The Inherent Inefficiency of the Point-to-Point Congestion Revenue Right Auction

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Abstract

Empirical evidence shows that the clearing prices for point-to-point congestion revenue rights, also known as financial transmission rights (FTRs), resulting from centralized auctions conducted by Independent System Operators differ significantly and systematically from the realized congestion revenues that determine the accrued payoffs of these rights. The question addressed by this paper is whether such deviations are due to price discovery errors which will eventually vanish or due to inherent inefficiencies in the auction structure. We address this question by studying a hypothetical DC-flow approximation model of a six-node system with known outage probabilities of each element and known statistical demand variability.

We show that even with perfect foresight of average congestion rents the clearing prices for the FTRs depend on the bid quantity and therefore may not be priced correctly in the financial transmission right (FTR) auction. In particular, we demonstrate that if all FTR bid quantities are equal to the corresponding average transaction volumes and the bid values are set at the expected congestion rent level, then the resulting auction prices systematically deviate from the known FTR values. We conclude that price discovery alone would not remedy the discrepancy between the auction prices and the realized values of the FTRs. Secondary markets or frequent reconfiguration auctions are necessary in order to achieve such convergence.

Keywords: financial transmission right, electricity auction, simultaneous feasibility, transmission pricing.

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1 Introduction

Point-to-point financial transmission rights (FTRs) (see [2] and [7]) and flow-gate rights (FGRs) (see [3], [4], and [6]) are two forms of Congestion Revenue Rights (CRRs) outlined in the Standard Market Design put forth by the Federal Energy Regulatory Commission (FERC) of the U.S. The purposes of the CRRs are two fold: a) Create a system of property rights to the transmission system that will offer economic signals for charging/compensating transmission usage/investment and that will facilitate the implementation of an economically efficient transmission congestion management protocol; b) Offer risk management capability to market participants entering into forward energy transactions so that they can hedge the uncertain congestion rents associated with such transactions. The allocation of FTRs can be done either on the basis of historical entitlements and use of the transmission system or through an auction whose proceeds are distributed to transmission owners or consumers who funded the construction of the system; or, through a combination of the two where unallocated FTRs and FTRs currently held by private parties are auctioned off through a centralized auction conducted periodically by an Independent System Operator (ISO). The latter approach is currently used by the three major ISOs in the northeastern US (New England, New York ISO and Pennsylvania-New Jersey-Maryland).

In this paper we primarily focus on the risk management aspect of FTRs and the extent to which FTRs are efficient instruments for trading and mitigation of congestion risk.

In evaluating a financial hedging instruments and its market performance, two questions must be addressed: How good is the hedge? Namely, to what extent does the payoff (or payout) of the instrument offset the fluctuations in the risky cash flow that the instrument is supposed to hedge. How efficient is the market for the instrument? That is, does the forward market price of the instrument reflect the expected risky cash flow hedged by the instrument with the proper risk premium adjustment.

Much of the discussion surrounding FTRs focuses on the first question and indeed FTRs provide a perfect hedge against real-time congestion charges based on nodal prices. A one Megawatt (MW) bilateral transaction between two points in a transmission network is charged (or credited) the nodal price difference between the point of withdrawal and the point of injection. At the same time (assuming that transmission rights are fully funded), a one MW financial transmission right (FTR) between two points is an entitlement (or obligation) for the difference between the nodal prices at the withdrawal node and the injection node. Thus regardless of how the system is dispatched, a one MW FTR between two nodes is a perfect hedge against the uncertain congestion charge between the same two nodes. This perfect hedging property makes FTRs ideal instruments for converting historical entitlements to firm transmission capacity into tradable entitlements that hold the owners of such entitlements harmless while enabling them to cash out when someone else can make more efficient use of the transmission capacity covered by these entitlements. In other words, FTRs make it relatively easy to preserve the status quo while opening up the transmission system to new and more efficient use.

From the perspective of new transmission users who view the FTRs as a mechanism to hedge their exposure to congestion risk (as well as old users who are actively evaluating their commercial options with respect to FTR entitlements) the second question is as relevant as the first. A purchaser of FTRs must assess whether the forward price of the instrument indeed reflects the value that it provides in making the decision whether to purchase/hold the instrument or to face the exposure to the real-time congestion charges.

