Efficiency Concerns in Auctions for Financial Transmission Rights

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Abstract

Wholesale deregulated electric power markets in the United States use Financial Transmission Right (FTR) contracts, which allow generators and wholesale consumers to partially hedge uncertain charges associated with a congested transmission network. These contracts are often initially sold in a multi-round auction, and due to the structured nature of the contract prices and a parallel structure for the payoffs, the format creates an arbitrage opportunity within the auction. Beyond the first round of the multi-round auction, a systematic bidding strategy results in price distortion inconsistent with the objective of the FTR auction. Public data reveals that investors have benefited from this opportunity. A simple change in the auction structure can eliminate this within-auction arbitrage opportunity.

1. Introduction

The nodal pricing system is fast emerging as an accepted mechanism for pricing in wholesale electric power markets following the deregulation of the industry in much of the United States. The concept originated with Fred C. Schweppe (1988) in the U.K. The prices of nearly 60% of the bulk electric power bought and sold in the United States is established using the nodal pricing framework (ISO/RTO Council, 2007). One of the distinguishing features of this mechanism is an equitable method to value congestion on the transmission network. Frequently, congested bottlenecks due to line capacities restrict the ability of the transmission network to fully support the desired injections and withdrawals of electricity. Under this framework, when the network is constrained, the users of the network – generators (wholesale suppliers) and load serving entities (wholesale purchasers) – are required to pay or collect a charge depending on whether their actions increase or relieve congested bottlenecks on the grid. The charges vary according to the location of the injection (source node) or withdrawal (sink node) relative to the overall transmission network topography and line capacities. Regions with surplus transmission capacity generally do not experience congestion unless the outage of a significant line occurs. However, most transmission regions in the United States today experience congestion. In 2007, the Pennsylvania Jersey Maryland (PJM) Interconnection L.L.C., one of the largest wholesale markets in the United States collected $1.845 billion as congestion charges (Market Monitoring

Unit (PJM), 2008). Given the complex physical laws governing the electric power flows on the network, as well as demand uncertainties, these charges are inherently volatile and difficult to predict.

Following Hogan (1992), a hedging instrument called the Financial Transmission Right Obligation, here after referred to as FTR, is incorporated in all wholesale power markets subscribing to the nodal pricing framework as a remedial measure to assist risk-averse users of the network in managing uncertain congestion charges. A FTR is a finite duration contract, defined jointly by: its source node, sink node, time period and capacity measured in MWs. The holder of a FTR is entitled to a revenue stream that exactly offsets the proportional amount (contracted capacity divided by total capacity) of congestion charges incurred by any network user transmitting electric power from the given source node to the given sink node. For instance, generators holding relevant FTR contracts, when faced with congestion charges will also receive offsetting payments thereby neutralizing their exposure to congestion-driven cost volatility.

Alternatively, a FTR could be viewed as a financial instrument, where the buyer exchanges a fixed one-time payment to acquire a stream of uncertain payoffs spread over the term of the contract. A peculiar characteristic of these payoffs, which is a result of how congestion charges are determined, distinguishes these contracts from other claims commonly traded in financial markets. The congestion payoffs associated with any two FTRs are generally not independent. Moreover there exist groups of FTR contracts, which taken individually yield uncertain payoffs, but as a portfolio yield a deterministic payoff.

Currently in most markets, FTRs are sold through an auction. In major markets, especially for long-term FTRs, a multi-round format is employed. (See tables 1 and 2.) A subset of available FTRs is sold in each round. The selection of winning bids and calculation of auction clearing prices are based on a principle that takes into account the underlying complexity of the physical laws associated with electric power flows, and similar calculations are used to determine the congestion payoffs for the FTR contracts. We show below that the current auction format adopted to sell FTRs combined with the structure of congestion payoffs creates a peculiar and potentially profitable bidding opportunity. The participants of this auction could potentially buy a portfolio of offsetting FTR contracts with zero-payoff for a net negative price.. In auction rounds beyond the first, buyers can use knowledge regarding clearing prices and their own successful bids to guide subsequent bids to profitably acquire an offsetting portfolio, indicating a possible inefficiency inherent within the format. The multi-round auction format however, is not without its benefits. It is widely used for selling a variety of objects such as wines and works of art. For instance, identical wines may be divided into lots and each lot sold to the highest bidder (Ashenfelter, 1989). The winning price of the previous lot conveys useful information to the bidders of the next lot. It has been argued that a multi-round format, which allows the bidders to re-evaluate their strategies mid-auction following the observation of their competitors' valuations, generates higher revenues to the seller compared to a single-round auction (Compte and Jehiel, 2007). However, to the best of our knowledge, none of the commonly auctioned objects share the value linkages introduced by the structured payoffs of the FTR contracts.

