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On distributive effects of optimal regulation for power grid expansion

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HIGHLIGHTS

- Distributive implications of incentive regulation on transmission networks have not been studied in the literature.
- The parameters that a regulator might use to achieve distributive efficiency have so far not been explicitly analyzed.
- Analyze how different weights affect the distributive characteristics of price-cap regulation in electricity transmission.
- Results: ideal (Laspeyres) weights tend to be more beneficial for the Transco (consumers) than for consumers (the Transco).

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ABSTRACT

To date, the distributive implications of incentive regulation on electricity transmission networks have not been explicitly studied in the literature. More specifically, the parameters that a regulator might use to achieve distributive efficiency under price-cap regulation have not yet been identified. To discern these parameters is the motivation for the research presented in this paper. We study how different weight parameters affect the distributive characteristics of optimal price-cap incentive regulation for electricity transmission. We find that a regulator's use of ideal (Laspeyres) weights tends to be more beneficial for the Transco (consumers) than for consumers (the Transco).

1. Introduction

Electricity transmission is a market that, generally speaking, moves towards natural-monopoly characteristics that then counteract full market efficiency as well as optimal social welfare. For this reason, the transmission of electricity requires oversight through regulation over certain components of the market. On one hand, a transmission company (Transco) normally has poor incentives to expand the electric grid due to revenues accruing from short-run congestion rents. On the other hand, an efficient expansion of the transmission network is crucial for optimal productive resource allocation and fair market prices. However, an inefficient transmission network poses congestion problems such as higher final costs of electricity, which has negative repercussions not only for the electric sector but also for the wider economy.

In response to this problem, various regulatory mechanisms have been proposed in the literature to promote transmission investment. One such framework is the Hogan–Rosellón–Vogelsang (HRV) mechanism, described in Hogan et al. (2010, HRV). This structure combines merchant and regulatory approaches to promote investment in electricity networks. Allocative-efficient transmission investment is incentivized through intertemporally rebalancing the fixed and variable charges included in the Transco's two-part tariff, all within a nodal pricing system employing financial transmission rights (FTRs).

The primary goal here is to create efficient transmission networks that achieve optimum social welfare, while maximizing Transco revenues so as to incentivize expansion investment. Without expansion of the network, inefficient networks allow Transcos to earn congestion rents through higher costs charged to end consumers. In efficient transmission networks, congestion rents are redistributed favoring the consumer, allowing for transmission prices to converge down to marginal cost, or Ramsey pricing. This creates a boon to all economic sectors due to lower realized energy costs. Transcos are typically unwilling to lower congestion because it affords them

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increased revenues, but through an efficient incentive structure Transcos can be compelled to invest in transmission expansion to their own benefit and to that of consumers.

However, the distributive implications of incentive regulation on transmission networks have not been widely studied in the literature. More specifically, the parameters that a regulator might use to achieve distributive efficiency have so far not been explicitly analyzed. This is the motivation for the research presented in this paper. We analyze how different weight parameters affect the distributive characteristics of the HRV incentive regulatory mechanism, as well as present analytically the effects of said variables.

This paper is organized as follows. In Section 2, we present the HRV model. Section 3 applies the HRV model to a stylized network in two periods, using both Laspeyres and ideal weights. In Section 4, we present in detail the analytical conditions that characterize the distributive effects of each type of weight. Numerical examples are also provided. Section 5 concludes with a discussion of our findings.

2. Material and methods: the HRV model

In the following pages we address the distributive efficiency implications of the HRV price-cap incentive mechanism which combines price cap regulation and FTRs with price-taking generators and consumers. The effects of physical constraints on electricity flows (given by the Kirchhoff laws) are considered as well as the topology of transmission networks. The HRV model redefines the output of the Transco in terms of point-to-point transactions given by long-term FTR obligations (LTFTRs). The Transco chooses variable and fixed charges so as to maximize profits subject to a price-cap constraint over its two-part tariff, following the regulatory logic in Vogelsang (2001). The fixed portion of the tariff can be seen as a complementary charge to recover fixed costs of generation and transmission (as in Rubio-Odériz and Pérez-Arriaga, 2000). The variable portion actually points to the price of the FTR based on nodal price differences. While Vogelsang (2001) is in principle only applicable to radial lines, the HRV mechanism is an upgrade designed to also deal with meshed transmission networks.