In typical financial and commodity markets, competition and liquidity push the forward prices to the expected spot prices with a proper (market based) risk premium adjustment. Such convergence is achieved through a process of arbitrage. Such arbitrage, however, may be more difficult when dealing with FTRs for several reasons: because of the large number of FTR types, the liquidity of these instruments is relatively low; and there is virtually no secondary market that enables reconfiguration and re-trading. In order to maintain financial solvency of the system operator who is the counter-party to FTRs, the configuration of FTR types must satisfy "simultaneous feasibility conditions" that are dictated by the system constraints. Consequently, pricing and trading of FTRs is done through a central periodic auction.

Because of the interaction among the different FTR types through the simultaneous feasibility conditions, prices of the FTRs resulting from the FTR auction as well as the congestion charges hedged by these FTRs are highly interrelated. An efficient market (that correctly prices FTRs) must anticipate not only the uncertainty in congestion prices due to technical contingencies and load fluctuation but also the shift in the "operating point" within the feasible region which is determined by the economic dispatch procedure.

Empirical evidence reported in [8] shows that the clearing prices for FTRs resulting from centralized auctions conducted by the New York Independent System Operator (NYISO) have differed significantly and systematically from the realized congestion revenues that determined the accrued payoffs of these transmission rights. The question addressed by this paper is whether such deviations are due to price discovery errors which will eventually vanish or due to inherent inefficiencies in the auction structure. We address this question by using a DC-flow approximation model of a six-node system (see [9] for a general AC-flow formulation) with known outage probabilities of each element and known statistical demand variability. We use this information to simulate the expected value of all point-to-point transmission rights taking into consideration all possible $n-1$ transmission contingencies and demand realizations. We then construct a hypothetical FTR auction in which all FTR bids are at the correct expected value whereas the bid quantities equal some uniform multiple α of the corresponding average point-to-point transaction volume. We present both theoretical and computational results that shed light on the observed discrepancies between realized FTR values and their auction prices.

The organization of our paper is as follows. In section 2, we formulate an FTR auction model which incorporates the simultaneous feasibility conditions under postulated contingencies on transmission line availability and load variation. We then provide theoretical results on the potential systematic biases in market clearing nodal prices with respect to rational expectations. A numerical example is presented in section 3 to confirm our theoretical findings. Finally, we conclude and point out future research in section 4.

2 The Point-to-Point Congestion Revenue Right Auction

We consider an FTR auction conducted by a system operator in an electric power grid with n buses and m transmission lines. The auction is cleared under the standard FTR auction rules that treat all FTR bids as simultaneous bilateral transactions that must satisfy all the thermal line limits under all $n-1$ contingencies and load realizations. The auction is cleared so as to maximize FTR revenues and the prices are set to the marginal clearing bids for each FTR. Equivalently, we can view the aggregation of all bilateral transactions corresponding to the FTR bids as supply and demand bids in a virtual energy market. Maximizing social surplus (i.e., the difference between demand willingness-to-pay and supply marginal cost) for all transacted energy under the assumption that all the awarded FTRs were exercised simultaneously, is equivalent to maximizing the total as-bid value of the awarded FTRs. Hence the prices of the FTRs can be obtained from the locational market clearing prices for virtual energy that results from maximizing the as-bid value of all awarded FTRs subject to the power flow constraints. The market clearing price per MW FTR between two grid points is the difference of the corresponding market clearing prices for virtual energy between the two points.

Without loss of generality we can assume that the FTR simultaneous feasibility auction is represented by an equivalent virtual energy auction as described above and make our assumptions directly about the energy auction from which we will derive both the expected congestion rents and the FTR clearing prices. Under this scheme, the expected congestion rent between any two network locations is the expected difference of locational energy prices between the two points. Likewise, the FTR clearing price between any two points is the difference between the locational clearing prices for energy in the virtual energy auction. It follows that correct prediction of expected congestion rents between any two points is equivalent to correct prediction of the expected locational energy prices. Thus, an energy auction where energy bids and offers at all nodes equal the corresponding expected locational prices under all transmission contingencies and load scenarios is equivalent to an FTR auction where all FTR bids between two points are equal to their expected payoffs. Such an FTR auction where all market clearing bids for FTRs between any two nodes are identical to the respective expected payoffs of the FTRs over all transmission contingencies and load scenarios would represent the outcome of perfect price discovery.