Most of the proceeds of this auction are paid ultimately to the original investors in the transmission system. The within-auction arbitrage profits, earned by some participants, therefore represent a loss to the investors in the transmission system,[1] which may in turn distort or reduce the incentives envisioned in creation of FTR auction.

An examination of the auction data from one of the largest wholesale power markets in the county – PJM Interconnection – reveals several instances where within-auction arbitrage profits were realized, suggesting the possibility that some participants could be systematically making bids to benefit from the unique opportunity facilitated by the multi-round format. In this paper we also develop a tractable method to determine the size of such profits earned by each investor. Furthermore, we compute the total potential for such profits given the cleared FTR contracts. This constitutes an upper bound on hypothetical arbitrage profits that could be earned post-auction.

To remedy this situation, we suggest an alternative format, influenced in part by the auction for electromagnetic frequency spectrum licenses conducted by Federal Communication Commission (FCC) that would preserve the benefits of a multi-round format, while eliminating the potential for earning within auction arbitrage profits.

2. The Nodal Pricing System

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[1] The congestion charges alone are insufficient to compensate the transmission owners with regard to the historical investment and ongoing operational expenses. Most Independent Systems Operators have parallel mechanisms to compensate transmission owners in addition to congestion charges.

Historically the unconventional nature of electric power as a commodity (lack of significant storage capability, need for substantial delivery infrastructure, etc.) sustained the perception that the electric power industry was a natural monopoly for many years. For that reason, the industry was highly regulated, and competitive market forces guided neither prices nor allocation of resources. States established Public Utility Regulatory Commissions to regulate various aspects of the industry and the utility firms were restricted to earn a mandated fixed rate of return on their equity (see Bonbright, et al., 1961). Beginning in the late eighties economists began to theorize that through a deliberately designed market architecture, it would be possible to closely replicate the production and consumption decisions that would have resulted from a hypothetical competitive market (Chao and Peck, 1996; Hogan, 1992; Schweppe, 1988). The structure, now commonly known as the nodal pricing system or the locational marginal pricing system, has gained wide acceptance as a means to organize wholesale electric power markets.

At the center of this market design is a not-for-profit authority called the Independent Systems Operator (ISO) that acts as an intermediary between buyers and sellers of electric power. Today there are six ISOs in the U.S. (see table 1), of which five employ the nodal pricing system with the remaining one expected to adopt this pricing system in 2010 (see table 2).

The core design feature of the nodal pricing system is an institutional arrangement equipped to regulate prices of electricity to create an outcome mirroring that from a hypothetical competitive market equilibrium. The generators submit price-quantity schedules to the ISO one day ahead of the actual dispatch. Most wholesale consumers[2] submit demand bids (anticipated demand for power within their customer base). For example, a generator may commit to sell up to 200 Megawatts (MW) of electric power for at least \$50 per Megawatt hour (MWh) and up to 100 MW of electric power for at least \$70 per MWh. Similarly, an example hourly demand bid could be 4,000 MWh.

