**Locational signals in zonal electricity markets**

A bilevel model of the effect of location-specific network charges on generation investment

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**Motivation and key research question**

The cost-optimal distribution of power generation entails a tradeoff between the cost of generation and the network costs. However, investors rarely consider the effect of their siting decisions on infrastructure requirements in zonal power markets. Locational signals that provide (dis-) incentives to invest in certain regions by reflecting the resulting network may be a solution. In practice, such locational signals come in the form of grid connection or grid usage charges or are built into capacity mechanisms and/or renewable support schemes (Eicke et al., 2020). In this contribution, I present a methodology to determine locational signals that minimize the overall system cost. Applying it to an exemplary system reveals fundamental properties of locational signals and their effect on welfare.

**Methods**

To determine the cost-optimal distribution of generation in a zonal power market, I apply a game theoretical approach to analyze the interaction between a regulator and a competitive electricity market. In the strategic game, the regulator first chooses the level of a locational signal that leads to the lowest system costs, including generation, investment, and network costs. In a second step, generators decide on the investment and the dispatch of power generation, while accounting for the locational instrument and the price signals of the zonal power market. Because the regulator (leader) anticipates the response of the generators (follower), I model this interaction as a Stackelberg game (Figure 1). Implemented as an Equilibrium Problem with Equilibrium Constraints (MPEC), this formulation permits to calculate the locational signal that maximizes welfare in a competitive zonal electricity market. A feature of this approach is that the regulator accounts for the network topology, while the participants in the zonal electricity market do not. This stands in contrast with most other system models that are either zonal or nodal on all levels. I apply the model to an exemplary power system with four technologies and two locations within a zonal market and compare the results with two reference scenarios: i) a uniform electricity market without additional locational signals, and ii) a nodal power market.

**Results and Conclusions**

The comparison of the three analyzed scenarios reveals the potential of significant welfare gains of locational signals in a zonal electricity market. Through a relocation of generation, locational instruments can significantly reduce network costs. The findings show an upper bound of the potential of locational instruments because such instruments are regulatorily determined and therefore sensitive to adequate input data and prone to political influence. In practice, the benefit might be below the presented estimates but are most likely to outperform a setting without locational signals.

While locational signals may provide investment incentives, they cannot compensate for the missing dispatch incentives and the lack of local incentives for demand flexibility in a zonal electricity market. Therefore, locational still lead to lower welfare compared to the nodal benchmark.

The analysis also reveals that the cost-optimal siting of generation differs between a zonal and a nodal power system due to differences in the dispatch. Intuitively, the additional costs for redispatch measures in zonal markets imply that it is better to locate generation and demand closer together as compared to a nodal benchmark. Finally, the exemplary power market model indicates that the cost-optimal locational signal is not only location- but also technology-specific. Depending on their generation profiles, some technologies result in much higher network costs than others. This implies that locational signals should differentiate between technologies, which is not the case in most systems.

**References**

Eicke, Anselm, Tarun Khanna, and Lion Hirth. ‘Locational Investment Signals: How to Steer the Siting of New Generation Capacity in Power Systems?’ The Energy Journal 41, no. 01 (1 September 2020). https://doi.org/10.5547/01956574.41.6.aeic.

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