The clearing mechanism for the FTR auction is formulated as follows. Let $C \equiv (c_1, c_2, \cdots, c_n)^T$ be a vector of energy bid prices at the n buses implied by the FTR bids and $Q \equiv (q_1, q_2, \cdots, q_n)^T$ denote the energy dispatch vector. Since we assume a single FTR bid price for each pair of nodes and a single virtual energy bid price at each node, knowing C uniquely determines the FTR bids as the difference between the corresponding elements of C (however, inferring C from the FTR bids does not produce a unique result since all components of C may be increased by a constant without affecting the implied FTR bids). As indicated above, maximizing the as-bid value of awarded FTRs is equivalent to maximizing social value of the nodal transactions in the equivalent virtual energy auction subject to the power flow feasibility constraints under all designated system reliability contingency scenarios. Let R denote the set of all reliability contingencies. Each scenario $r \in R$ represents the outage of at most one transmission line. The virtual energy auction is conducted by solving the following optimization problem.

$$\begin{array}{lll} \max\limits_{Q} & C^T Q & \\ s.t. & e^T Q = 0 & \\ & G_r \cdot Q \leq L & \forall r \in R \\ & -G_r \cdot Q \leq L & \forall r \in R \\ & I \cdot Q \leq \widehat{Q} & \\ & Q \geq 0 & \end{array} \qquad (1)$$

where L is the vector of transmission line capacity limits, $\widehat{Q}$ is the upper bound vector for energy bids as implied by the FTR quantity bids, G_r is the power transfer distribution factor matrix with bus-n chosen as the swing bus in each contingency scenario r, I is the $n \times n$ identity matrix, and e is a vector consisting of "1"s and "-1"s with "1" indicating a load bus and "-1" indicating a generation bus.

To fully specify the FTR auction in terms of a virtual locational energy market, it is also necessary to assume a bid quantity for each FTR type. For the purpose of our analysis we assume that the bid quantities in the FTR auction are some fixed multiple of the average transaction volume between the corresponding points. We introduce a proportionality parameter α on which we will perform sensitivity analysis. Again we can implement this assumption within the framework of a virtual locational energy market by making the nodal quantity bound of the supply or demand bid at each node in the virtual energy market equal α times the average (or expected) quantity produced or consumed at that node over all transmission contingencies and load scenarios. Thus the quantity bound of each nodal bid $\widehat{Q}$ is modelled by α multiple of the average nodal quantity $\overline{Q}$ at the expected nodal price. Namely, $\widehat{Q} = \alpha \cdot \overline{Q}$. We will show that the clearing prices depend on the quantity multiple α. Furthermore for α being unity (i.e., all FTR bids are for the average quantity at the expected price) the resulting auction prices deviate from the expected FTR values (that were known *ex ante*). Let λ, μ_r^+, μ_r^- and η be the dual variables associated with the first 4 categories of constraints where λ is a scalar, μ_r^+, μ_r^- $(\forall r \in R)$ are m-vectors and η is a n-vector. The dual problem of (1) is as follows.

$$\begin{array}{cc} \min\limits_{\lambda,\mu_r^+,\mu_r^-,\eta} & \sum_{r\in R}[(\mu_r^+)^T + (\mu_r^-)^T]L + \eta^T \widehat{Q} \\ s.t. & \lambda \cdot e^T + \sum_{r\in R}[(\mu_r^+)^T - (\mu_r^-)^T]G_r + \eta^T I \geq C^T \\ & \mu_r^+ \geq 0, \mu_r^- \geq 0, \forall r \in R, \text{ and } \eta \geq 0. \end{array} \quad (2)$$

Proposition 2.1 *If none of the quantity bound constraints in (1) are binding, then the market clearing nodal prices resulting from the virtual energy auction are equal to the bid vector C.*

If a bid quantity bound constraint at a bus i is binding, then the resulting market clearing nodal price P_i differs from the bid price c_i. Specifically, P_i is greater/less than c_i if bus i is a generation/load bus.