Based on the offer schedules, the ISO optimally schedules the generators so as to

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[2] They are otherwise known “load-serving entities”. They act as an intermediary between the ISO and retail customers. Since they do not exert control over the downstream consumption of electric power, they merely act as price takers.

minimize the system-wide cost of reliably[3] meeting the next day's demand.[4] Hourly prices are computed for every node, and at each node, the price is set to the cost of reliably delivering the market clearing marginal unit. Thus defined the nodal prices reflect the opportunity costs associated with the limited generation and transmission capacity needed to meet a given demand situation[5] (Chao and Peck, 1996, Hogan, 1992). The nodal price is also referred to as the locational marginal price.

The nodal price has three components: a generation component, a loss component and a congestion component. The congestion component at every node will be zero if transmission capacity is adequate to support all power-flows. On the other hand, if transmission capacity is insufficient to accommodate the power-flows desired by the market, i.e. if the lines are congested, the congestion component will not be zero and nodal prices will diverge across the network.

Under congested conditions, the congestion component of the price at a node reflects the net contribution of injections and withdrawals of electric power made at the node towards causing the congested bottleneck. Accordingly, for a given source node and sink node, the difference in their respective congestion components represents the opportunity cost of the transmission network in facilitating the directed electric power flow from the source node to the sink node. This difference is referred to as the congestion charge. The congestion charge could be positive or negative with the reverse direction congestion charge always being equal to the negative of the original direction congestion charge (i.e. the congestion charge from A to B is always equal to the negative of the congestion charge from B to A). The following example clarifies the definition of the congestion charge.

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[3] Reliability in this context means scheduling generators such that the entire grid's operation is not affected by the failure of at most one critical element such as transmission line, transformer or generation unit. Not surprisingly, reliability is always at a premium.

[4] This constitutes, what is commonly called the "Day Ahead Market." A balancing market for meeting demand above and beyond what is cleared in the Day Ahead Market is conducted in five-minute intervals the following day.

[5] The nodal prices are derived from the dual variables within the optimal dispatch linear programming problem solved by the ISO.

Consider a utility company with a generator located at Node A and a commitment to deliver power to Node B. Suppose for some arbitrary hour, the ISO posted congestion components of the nodal prices at Node A and Node B are –\$25 and \$20 per Megawatt-hour (MWh) respectively. Therefore the congestion charge paid by the utility company for transmitting 1 MWh of electric power during that hour from Node A (source) to Node B (sink) is \$[20 – (–25)] = \$45. Similarly, a generator located at Node B, transmitting power in the reverse direction to Node A will incur a negative congestion charge (–\$45).

Congestion charges are highly volatile. Typical off-peak hours (nights and weekend days), are characterized by zero congestion charges, since during those hours, demand is generally low and transmission capacity is adequate to support all power flows. Less frequently, a critical link, not necessarily a high-capacity line, going out of service may lead to other lines becoming congested causing the nodal prices to diverge across the network.

Hogan (1992) predicted that the adoption of the nodal pricing system characterized by volatile congestion charges would introduce an unprecedented uncertainty to the stakeholders of the industry largely accustomed to stable incomes guaranteed by regulators. As a remedial measure to cushion the transition and consequently earn the necessary political capital to introduce reforms, Hogan (1992) proposed the creation of a hedging contract that came to be known as the Financial Transmission Right (FTR). Every ISO employing the nodal pricing system has also instituted a parallel market for FTR contracts; although they are known by different names in different markets (see table 2).

FTRs are designed to provide a partial hedge to the user of the network through a payoff stream of offsetting congestion charges. A FTR for a given source node and sink node, is designated in MWs with a specified time period. For instance, a generator transmitting 1 MW of electric power from Node A to Node B, through holding a 1 MW A-to-B FTR earns a payoff every hour that exactly offsets the incurred congestion charge. It is important to note that FTRs do not eliminate all the risk faced by the generator. For example in a simplified network with only two nodes, the generator at node A transmitting 40 MW of electric power to node B, needs to be equipped with exactly 40 MW worth of identical source-sink FTR to completely hedge congestion charges. It is hard to precisely predict the generator's output and even harder to acquire FTRs with the desired source-sink combination and MW capacity.

