**The Green Game Changer: An empirical assessment of the effects of renewable energies on prices and the generation mix**

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***Overview***

The transition of the electricity-generating sector in Europe towards a system based on low carbon emission has a fundamental impact on power markets. While countries traditionally relied on conventional generation technologies, e.g., coal and gas-fired plants, the generation share of plants based on renewable energy sources (RES) continues to grow. This transformation, based on state-supported schemes and driven by ecological considerations, has raised heated debates about efficiency and hidden costs. The transformation affects not only the security of supply and market design. It also influences the technological composition of the power plant portfolio and power prices.

The challenges to the wholesale market stem from two sources, the out-of-market support schemes, such as prioritized feed-in and feed-in tariffs, to foster RES production and the stochastic production of wind and solar. As a result, solar and wind generation is independent of market conditions. The result is a one-sided competition relationship between stochastic RES and conventional generation. Thus, the feed-in of RES exerts an exogenous supply shock to the power market. As a result, conventional power plants have to adapt to this shock. This adaption process is described as merit-order effect.

Theoretical predictions of this merit-order effect as to which conventional technology is being crowded out are not clear. [1] While the classical approach argues that the most flexible power plants, only dispatched during high demand periods, are driven out of market, a contradictory approach expects base load plants to exit the market due to the combination of low power prices and insufficient runtime. So empirical evidence from country studies may serve as an indicator as to which adjustments have to be made to market design and the technological composition of the power generation portfolio.

***Empirical Approach***

Our approach differs from other empirical studies[2] in that we use the merit order as the underlying theoretical structure and endogenize supply, adjusted demand and prices in a structural VAR model, incorporating solar and wind as exogenous shocks. Based on daily data from 2010-2012, the estimation procedure is conducted for the full set of years and on a yearly basis. While the structure laid upon is strict, it has been serving as a correct depiction of the realized merit order for many markets nonetheless.

In detail, we follow Zöttl (2011) to formalize the merit order. Operators of the technology with the cheapest variable costs of production, e.g. hydro or nuclear fueled power plants, decide upon their

[1] See Vives (1989) and Jensen et al. (2002) for a theoretical.
[2] See e.g. Green and Vasilakos (2010), Weigt (2009) and Gelabert et al. (2011).

quantity depending on the forecasted state of demand, its respective fuel costs and available capacity. Absent strategic behavior, if demand is higher than the aggregated available capacity of this cheap technology, then the next cheapest type of power plant will be utilized. The latter's production decision is not only based on the parameters mentioned before, but also whether the previous technology was fully capacity constrained. Analogously, this optimization problem continues until demand is satisfied.

In addition to the structure laid upon the estimation model, Our approach differs from other empirical studies[3] we instrument demand to account for a possible simultaneous causality bias and control for potential cost shocks to the supply side. Therefore we isolate the potential decrease in prices and conventional quantities caused by solar wind power generation

***Results***

We find that solar and wind generation exerts an overall negative influence on the prices. However, wind generation appears to be more consistent in its negative influence, as the coefficients remain quite stable comparing results from the full-range estimation with yearly estimations. Solar power, however, is only relevant during day-time and significantly affects wholesale prices in the later years. This can be explained by the increase in installed solar capacities.

With regard to the effect on the conventional quantities produced, differentiated by technology, the results are mixed. For instance, wind power affects every conventional technology while solar mainly influences peak load plants. This result is quite intuitive because peak plant activity is driven by high demand, which happens to be most frequent in day-time and specifically in summer in Spain. However, base load plants were barely affected by solar production. Therefore, the merit-order effect is not as clear cut, as theory predicts.

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[3] See e.g. Green and Vasilakos (2010), Weigt (2009) and Gelabert et al. (2011).