Proof: The market clearing nodal price vector P of the FTR auction (1) is given by:

$$P \equiv \lambda \cdot e^T + \sum_{r\in R}[(\mu_r^+)^T - (\mu_r^-)^T]G_r. \quad (3)$$

The conclusions can be drawn by inspecting the dual problem (2) and the strong duality between the primal and dual problems. ¶

When the nodal clearing price at a node in the virtual energy auction differs from the expected nodal price at that node under the various transmission contingencies and load scenarios, the resulting FTR clearing prices for FTRs involving that node also differs from their expected payoffs. In the following section we will demonstrate this phenomenon by means of numerical examples.

3 Numerical Examples

Consider a 6-bus network example used in [5] and [6] (see Figure 1). Buses 1, 2 and 4 are generation nodes while bus 3, 5 and 6 are load nodes. The supply and demand functions at the 6 nodes are assumed to be linear with parameters given in Table 1. We randomly choose a set of 5 reliability scenarios for an FTR auction: no line outage, line-13 out, line-45 out, line-16 out, and line-25 out.

Bus-ID	Supply Bids	Bus-ID	Loads
Bus-1	$10 + 0.05 \cdot q$	Bus-3	$37 - 0.05 \cdot q$
Bus-2	$15 + 0.05 \cdot q$	Bus-5	$75 - 0.1 \cdot q$
Bus-4	$42 + 0.025 \cdot q$	Bus-6	$80 - 0.1 \cdot q$

Table 1: Bid Functions of Generation and Load

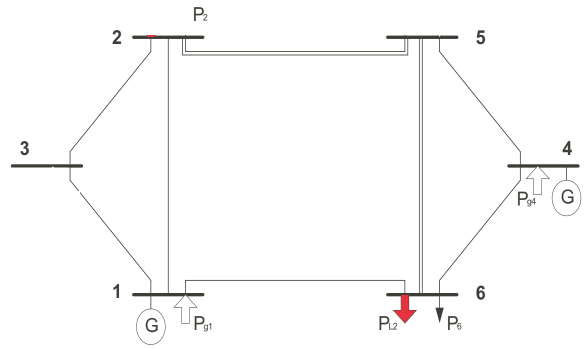

Figure 1: A 6-Bus Example

3.1 Case 1: transmission line contingency but no load variation

We shall use the same supply and demand bid functions as in Chao et. al. [6]. The *ex post* nodal prices in each of the 5 contingencies are given in table 2 (parenthesis in the first column represents the loss of a line). Suppose the probabilities of the contingencies happening are [0.6 0.1 0.1 0.1 0.1]. The expected nodal prices are also given in the last row of table 2.

Scenario	bus-1	bus-2	bus-3	bus-4	bus-5	bus-6
Normal	26.5	26.5	26.5	48.5	48.5	48.5
(L-13)	24.13	24.13	31.25	48.5	48.5	48.5
(L-16)	20.63	25	29.38	50	50	50
(L-25)	24.17	22.27	26.042	47.98	59.41	53.69
(L-45)	26.11	26.48	26.92	48.49	48.56	48.49
$E[Price]$	25.40	25.69	27.26	48.60	49.75	49.17

Table 2: *Ex Post* Nodal Prices and Expected Nodal Prices

Suppose the FTR market participants submit FTR bids that are equal to the expected payoffs over all contingencies. These bids are the differences in the expected nodal prices given in table 2. Then the nodal price bids c_i's in the virtual energy auction corresponding to the FTR auction can be set to the expected nodal prices given at the bottom of table 2. We assume that the bid quantity for each FTR type is given by α times the expected transaction volume between the corresponding points so that the quantity bound at each node is set to $\alpha \cdot \overline{Q}$ (i.e. $\widehat{Q} = \alpha \cdot \overline{Q}$ in (1)). For this data we compute the resulting market clearing nodal prices P_i's to examine whether $c_i = P_i, \forall i = 1, 2, \cdots, 6$.