Since the congestion pattern varies by the hour of the day, ISOs have structured FTRs into multiple categories. Typically, an On-Peak FTR is associated with weekday day-time hours and an Off-Peak FTR is associated with weekday night-hours and all hours of weekends and holidays. In addition to offering FTRs with one year and one month terms, some ISOs offer FTRs with a term coinciding with a particular season. Examples include a summer season FTR and a fall season FTR.

Since a congestion charge could be positive or negative, FTRs also may have a positive or negative value. When the congestion charge is negative, the purchaser of the FTR is liable to the ISO. For this reason, every ISO requires investors to post sufficient collateral before buying FTR contracts and limits the number of FTRs awarded to a single investor.

3. Unique Payoff Structure of FTR Contracts

The generators and other users of the transmission network benefit from the hedging capability offered by FTR contracts. However, the current trading rules in all wholesale markets permit any investor with sufficient collateral to buy and hold FTR contracts. From the perspective of pure speculators, a FTR contract is like any other financial asset, promising a stream of uncertain payoffs spread over the term of the contract. Therefore, theoretically, like any other financial claim, the value of an isolated FTR to a speculator should equal the discounted expected value of the aggregate congestion charge.

However, the nature of payoffs (congestion charges) differentiates FTR contracts from other claims generally traded on financial markets. This is because the payoffs of any two same-category FTR contracts with concurrent terms are in general not independent. In any given hour, the congestion charges are defined such that even a single congested line on the network affects payoffs associated with all active FTRs in a structured manner. Consequently, there exists a relationship between payoffs associated with any two concurrent-term FTRs, although of a kind that is extremely complex to characterize.[6] However, for a particular type of portfolio of FTR contracts, the relationship is quite simple as we explain below.

As described in the previous section, in any given hour t, the payoff to a FTR with source node at A and sink node at B is defined as the congestion component of nodal price at Node B ($CC_{B,t}$) less the congestion component of nodal price at Node A ($CC_{A,t}$). The value of (A→B)

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[6] This follows from the duality principles of the linear programming optimization problem employed by the ISO to optimally schedule generation resources to meet forecasted demand.

FTR to a speculator, ($\Phi_{A\to B}$) therefore is,

$$\Phi_{A\to B} = \sum_{t=1}^{T} \beta_t CC_{B,t} - \beta_t CC_{A,t} \tag{3.1}$$

where T denotes the total number of hours specified by the term of the FTR contract and β_t is the hourly discount factor.

The above structure immediately suggests that the payoff to a portfolio of FTRs, such that they form a closed loop, should be zero. For instance, $\text{FTR}_{A\to B}$, $\text{FTR}_{B\to C}$ and $\text{FTR}_{C\to A}$ form a closed loop. If each of these FTRs is for the same number of MWs and is for the same time period, the congestion payoffs from the individual FTRs offset each other perfectly, resulting in a zero payoff. Accordingly, to preclude arbitrage opportunities, the value of such an offsetting portfolio of FTRs should always be zero. This aspect of the payoff structure for FTR contracts is unique among financial contracts. For an offsetting portfolio of FTRs with the same capacity and time period, the individual contracts yield uncertain payoffs, but the portfolio always yields a deterministic payoff of zero.

4. Inefficiency in the Multi-round Format for FTR Auctions

Since the adoption of the nodal pricing system, ISOs have served the role of being the sole counterparty to all initial buyers of FTR contracts. In the beginning years, many ISOs allocated these contracts among the users of the network (Market Monitoring Unit (PJM), 2008). Currently, the accepted approach is to conduct periodic auctions to sell FTR contracts. Post-auction, the ISO is responsible for collecting and disbursing congestion charges, once every hour as they are realized during the term of the FTR contract. The ISO is regulated as an independent entity with no profit motivation[7] and is required to balance the potential congestion charge outflows and inflows. Hogan (1992) showed that this could be achieved by allowing only a subset of FTRs to be outstanding at any given point in time. He further showed that this condition, now referred to as the simultaneous feasibility condition, depends only on the network configuration.