Mathematically, the HRV is a bi-level programming model. The upper level problem models the Transco's profit maximization subject to a price-cap constraint that usually relies upon the use of previous period quantity weights (Laspeyres) or ideal quantity weights (proposed in Laffont and Tirole, 1996). The lower level problem is actually a power-flow program where an independent system operator (ISO) maximizes social welfare subject to generation, line-capacity and energy balance constraints in order to achieve maximal production of and revenue from dispatched electricity generation.

In the HRV regulatory model, the expansion of the transmission network naturally implies a reduction of the congestion rents accruing to the Transco. The Transco might compensate such revenue reductions with an increase in the fixed charge portion of its two-part tariff that are constrained by a price cap. As shown in various applications of the HRV model, such increases in the fixed charge may result in overly high price levels. Such issues are critical when considering real-world applications.

2.1. Upper level

In the upper level of the HRV model, the Transco maximizes its profits subject to an intertemporal price-cap constraint

$$\max_{k,F} \pi = \sum_{t}^{T} \left[\overbrace{\sum_{ij} \tau_{ij}^{t}(k) q_{ij}^{t}(k)}^{A} + \overbrace{F^{t} N^{t}}^{B} - \overbrace{\sum_{ij} c(k_{ij}^{t})}^{C} \right]; \quad i \neq j \tag{1}$$

subject to

$$\sum_{ij} \tau_{ij}^{t}(k) q_{ij}^{w}(k) + F^{t} N^{t} \leq (1 + RPI + X) \left[\sum_{ij} \tau_{ij}^{t-1}(k) q_{ij}^{w}(k) + F^{t-1} N^{t} \right] \tag{2}$$

The objective function (1) of this problem runs over T periods with line capacities k and fixed charge F as choice variables. It consists of two revenue sources, (A) and (B), as well as of a cost term, (C). Term (A) represents congestion rents, which are defined by the FTR point-to-point transactions, q_{ij}^t, between nodes i and j, multiplied by the FTR auction price, τ_{ij}^t. The second term (B) denotes the fixed fee that is charged to the N users of the transmission network, and the third term, (C), is the cost $c(k_{ij}t)$ faced by the Transco due to the line expansion between nodes i and j. The regulatory constraint (2) is a cap over the Transco's two-part tariff with efficiency x and inflation RPI adjustments. The regulator chooses the weights w in order to promote the convergence of the mechanism to an allocative-efficient steady state equilibrium (see Vogelsang, 2001). The ability to rebalance the two parts of the tariff guarantees that the Transco achieves individual rationality during the expansion of the transmission network, even under decreasing congestion rents.

In order to avoid working explicitly with the profits from the auctions of FTRs, the program given by (1) and (2) is usually redefined in terms of capacity investment as a choice variable (as opposed to the variable fee of the two-part tariff) (see Hogan et al., 2010):

$$\max_{k,F} \pi = \sum_{t}^{T} \left[\sum_{i}^{I} (p_i^t d_i^t - p_i^t g_i^t) + F^t N^t - \sum_{ij}^{I} c(k_{ij}^t) \right] \tag{3}$$

subject to

$$\sum_{i}^{I} (p_i^t d_i^w - p_i^t g_i^w) + F^t N^t \leq (1 + RPI + X) \left[\sum_{i}^{I} (p_i^{t-1} d_i^w - p_i^{t-1} g_i^w) + F^{t-1} N^t \right] \tag{4}$$

In this way, the congestion rents and the regulatory constraint are redefined in terms of the load cost difference $p_i d_i$ and the generators' costs $p_i g_i$.