We choose the expected dispatch quantities over all five reliability contingencies at all nodes to be $\overline{Q}$. Namely, $\overline{Q} =$

(308.053, 213.733, 204.837, 243.855, 252.535, 308.320) MW and vary the bounds for FTR quantity bids by varying the value of α. When $\alpha = 1$, none of the FTR quantity bids is binding and the resulting P_i's, as reported in the second column of table 3, are the same as the c_i's (last column of table 3). When $\alpha = 0.7$ or $\alpha = 0.5$, some of the FTR quantity bids reach the upper bounds thus resulting in market clearing prices P_i's (see table 3) that are different from the bid prices c_i's. In particular, Gen-1, Gen-4 and Load-5 reach their respective upper bounds when $\alpha = 0.7$ while Gen-1, Gen-2, Load-5 and Load-6 reach the upper bounds when $\alpha = 0.5$. The market clearing nodal energy prices for different α's are shown in table 3.

	$\alpha = 1$	$\alpha = 0.7$	$\alpha = 0.5$	FTR Bids
bus-1	25.403	25.687	27.258	25.403
bus-2	25.687	25.687	27.258	25.687
bus-3	27.258	27.258	27.258	27.258
bus-4	48.596	49.168	48.596	48.596
bus-5	49.747	49.168	48.596	49.747
bus-6	49.168	49.168	48.596	49.168

Table 3: FTR Auction Market Clearing Nodal Prices

Table 4 provides a comparison of the FTR values under three different α values. The last column reports the *ex ante* FTR price bids.

FTR \ α	$\alpha = 1$	$\alpha = 0.7$	$\alpha = 0.5$	FTR Bids (*ex ante*)
FTR-12	0.28	0	0	0.28
FTR-13	1.86	1.57	0	1.86
FTR-14	23.19	23.48	21.34	23.19
FTR-15	24.34	23.48	21.34	24.34
FTR-16	23.77	23.48	21.34	23.77
FTR-23	1.57	1.57	0	1.57
FTR-24	22.91	23.48	21.34	22.91
FTR-25	24.06	23.48	21.34	24.06
FTR-26	23.48	23.48	21.34	23.48
FTR-34	21.34	21.91	21.34	21.34
FTR-35	22.49	21.91	21.34	22.49
FTR-36	21.91	21.91	21.34	21.91
FTR-45	1.15	0	0	1.15
FTR-46	0.57	0	0	0.57
FTR-56	-0.58	0	0	-0.58

Table 4: FTR Price Comparison under Transmission Contingencies Only

3.2 Case 2: both transmission line and load contingencies

Next we assume that under each transmission contingency there are three equally likely scenarios for loads: no change in loads, 25% more loads, and 25% less loads. Table 5 lists the load curves in all three scenarios at nodes 3, 5 and 6. The assumed joint probability distribution of the load and

	Node 3	Node 5	Node 6
no-load change	37.5-0.05q	75-0.1q	80-0.1q
load +25%	46.875-0.05q	93.75-0.1q	100-0.1q
load −25%	28.125-0.05q	56.25-0.1q	60-0.1q

Table 5: Load Contingencies

transmission line contingencies is given in table 6.

	Normal	(L-13)	(L-16)	(L-25)	(L-45)
Base Load	0.2	0.04	0.04	0.04	0.04
load +25%	0.2	0.03	0.03	0.03	0.03
load −25%	0.2	0.03	0.03	0.03	0.03

Table 6: Joint Distribution of Transmission and Load Contingencies

The computational results on market clearing nodal energy prices, energy quantities, and auction-clearing FTR prices are given in tables 7 and 8. The first row in table 7 shows the expect nodal energy prices and the dispatch quantities at the 6 buses over the 15 combined load and transmission line contingencies. We now assume that the FTR auction is conducted based on the price and quantity bids being set to the corresponding numbers in the first row of table 7. That would correspond to an FTR auction under the assumption of perfect price discovery. The rest of table 7 contains the resulting nodal prices and dispatch quantities at the 6 buses for $\alpha = 1.5$, 1.0, 0.7, and 0.5.

Comparisons of the FTR values for 4 different α's are shown in table 8.