All ISOs have adopted a common format where bids are invited from network users and outside speculators. Each FTR bid specifies its source node, sink node, number of MWs and a reserve price. The participants are allowed to place multiple bids for the same source-sink

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[7] Even though, the ISO in its entirety may operate as a for-profit organization, they are regulated by FERC not to earn any profit conducting the FTR markets.

combination. Some ISOs have adopted a multiple round format (see table 2). As an example, table 3 shows bid schedules placed by a participant for the same FTR contract in the 2007-08 Annual FTR auction conducted by the PJM Interconnection. The participant in the example placed a bid to buy up to 5 MWs of Western Hub → Eastern Hub On-Peak FTR in the first round of the auction for at most $28,606 per MW. In the same round, the participant was further willing to buy an additional 5 MWs of the same Western Hub → Eastern Hub On-Peak FTR for at most $27,761 per MW and so on.

The ISO chooses a subset of FTR bids that are "simultaneously feasible" such that total auction revenue is maximized. In a multiple-round format, the simultaneous feasibility condition is progressively relaxed from one round to another. For instance with a four-round auction format, in the first round the simultaneous feasibility conditions are specified as if only one-fourth of every line's capacity is available. A subset of FTRs is selected among the first round's received bids such that they satisfy the simultaneous feasibility condition while maximizing the auction revenue. In the next round, each line's capacity is expanded to half of their actual capacity less any awarded FTRs to derive a new set of simultaneous feasibility conditions. A new subset of FTRs is selected among the second round bids that satisfies the expanded simultaneous feasibility condition along with the cleared FTRs of the previous round while maximizing the auction revenue.

All ISOs have adopted a uniform pricing format. In any given round for a particular FTR, all winning bidders pay the same price called the market clearing price (MCP).[8] At the end of each round, in addition to publishing market clearing prices for all cleared FTRs, the ISO also publishes a useful indicator called nodal clearing price (NP) for all listed nodes. The market clearing prices for individual FTRs are deduced from those prices using the following relationship.

$$MCP_{A\to B} = NP_B - NP_A \tag{4.1}$$

For example, in PJM's 2007-08 Annual FTR Auction, the first round nodal clearing price for Western Hub, On-Peak was –$21,855.15. In the same round, the nodal clearing price for

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[8] The market clearing price is defined as the bid value of the marginal FTR that if awarded results in the violation of the simultaneous feasibility condition. The market clearing prices are derived from the dual variables from the constrained auction revenue maximization problem.

Eastern Hub, On-Peak was \$4,917.61. The market clearing price for Western Hub → Eastern Hub On-Peak FTR follows as \$(4,917.61 – (–21,855.15)) = \$26,772.76. The method conveniently allows for deducing not only the price of cleared FTRs, but also the prices of those that either did not clear or did not receive any bids. More importantly, this procedure for calculating prices imposes a structure on market clearing prices that is consistent with their respective payoffs – i.e. for any set of FTRs for an equal number of MWs that form a closed loop, the market clearing prices determined within a particular round of the auction sum to zero.

The FTRs cleared in a single round auction therefore conform to the basic principle that a financial claim with deterministic future payoff is at most worth the payoff amount.[9] However, there is no guarantee that this principle holds in a multi-round FTR auction. Barring the extremely unlikely situation where the market clearing prices of all FTRs are identical in all rounds, the clearing prices of the above described offsetting portfolio with a deterministic zero payoff may not be zero. The following example contrasts a single round with a multi-round FTR auction.

Suppose the clearing prices of three offsetting FTRs -- $FTR_{A\rightarrow B}$, $FTR_{B\rightarrow C}$ and $FTR_{C\rightarrow A}$ of 1 MW each for the same time period – at the end of the first round of the auction are –\$550, \$150 and \$400, respectively. In the second round, let the clearing prices of the same set of FTRs be –\$480, \$130 and \$350, respectively. Since the three FTRs in the portfolio complete a closed loop, the congestion payoffs perfectly offset each other. The portfolio thus earns a zero payoff regardless of how congestion materializes on the network. An investor could acquire all three FTRs together in the first round or the second round for \$0. In such a situation, the clearing-price of the offsetting portfolio and its payoff stream are consistent. Alternatively, if an investor acquires the first two FTRs ($FTR_{A\rightarrow B}$, $FTR_{B\rightarrow C}$) in the first round of the auction and the last FTR ($FTR_{C\rightarrow A}$) in the second round of the auction, the total cost of acquiring the portfolio is –\$550 + \$130 + \$350 =–\$70. In this situation, the investor is able to acquire a zero-payoff portfolio for a negative price thus earning a profit within the auction clearing process. Similarly, it is also possible for an investor to incur a loss by acquiring a portfolio of offsetting FTRs for a positive

