Blowing Water Away
Increased Wind Power in a Stored Hydro Power System

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***Abstract*—The transition to a low-carbon future will lead to a substantial increase in electricity production from intermittent sources. An econometric structural model of demand and supply in Denmark and Norway is used to simulate the effect of increased wind production on hydro power producers with limited storage capacity. The results show that there are substantial shifts in surplus from hydro producers to consumers, and that spillover from the reservoirs are much more likely unless there is a substantial retirement of thermal generating capacity. The modeling framework allows for detailed assessments of the uncertainty in model predictions.**

***Keywords*— electricity markets, hydro power, intermittent production, renewable sources, wind power.**

1. OVERVIEW

The transition to a low-carbon future will lead to a substantial increase in electricity production from new renewable sources and phasing out of traditional thermal generation. Many of the new generating sources such as wind, solar and small-scale hydro are intermittent sources and can not be trusted for a reliable delivery of power without either energy storage or supplementary generating sources. Hydro based power generation can provide a viable and clean complementary source of power provided sufficient storage, generating and transmission capacity. From a European perspective hydro power in Norway and Sweden can serve in this capacity.

The interaction between thermal generation and hydro power has been discussed, among others, by Førsund (2007) and Bobtcheff (2011). Førsund (2011) presents and discusses a dynamic model where a reservoir based hydro system is used to absorb and even out the stochastic nature of wind power production.

The purpose of this paper is investigate the effects of a substantial increase in stochastic and unregulated wind power production in a combined thermal and hydro system with reservoirs. We use an econometric structural model of demand and supply in one country with thermal and wind production connected through limited transmission capacity with another country with exclusively stored hydro production. By changing the scale of wind production and the capacity of transmission between the two countries we are able to trace the effects of expanded wind production and system integration on prices, quantities, and consumer's and producer's surpluses.

2. METHODOLOGY

We estimate, using a hierarchical Bayesian instrumental variables method (Lancaster (20014), Lopes and Polson (2014)), a structural econometric model for supply and demand in Western Denmark, representing a combined thermal and wind production system, and for supply and demand in Southern Norway, representing a pure reservoir based hydro power system. The supply function for the hydro producers depends on the water value, or the shadow price on stored water, which in turn depends on the current reservoir content relative to normal reservoir content for the season. Such a specification is consistent with the theoretical model by Evans, Guthrie and Lu (2013). This gives a dynamic model of the hydro system. Using historical data for wind production, water inflow and demand drivers such as temperature and daylight we are able to simulate the power production, consumption and prices as well as the direction of the power flow between the two countries. Furthermore, the model gives detailed information about changes in consumer's and producer's surplus in the two countries. The model can be used to simulate, among other things, the effects of increased wind power production capacity, reduced thermal production capacity and expanded/contracted transmission capacity between the two countries. The Bayesian estimation employs a Markov Chain Monte Carlo method, and the resulting posterior distributions for the model parameters are used to obtain the posterior predictive distributions of all the

simulated variables. Thus we are able to supplement the model results with detailed uncertainty assessments of all results.

3. EXPECTED RESULTS

By increasing the production of wind power the average price falls in both countries. The consumer's surplus increases in both countries, while producer's surplus decreases for thermal producers. The effect on hydro producers is not unambiguous; for small increases in wind power production the hydro producers' surplus increases, while for larger increases the price effect of the outward shift in the supply schedule also leads to a decrease in producers' surplus for the hydro producers. Furthermore, the amount of spilled water (overflow of the reservoirs) is increasing with increased wind power production. Larger transmission capacity between the countries evens out price variations and differences, and reduces the amount of spilled water. The uncertainty in the numerical results is large with highly skewed distributions. The first two moments are not sufficient to adequately represent these distributions.

If the expansion of wind power is combined with a more active retirement of thermal production capacity the prices remain high (at initial levels) in both countries. Both the price variability in the country with wind production and the amount of spilling in the hydro based country depends strongly on the (relative) transmission capacity between the two countries.

4. CONCLUSIONS

The empirical analysis shows that a hydro power systems with sufficient reservoir capacity and sufficient transmission capacity between the two countries, large scale introduction of stochastic wind production can be absorbed into the energy system resulting in only small increases in price volatility. However, the increased wind production results in more frequent periods where water is spilled due to overflow of the reservoirs. The reservoir capacity is valuable as a “storage” of wind power, but the implied increase in production of electric power tend to reduce prices as long as the thermal production capacity remains active. A decrease in thermal capacity along with an expansion in wind production is possible without a sharp increase in price volatility as long as the transmission capacity is sufficient large.

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