4 Conclusion

In summary, we demonstrate that FTR auctions enforcing the simultaneous feasibility constraints have inherent properties that result in fundamental inefficiency in the FTR market. Specifically, the clearing prices do not converge to the expected payoffs of the auctioned instruments. Our analysis indicates that such divergence, which has been demonstrated empirically, cannot be attributed to lags in price dis-

	bus-1	bus-2	bus-3	bus-4	bus-5	bus-6
P ($)	24.3	25.5	28.5	47.1	53.9	50.8
Q (MW) (FTR)	286.4	210.6	180.0	185.4	210.8	291.6
P ($)	24.3	25.5	28.5	47.1	53.9	50.8
Q (MW) (α : 1.5)	250.0	75.0	125.0	241.7	133.3	308.3
P ($)	24.3	25.5	28.5	47.8	53.9	50.8
Q (MW) (α : 1.0)	250.0	75.0	125.0	185.4	189.6	195.8
P ($)	25.5	25.5	28.5	50.8	50.8	50.8
Q (MW) (α : 0.7)	200.5	124.5	125.0	129.8	147.5	182.3
P ($)	28.5	28.5	28.5	47.1	47.1	47.1
Q (MW) (α : 0.5)	143.2	105.3	48.5	51.2	105.4	145.8

Table 7: FTR Auction Bids and Market Clearing Prices and Quantities under Load and Transmission Contingencies

α	1.5	1	0.7	0.5	FTR Bids (*ex ante*)
FTR-12	1.21	1.21	0	0	1.21
FTR-13	4.18	4.18	2.97	0	4.18
FTR-14	22.82	23.43	25.31	18.64	22.82
FTR-15	29.60	29.60	25.31	18.64	29.60
FTR-16	26.52	26.52	25.31	18.64	26.52
FTR-23	2.97	2.97	2.97	0	2.97
FTR-24	21.60	22.22	25.31	18.64	21.60
FTR-25	28.39	28.39	25.31	18.64	28.39
FTR-26	25.30	25.30	25.31	18.64	25.30
FTR-34	18.64	19.25	22.34	18.64	18.64
FTR-35	25.42	25.42	22.34	18.64	25.42
FTR-36	22.34	22.34	22.34	18.64	22.34
FTR-45	6.79	6.17	0	0	6.79
FTR-46	3.70	3.09	0	0	3.70
FTR-56	-3.09	-3.09	0	0	-3.09

Table 8: FTR Price Comparison under Both Load and Transmission Contingencies

covery. We show that even with perfect foresight of expected payoffs the FTR auction would produce clearing prices that differ from the expected FTR payoffs. Based on our analysis, it is evident that the clearing prices depend on the quantity multiple α which measures the total quantity of submitted FTR bids. When the FTRs serve primarily as hedging instruments, bid quantities for FTRs tend to track expected transaction volumes and FTR bids are spread over large number of node pairs. Such spread, however has the effect of imposing quantity limits on certain FTR awards causing the clearing prices to deviate from the initial bid prices. In a more speculative market where FTR bid quantities exceed hedging needs, larger quantities of fewer FTR types would be awarded and auction clearing prices are likely to better match their *ex ante* valuations. We conclude that price discovery alone does not remedy the discrepancy between the auction prices and the realized values of the FTRs. Such convergence is essential if the FTRs are to fulfill the need for efficient risk management and provision of correct price signal for transmission usage and investment. More liquidity in the FTR market through frequent reconfiguration auctions and the introduction of flowgate rights that can be traded in secondary markets are ways through which better convergence between forward prices and spot realization of the congestion rents can be achieved.

Finally, we should point out that discrepancies between FTR auction prices and the realized FTR settlements may also be attributed in part to inaccuracies due to the use of DC-flow network models in an FTR auction and in determining nodal prices and congestion settlements. DC-flow models are not realistic especially for heavily loaded systems. In a congestion-prone system, FTR prices can be quite volatile as the nodal prices are drastically influenced by congestion. Thus, the differences between a real grid system and the DC-flow approximation model may amplify the error between FTR auction prices and the settlements. We are currently working on developing more realistic approximations to an AC-flow system model that will improve the computational accuracy of nodal prices and congestion settlements. However, such improvements are unlikely to resolve the inherent efficiency problems described in this paper.

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