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# Transmission pricing and investment incentives☆

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ABSTRACT

The allocation of limited transmission resources has considerable impact on investment incentives in electricity markets. We study the long–term effects of two common network congestion management regimes on investment in production and transmission facilities. We compare locational marginal pricing, where transmission constraints are directly taken into account by spot–market prices, with a regime of uniform prices, where transmission constraints are taken into account by subsequent congestion measures. We propose an analytically tractable framework to show that, as compared to locational marginal pricing, uniform pricing can lead to overinvestment in transmission facilities and total production capacities.

## 1. Introduction

When a product is sold through a network, one of the important questions to be answered is whether locationally differentiated prices or a uniform market price should be charged. Locationally differentiated market prices take potential network congestion directly into account. A uniform market price 'enlarges' the spot market by initially ignoring congestion. It also makes a subsequent mechanism outside the market necessary to alleviate potential congestion. A prominent example is given by the management of transmission capacity in liberalized electricity markets. Most European electricity markets rely on a system of zonal pricing, where uniform prices obtain within each zone (usually a country) and inter–zonal transmission capacities are allocated on the basis of implicit auctions at the spot market. Uniform spot prices within each zone are determined independently of potentially arising transmission constraints, however. After the spot market has taken place, resulting network congestion is resolved by the network operator by so–called redispatch.[1] In contrast, in the US and Canada a system of locational marginal pricing (also referred to as "nodal pricing") is implemented where prices can differ among locations and transmission constraints are implicitly priced at the spot market.[2] There is an ongoing academic and policy debate on the desirability and the properties of the different congestion management regimes.[3] Our analysis considers the impact of different congestion management regimes on investment in generation and transmission facilities in those markets.

We develop an analytically tractable framework with endogenous generation and transmission investment in a network context. Competitive firms invest in two different generation technologies that allow production at different levels of marginal cost. Transmission investment by a network company is assumed to be welfare–optimal, anticipating subsequent generation investment by private firms. The capacity of the transmission line limits the amount of physical trade that can take place. As transmission constraints might potentially exist in this network, a mechanism for transmission capacity allocation is needed. We investigate two different, frequently applied mechanisms for transmission allocation. The benchmark case is given by *locational marginal pricing*, where separate spot–market prices are formed at the different nodes in the network. Whenever the level of demand and hence the amount of trade is high, such that the transmission line is constrained, then the spot–market prices depart from each other. For

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[1] Compare Bjorndahl et al. (2013), or Holmberg and Lazarczyk (2015).

[2] For a description of the regional electricity markets in the US compare, e.g., http://www.ferc.gov/.

[3] Compare, e.g., Ofgem (2010, 2014) and Redpoint Energy (2011) for the British discussion and Acer (2015), ENTSO-E (2018), and European Commission (2015) for efforts on the European level.

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*uniform pricing*, a single spot–market price is formed for both nodes. Whenever the level of demand is high, such that the transmission line is congested, then the spot–market outcome becomes physically infeasible, however. In order to achieve proper market clearing, an adjustment process has to be conducted where the network company engages in redispatch. That is, the network company acts as a seller at the exporting side of the constrained line and as a buyer at the importing side of the constrained line. These additional transactions reduce the level of trade between the two nodes to a physically feasible level. All expenses of the transmission company are recovered by collecting transmission fees from market participants. As a reference case we analyze the case of perfect competition in sections 3 and 4. We generalize those results to the case of strategic firms in section 5.

This work is related to the peak–load pricing literature that analyzes generation investment incentives under fluctuating and potentially uncertain demand, typically in the absence of network restrictions.[4] A good overview of the literature is provided by Crew et al. (1995). Recent articles analyze the impact of spot–market design on investment incentives also for strategically acting firms. Boom (2009) and Fabra et al. (2011) analyze the effect of auctions at the spot market. Reynolds and Wilson (2000) and Fabra and de Frutos (2011) analyze the case of Bertrand spot markets. Murphy and Smeers (2005), Zöttl (2011), and Grimm and Zöttl (2013) analyze strategic investment prior to Cournot competition. Closely related to the peak–load pricing literature, there is an intensively led debate on adequate investment incentives in production facilities in liberalized electricity markets. Compare for example Oren (2005), Hogan (2005), Cramton and Stoft (2006), Joskow (2007), Cramton and Ockenfels (2011), and recently Bajo–Buenestado (2017). Those contributions provide analytical as well as numerical approaches. All those contributions abstract from potentially arising problems due to network constraints, however.