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[9] More generally, it should be worth slightly less, once discounting is taken into account. However, for short-term FTRs and low interest rates, the impact of discounting on the value is generally negligible.

price.

Given their unusual payoff structure, the ISO's strategy to sell FTRs in a multi-round auction format inherits a shortcoming with a potential loss of efficiency. It is plausible to expect some investors to attempt to strategically acquire offsetting portfolios for a negative net clearing price. One possible strategy is to acquire neighboring FTRs in the initial rounds of the auction. Conditional on the successful acquisition of FTRs in those rounds, investors could strategically bid on other FTRs needed to profitably acquire an offsetting position. Naturally, there is an economic cost involved in executing this strategy. The investors' bids may not clear at desired prices – a possibility representing the risk of not acquiring all offsetting FTRs. This risk is probably enough to deter some investors from attempting to acquire offsetting portfolios. On the other hand, the multi-round format likely benefits other regular investors, who participate in the auction regardless of the profitable trading opportunities afforded by the FTR's unique payoff structure. These investors, who primarily take part in the auction to buy FTR contracts for their hedging and speculative features, are by nature well positioned to carry out the strategic bidding – enabling them to extract profits by constructing offsetting portfolios where feasible in the course of the auction. In this regard, the multi-round format for auctioning FTR contracts could be seen as facilitating rent extraction opportunities for some investors. In the following section, we examine bidders' behavior within a real-auction setting.

5. PJM – Annual FTR Auction

Despite being theoretically plausible, several factors influence the profitable acquisition of offsetting FTRs. The extent to which investors are successful depends not only on the bidders' risk preferences, market competitiveness and information environment characterizing participants' valuations, but also on the technical features of the network manifested through simultaneous feasibility conditions. Given the influence of several such factors that ultimately affect the investor's realization of profits, it is worthwhile to study the bidders' observed behavior in an auction setting. Although any conclusions are likely specific to the market being analyzed, evidence of proactive bidding as well as the size of realized profits could serve as a useful indicator for performance of these markets.

The PJM Interconnection is a natural choice given that the market is the oldest as well the largest in the United States. Following is a brief description of the auction.

5.1 Auction Format

PJM Interconnection was the first to adopt the nodal pricing system in the United States. For every year since 2003, PJM has conducted a four-round auction to sell annual FTR contracts. In each round, roughly a quarter of the available transmission capacity is auctioned. The FTRs[10] are classified into three types: On-Peak, Off-Peak and 24-Hour. The On-Peak FTR is associated with congestion charges incurred during the peak-hours (7:00 a.m. to 11:00 p.m.) of every weekday except for holidays. All hours that do not fall within the On-Peak category are considered Off-Peak. The 24-Hour FTR is associated with all hours – both On-Peak and Off-Peak – within the year.

Each bid is required to specify the source node, the sink node, the quantity in MW, and the price in dollars per MW. PJM releases a list of "valid" nodes prior to the beginning of the auction. Among those listed nodes, the participants freely choose any number of directed pairs (sources and sinks) for their FTRs. The bidder agrees to purchase any quantity equal or less than the specified MW at no more than the specified price. The bidders are allowed to place multiple bids on the same FTR source-sink combination (see Table 3). In addition, PJM requires every participant to post collateral before the beginning of the auction. Since FTRs incur negative payoffs – an obligation from the perspective of the holder – this provision is intended to protect the ISO in the case of investor's failure to pay. The market value of the posted collateral limits a participant's scope of bidding. Larger collateral allows an investor to bid on a larger volume of FTR contracts or equivalently a larger portfolio of FTR contracts. The participants are allowed to sell their prior acquired FTRs in the subsequent rounds of the auction.

