***LOCATIONAL INSTRUMENTS in zonal electricity markets***A bilevel model of the effect of location-specific network charges on generation investment

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## Overview

Rarely do investors in power generation consider the effect of their siting decisions on infrastructure requirements in zonal power markets. However, the cost-optimal distribution of power generation within a liberalized zonal electricity market entails a tradeoff between the cost of generation and the resulting network costs, including redispatch measures. Internalizing the network costs through location-specific charges on generators leads to the cost-optimal distribution and technology mix of generation. This internalization is possible via regulatory determined locational signals that provide (dis-) incentives to invest in certain regions by reflecting the resulting network cost for each side (and generation profile). In practice, such locational signals come in form of grid connection or grid usage charges or are built into capacity mechanisms and/or renewable support schemes (Eicke et al., 2020). However, the implementation and the determination of the signals strength are often arbitrary, and no obvious best-practice approach exists. Most locational instruments are designed to identify the responsibility of specific generators on network costs and base on complex calculations of line loads with and without the generator of concern. The rationale behind this approach is that the cost-internalization leads to a cost-optimal distribution of generation in a zonal market. I propose an alternative perspective, which results in a different methodological approach: Instead of determining the network externalities of each generator, I calculate the level of charges that minimizes the overall system cost. In theory, both approaches lead to the same outcome but the latter allows to determine the long-run equilibrium. In addition, it permits to estimate the long-run network costs for each type of generation.

The main contribution of this paper is is novel methodological approach, which allows estimating cost-optimal, location-specific investment incentives in a zonal electricity market. Applying this approach to a simplified power system reveals some fundamental properties of cost-optimal locational instruments and their impact on the distribution of power generation.

## Methods

## To determine the cost-optimal distribution of generation in a uniform power market, I modell the interaction between a regulator and a competitive electricity market. The regulator first chooses the level of a locational instrument (here a capacity-based charge, e.g., a grid connection charge) that leads to the lowest overall system costs (including generation, investment and network). Because the regulator (leader) anticipates the response of the generators that compete on the power market (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 which maximizes welfare in a competitive zonal electricity market. A special 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 power market models.

Outer Problem (Regulator)

Chose the locational signal (per energy or per capacity) that minimizes system costs (including transmission costs) by providing incentives for a system cost-optimal generation expansion.

Inner problem (Competitive wholesale market)

For a given locational signal within a uniform pricing zone, minimize the cost of power supply (excluding transmission) by choosing the mix and distribution of generation technologies.

Figure 1: Interplay between regulator and competitive market as Stackelberg problem

To analyse the effect of this formulation, I apply it on an exemplary power system with two locations within a uniform (zonal) market. I thereby determine the optimal capacity mix and the optimal distribution of five exemplary technologies, including wind, solar, and three conventional technologies. The model consist of 20 timesteps. The profiles of wind and solar generation and the price-elastic electricity demand differ between the two locations and are loosely calibrated with data from northern and southern Germany. Besides the novel formulation of a zonal electricity market with locational instruments, I model two reference scenarios: i) a uniform electricity market without additional locational instruments, and ii) a nodal power market. In this strongly simplified setup without market power and with perfect transmission investment this nodal market serves as a benchmark with the highest possible total welfare.

## Results

The comparison of the three analysed scenarios shows significant welfare gains resulting from the optimal placement of generation in a zonal electricity market through the introduction of locational instruments. However, locational instruments can not compensate the missing dispatch incentives and the lack of local incentives for demand flexibility that result from nodal electricity prices and therefore still lead to a lower overall 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 of generation. 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.

The exemplary power market model indicates that the cost-optimal locational instrument is not only location specific but also technology-specific. Due to the different generation profiles, some technologies result in much higher network costs than others, which is reflected in the diverging level of charges. This implies that an implicit technology bias arises when locational instruments do not differentiate between technologies, as it the case in most implemented instruments.   
At increasing shares of renewable energy sources (RES) in the power mix, locational instruments become even more relevant. This is highlighted by larger welfare difference between scenarios at increasing RES shares but also through the higher strength of the optimal instruments. Translated into the cost-internalization perspective, this indicates that the additional network costs resulting from the higher renewable penetration increases. More generally, locational instruments are stronger for renewable energy sources (which have different availabilities by region) than for conventional generators.

## Conclusions

In this contribution, I distinguish between two perspectives on locational instruments.

Most locational instruments are designed to identify the responsibility of specific generators on network costs. The internalization of these costs leads to cost-optimal investment decisions of power generation but is difficult to determine. I propose another perspective that allows to determine the long-run effect of locational instruments. The analysis highlights the large cost-saving potential of locational instruments in zonal power markets. If adequately implemented, such instruments cause a significant reduction in network costs through a relocation of power generation. Obviously, such instruments need to be determined in a model and are therefore sensitive to adequate input data and prone to political influence. The presented results therefore show an upper bound of the potential of locational instruments which will most likely remain unachievable in practice.

## 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>.