Climate Policy and Strategic Operations in a Hydro-Thermal Power System

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In conjunction with the European Union (EU) target to reduce greenhouse gas emissions by 55% by 2030 relative to 1990 levels, the Nordic countries aim to decarbonise their power sectors by 2040. While phasing out of fossil-fuelled power plants and integration of variable renewable energy (VRE) technologies, such as wind and solar power, could pose a challenge, the Nordic region appears relatively well positioned to cope with this sustainable energy transition. Indeed, with its vast hydro reservoirs and ample transmission capacity, the regional electricity market, Nord Pool, is held up as an exemplar with low carbon intensity and limited scope for the exercise of market power. Thus, intermittencies stemming from the widespread adoption of VRE could be mitigated by deploying flexible assets such as hydro storage.

Although market-clearing prices in Nord Pool are generally close to marginal costs, empirical evidence hints at the potential exercise of market power from hydro reservoirs, strategic withholding from fossil-fuelled plants, and collusion among jointly owned nuclear plants. Moreover, game-theoretic analyses of the Nordic region identify situations in which owners of flexible plants could exploit their leverage to exert market power. Such strategic behaviour by hydro reservoirs could be exacerbated in a future power system with a high CO_2 price and greater VRE penetration due to the additional need for flexibility. In such a situation, strategic hydro reservoirs would have a stronger incentive to conduct temporal arbitrage, viz., by withholding their production during peak periods and increasing it during off-peak ones. In effect, they would have the potential to increase (decrease) market-clearing prices during peak (off-peak) periods even if they did not "spill" their annual production.

The prospect for this type of distortion to arise in the future Nordic power system has not yet been addressed. In particular, the empirical studies have used data from 2011-2013, whereas the game-theoretic models have treated hydro as a generic flexible resource without explicit modelling of reservoir constraints. Given the ramifications for other hydro-thermal power systems and generic storage devices from the exertion of temporal arbitrage, we devise a Nash- Cournot framework with a representation of the Nordic region's spatio-temporal features and reservoir operations in order to address the following research questions (RQs):

1. How are social welfare, reservoir operations, and CO_2 emissions affected by market power in the current Nordic power system?
2. What will be the impact of future climate policy comprising a high CO2 price and expanded VRE capacity on the potential for the exercise of market power by both hydro and thermal producers?

In terms of RQ 1, we implement numerical cases for the year 2018 in which either all firms are perfectly competitive (PC), large firms behave à la Cournot in thermal generation (COG), or

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large hydro reservoir owners behave à la Cournot (COR). Using the average EU Emissions Trading System (ETS) price of €15/t for 2018, we find that modelled electricity prices under PC are close to the observed ones for the year. Market power in thermal generation as in COG leads to withholding of nuclear capacity, which causes prices and CO_2 emissions to soar as relatively costly and polluting gas-fired plants operate more. Such exertion of market power is not plausible because it would be obvious to market inspectors. However, temporal arbitrage as in COR that deploys more water from reservoirs in the off-peak season (spring) and less in peak seasons (winter and fall) results in subtly higher electricity prices and an increase of 1.99% in producer surplus for the largest hydro-owning firm vis-à-vis PC. This is in spite of a regulatory constraint that forces such firms to generate the same annual energy from reservoirs as under PC.

We address RQ 2 by devising a plausible year-2030 scenario with a CO_2 price of €100/t and double the year-2018 VRE capacity in the firms' existing portfolios. The purpose of this so-called 2030CV scenario is to explore how structural changes to the supply side stemming from climate policy affect the leverage exerted by strategic hydro- reservoir and thermal producers. Consequently, gas-fired plants become uneconomical, CO_2 emissions decrease by over 90% relative to 2018 levels, and equilibrium prices are about 25% lower than those in 2018. More important, there is increased benefit to firms from exerting market power via either thermal or hydro-reservoir generation. Relative to 2018, nuclear plants are more likely to be price setters, which makes it easier for them to raise the price under COG by withholding output to render gas-fired plants as the marginal technology. As for COR, reservoir operators face less of a barrier in shifting water from peak to off-peak seasons for three reasons. First, the lower prices in the peak seasons mean less forgone revenue from shifting production away. Second, increased intermittency from VRE output enables "excess" hydro generation to be exported. Third, decreased gas-fired generation due to the high CO_2 price means less of a response by price-taking flexible producers to such temporal arbitrage. These factors culminate in an 11.9% increase in the largest hydro-owning firm's producer surplus vis-à-vis PC. Hence, future climate policy could enhance the prospects for the exercise of market power even in the Nordic region.