A growing research literature focuses on the impact of the congestion management regime applied in liberalized electricity markets. Several articles have proposed computational and empirical frameworks that allow to quantitatively assess the impact on market performance. Bjorndahl and Jornsten (2001) and Ehrenmann and Smeers (2005) propose unified computational frameworks allowing to quantitatively analyze short–run market interaction for different congestion management regimes. Green (2007, 2010) calculates the welfare loss associated with uniform pricing relative to locational marginal pricing in England and Wales. Wolak (2011) measures the benefits from introducing locational marginal pricing in the Californian electricity market.

Other contributions provide analytical results regarding the impact of different congestion management regimes on market outcomes. Borenstein et al. (2000), Joskow and Tirole (2000), Gilbert et al. (2004) provide analytical insights regarding the proper allocation of transmission capacities to counter the exercise of market power of strategic generators. Willems and Küpper (2010) consider a dominant generator that can engage in regional price-discrimination. They show that an open trading mechanism for transmission rights might be dominated by an exclusive granting. Dijk and Willems (2011) analyze entry decisions of strategic generators, both for the case of nodal pricing and of uniform pricing. In a recent contribution, Holmberg and Lazarczyk (2015) provide a general analysis of strategic bidding behavior of producers for the different congestion management regimes. Whereas those studies propose a detailed analysis of short–run market interaction that allows to determine firms' profits for given production and network capacities, we determine equilibrium investment, both in network and productive capacities.

Further work explicitly considers the long–run perspective in the context of network problems. Sauma and Oren (2006) show in their computational framework that analyzing transmission investment, taking the generation capacity in the market as given, leads to significantly distorted predictions. Rious, Glachant and Dessante (2010) extend this numerical analysis by assuming that anticipation is costly. van der Weijde and Hobbs (2012) computationally analyze optimal transmission planning when taking uncertainties into account. Oggioni and Smeers (2012, 2013) numerically analyze different degrees of coordination of redispatch activities for the uniform price-regime in case of several network companies. Jenabi et al. (2013) provide a computational framework that allows to numerically solve for optimal network investment anticipating investment of competitive generators in a framework of nodal pricing. Grimm et al. (2016) quantitatively analyze optimal network expansion that anticipates the market equilibrium of competitive generators for the case of uniform market prices and for different network fee regimes. In a recent contribution Pechan (2017) provides a computational analysis that allows to determine the impact of the congestion management on incentives to install and locate wind power plants. All of these approaches allow to explicitly compute results for specifically chosen numerical settings. This typically allows to incorporate detailed realistic features relevant for the analysis of electricity markets such as for example complicated network topologies taking into account potentially arising loop-flows (e.g. by using the usual DC-flow approximation, compare Schweppe et al. (1988)). Whereas those computational contributions allow to obtain important insights regarding specifically considered numerical setups, by construction, they typically do not allow to provide general analytical results that allow to form a broader intuition regarding the applicability and limits of the numerical results obtained.

Perfectly complementary to such computational approaches several contributions derive analytical results regarding network investment. Those analytical approaches are typically based on much simpler network representations, but allow to derive generally valid results regarding cost and demand parameterizations. Several articles analyze regulatory regimes inducing efficient network investment. Compare e.g. Léautier (2000) and Vogelsang (2001).[5] Saguan and Meeus (2014) analyze missing coordination among EU-Member countries when planning their network.

Another strand of the literature analytically analyzes the incentives of merchant investors to choose proper transmission investment in a system of nodal prices based on financial transmission rights. Compare Hogan (1992) Bushnell and Stoft (1996, 1997), Wu et al. (1996), or Chao and Peck (1996) for seminal contributions. See Joskow and Tirole (2005), Sauma and Oren (2009), Hogan et al. (2010) for further extensions of those arguments. All those contributions provide thus interesting insights on the analytical analysis of investment incentives in systems of nodal pricing by analyzing incentive structures for network companies inducing efficient network investment for exogenously given generation investment. They neither analyze nor compare inefficiencies arising due to congestion management organized by a uniform price regime followed by redispatch, however. In the present analysis we abstract from potential inefficiencies arising due to incentive problems of network companies, but assume that network investment takes place such as to maximize overall welfare.

As a new contribution to the analytical literature, however, we study the impact of congestion management organized by uniform pricing both on generators' investment and production decisions. We compare this to the case of nodal pricing and analytically determine its impact on investment in transmission and generation facilities. In the case of uniform pricing and perfectly competitive generators, we find that investments in generation and transmission facilities are

[4] In a recent contribution Grimm et al. (2017) show existence and uniqueness of a peak–load pricing framework under perfect competition in the presence of network constraints, they do not analyze network expansion and congestion management regimes, however.

[5] Hoeffler and Wambach (2013) discuss commitment problems of the regulator and the resulting impact on network investment.