Market Power and Hydro Power in the Nordic Countries

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Project Summary
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Summary

- The objective of the project was to assess the applicability of remote sensing data in analyzing the production decisions associated with hydropower production.
- Remote sensing data from the Sentinel-2 mission was collected on over 300 hydropower reservoirs in Norway, in particular the NO5 pricing area in Western Norway using a purpose-built algorithm developed for this project.
- This data was used together with market and plant ownership data and structural assumptions to analyze imperfect competition in the Nordic day-ahead market for electricity.
- Results suggest that large hydropower producers withhold production when demand is relatively elastic compared to smaller producers, consistent with the hypothesis of imperfect competition.
- Remote sensing data can be useful in uncovering imperfect competition in markets that rely on hydropower production when data on reservoir levels is otherwise unavailable.

Objectives of the Project

- The objectives of the project were twofold:
  1. to assess the viability of remote sensing data in obtaining data on the water levels of hydropower reservoirs
     - To this end, a literature review was also conducted to assess whether the remote sensing indices available can be used to infer the water levels of small water bodies
  2. to use remote sensing data, along with market data and structural assumptions, to analyze and gather evidence of imperfect competition in the Nordic wholesale market for electricity.

How was remote sensing data collected?

- Data on the water levels of reservoirs was collected using the NDWI index calculated from data from the Sentinel 2 mission. A NDWI "image" was collected of the area containing the reservoir and ran through a purpose-built algorithm that estimates the water volume from NDWI data. The algorithm works as follows:
  1. NDWI images[1] are collected in a time interval at a desired time resolution.
  2. Pixels that obtain values higher than a set threshold are classified as water pixels, pixels that do not obtain values higher than the threshold are classified as non-water pixels. The largest contiguous water body is then detected from the resulting image using the raster package in R. This classification step is only done once for a set date. The same date is used for all reservoirs.
  3. The sum of the NDWI values of the pixels inside the largest contiguous water body is then understood to be the water level of the reservoir at a certain date.

[1] I.e., a two-dimensional matrix where the value of a pixel corresponds to the value of the NDWI index at that pixel

Remote sensing algorithm: illustration

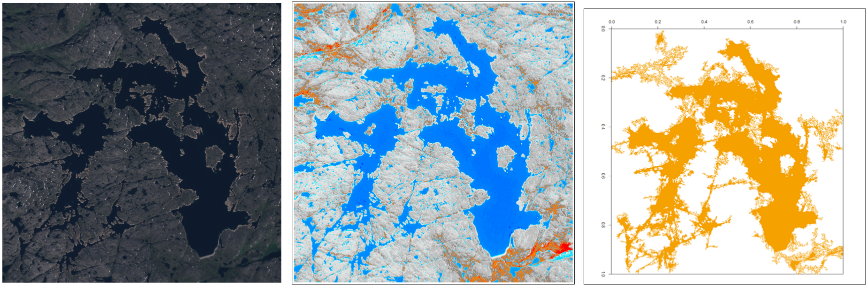


Figure: Illustration of the remote sensing algorithm. The image on the left is a true-colour image of lake Blåsjø, which is used as a hydropower reservoir. The image in the middle is a stylized NDWI image, where pixels below a certain threshold are represented by gray, orange and red, and pixels above the threshold are represented by different shades of blue, depending on the NDWI value. The image on the right represents the largest contiguous water body that was detected from the NDWI image using the raster package in R. Pixels that are connected to each other are considered to be a part of the water body, improving the robustness of the algorithm.

How was remote sensing data collected?

- The Sentinel 2 mission has a revisit rate of about two to three days. Theoretically, it would be possible to obtain ten to fifteen observations per month.
- However, Scandinavia and in particular Norway is one of the most cloudy regions in the world. Cloudiness makes about 80% of the observations not fit for use. Two observations per month is the highest time resolution that can be obtained somewhat reliably, but in practice one observation per month is the highest resolution where missing values are not a major issue.
    - Using a resolution of one month means that sometimes multiple observations are mosaiced together. In the data collecting of this project, the mosaicing priority used was least cloud cover. I.e., in prioritizing which pixels are used when mosaicing multiple images, the pixel with the least cloud cover was used. This implies that the composite images used in the algorithm can be considered to represent the average water level in a particular month. Using a resolution of one month is reasonable considering the month-based identification strategy used in the estimation (more on this later).

How was remote sensing data used?

- Remote sensing data was used to indirectly observe the production decisions of hydropower producers. The main analysis focused on a small pricing area, which allowed for the assumption that all reservoirs experience the same inflow patterns. Thus, comparing the reservoir level(s) of plant i in period t to the mean of all reservoir levels in period t reveals how the production level of plant i differs from the production levels of other plants in this period.
    - Firm-, reservoir-, and month fixed effects used in the estimation control for differences in baseline reservoir water levels. Some reservoirs might be kept fuller than others for reasons unrelated to the optimization problem producers face.
    - Systematic differences in the production levels of the plants owned by large producers and the plants owned by smaller producers can thus reveal the presence of market power.

