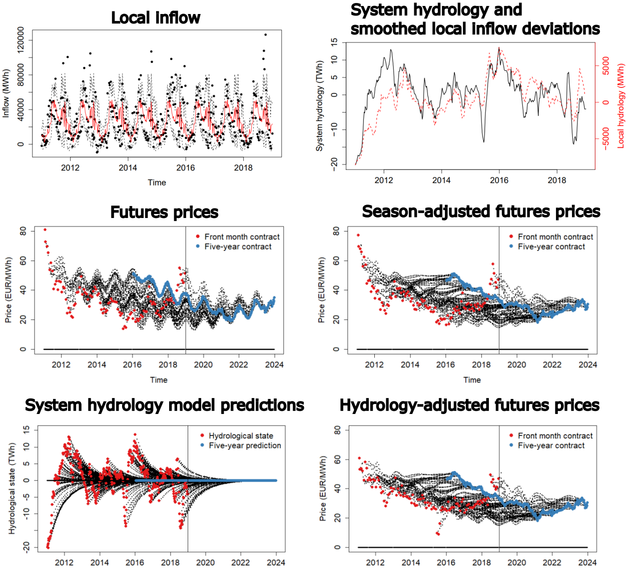
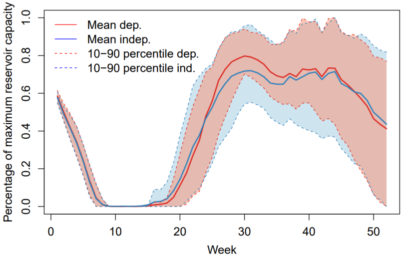
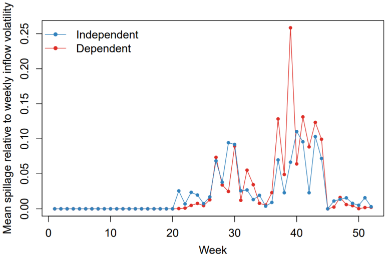
- Our approach
  - Develop a stochastic model with joint behavior of local inflow, system hydrology, and system price
  - Discretize the joint process into a lattice
  - Solve a one-reservoir seasonal hydropower planning problem using SDDP

# Stochastic model



# Numerical study



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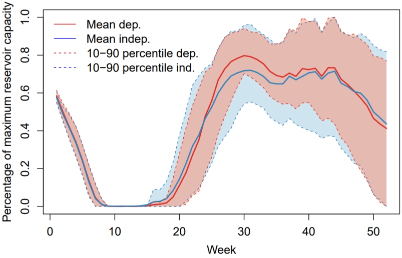


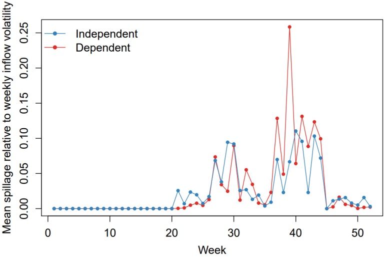


## Findings

Estimated loss 0.17% in basecase, and between 0.10%-0.30% in other case studies

# Conclusions

- We developed a stochastic model with joint dynamics between local inflow, system resource availability, and system price
- Common business practice is to ignore joint relationships when computing water values (SDDP backward recursion)
- We showed that the water value is underestimated if the system price and local inflow are assumed to be uncorrelated
- Our numerical findings indicate that the loss is modest

Thank you!