Results

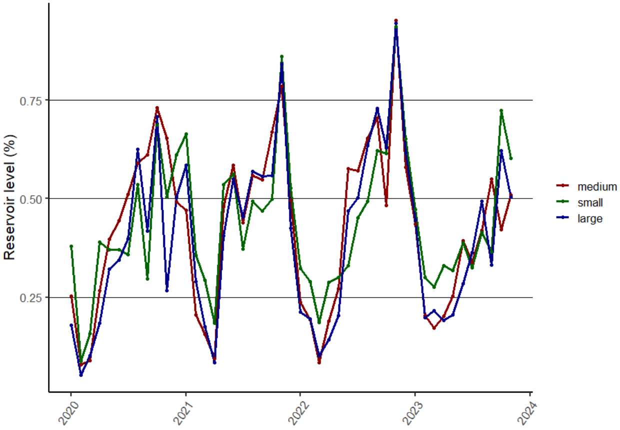
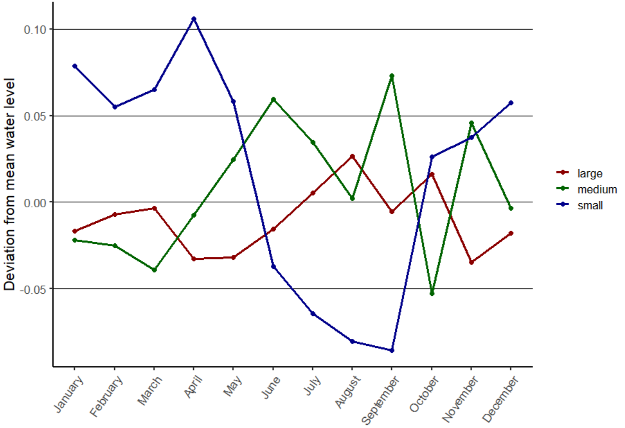


Figure: Results from the remote sensing data collection. The results are plotted separately for reservoirs operated by firms of different sizes.

Results

- The results reveal persistent differences in monthly normalized reservoir water levels between plants administered by large, mid-sized and small producers.



Results

- The empirical hypothesis was that large producers with market power withhold production when the price elasticity of demand is high compared to smaller producers (with little or no market power) and consequently produce relatively more when the price elasticity of demand is low.
- The empirical hypothesis was tested using different measures of market power:
  - Market capitalization class (large, mid-size, small)
  - Firm *i*'s share of all reservoir water in the market area (capacity to produce)
  - Lerner index (measured at the aggregate level using the method proposed by Tangerås and Lundin (2020))

Results

- Price elasticity of demand was estimated from Elspot market data by taking a small quantity window around equilibrium price and calculating the difference in price inside the window (this measure is known as the arc elasticity).
- In addition to a direct measure of demand elasticity, a month-based approach was also applied. This is based on established patterns of variation in monthly demand elasticity in the Nordic market for electricity.
    - Assuming that the sample years experience normal seasonal variation, the interaction variable Market power$\times$ month is used to identify the presence of market power (McDermott (2020))

Results

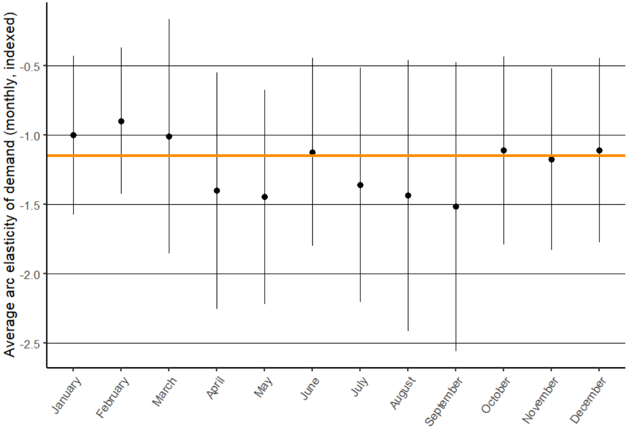


Figure: Monthly price elasticity of demand in Elspot in the years 2020−2024

Publication of results

- The data collected through remote sensing, as well as all other market and auxiliary data can be found in this GitHub repository[2]
- The full code of the remote sensing algorithm can be found in this GitHub repository[3]
- The master's thesis this remote sensing project was a part of can be found on this page[4][5]

[2] https://github.com/Akselivv/Hydropower-and-market-power/tree/main
[3] https://github.com/Akselivv/Reservoir-levels-from-satellite-imagery/blob/main
[4] https://helda.helsinki.fi/items/d4aaa25f-5688-4554-a40e-ef1180652176
[5] The thesis was recently submitted, and the full text will not be available immediately. It should be visible at latest at the end of July 2024.

Conclusion

- This project used remote sensing data from the Sentinel mission to collect data on reservoir levels of hydropower plants in Norway to test the empirical hypothesis that larger hydropower producers withhold production when price elasticity of demand is high and overproduce when the price elasticity of demand is low.
- The results support the empirical hypothesis. Market power and producer market capitalization have a statistically significant effect on reservoir management.
- The results are in line with previous literature that analyse imperfect competition in the Nordic day-ahead electricity market.
- Using remote sensing data to estimate imperfect competition in hydro-dominated electricity markets is a viable strategy, and can be used in other markets where data on reservoir water levels is not collected or otherwise available.

References I

McDermott, G. R. (2020). Hydro power. market might. Working paper.

Tangerås, T. and Lundin, E. (2020). Cournot competition in wholesale electricity markets: The nordic power exchange, nord pool. *International Journal of Industrial Organization*, 68:102536.