The PJM Interconnection, once for every round of the auction, solves the constrained auction revenue maximization problem and chooses a "simultaneously feasible" subset of FTRs among the received bids.

5.2 Disclosure Policy

At the end of every round, for every cleared bid, PJM announces the identity of the bidder, the MW size of the bid cleared and the clearing price. In addition, PJM also publishes nodal clearing prices for every "valid" node. The prices of all FTRs including those that did not clear could be

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[10] PJM calls conventional FTRs FTR Obligations to differentiate from FTR Options also issued by PJM in the same auction. The owner of a FTR option is entitled to receive, but not obligated to pay congestion charges. Here we focus only on FTR obligations.

inferred from the nodal clearing prices via (4.1). However, PJM does not disclose the bid data until six months later. Even then, PJM does not make public the identity of the bidder. For accuracy and convenience, the data is reorganized slightly as described in the following sections.

5.3 Accounting for Affiliate Relationships

The PJM Interconnection assigns a unique identification code to every participant. However, in several instances, multiple affiliates of a firm are recognized by the PJM as independent participants and hence were assigned different identification codes. It is plausible to expect that these investors potentially cooperate among themselves to profitably acquire FTRs. Ignoring the potential for coordinated bidding in the FTR auction could result in undervaluing the magnitude of arbitrage profits. Therefore, to the extent feasible, affiliate relationships are uncovered from reputable sources such as investors' filings with Securities and Exchange Commission (10-K reports). Every group of affiliated participants is treated as a distinct participant. In addition, in many instances, PJM has assigned multiple participant codes for the same investor. Removing such redundancies and accounting for affiliate relationships resulted in the grouping of 263 participants into 128 participants.

5.4 Reclassifying FTRs

The PJM Interconnection sells 24-Hour FTRs, which entitle the owner to both On-Peak congestion charges and Off-Peak congestion charges. Consequently, a 24-Hour FTR could be used to offset a pair of On-Peak and Off-Peak FTRs. Therefore to account for this feature, every 24-Hour FTR is treated as an equivalent pair of On-Peak and Off-Peak FTRs. The prices of these partitioned FTRs are inferred from the respective On-Peak and Off-Peak nodal clearing prices published by the PJM Interconnection via (4.1).

6. Proactive Bidding

In select instances, the choice of FTR's source and sink nodes, bid price and prior acquired FTRs adequately reflect the bidder's intention to profitably complete an offsetting portfolio. However, to reasonably determine an investor's motive, we need the complete bid sequence – bids placed by the investor in every round of the auction. Given PJM's disclosure policy, it is impossible to uniquely ascribe bids to their respective investors in most cases. Nevertheless, since PJM discloses all other attributes of a bid, it is possible to identify those investors who are successful in their attempt to acquire offsetting portfolios. The identity of the remaining investors, who have tried and failed in their attempts, cannot be determined using this data. Despite these limitations, following the principles of linear programming and published attributes of bids, it is possible to unearth select instances of proactive bidding. The following is one such case observed in the 2007-08 PJM Annual FTR auction.

The three off-peak FTRs: BGE → WESTERN HUB, WESTERN HUB → JCPL and JCPL → BGE form a closed loop and therefore constitute an offsetting portfolio of FTRs. Tables 4-6 show the published and imputed information for these three offsetting FTRs. For example, the first four columns of table 4 show the published auction results for BGE → WESTERN HUB off-peak FTR cleared in the first round of the auction. Only one FTR cleared, and it was acquired by Investor A.[11] There are however 13 bids received by the PJM Interconnection for this FTR. Since the ISO's objective is to maximize the auction revenue, the bids clear in the order of highest to lowest price (the least negative in this case clears first). By sorting the published bid information in decreasing price order and matching bid quantity against cleared quantities, investors' identities may be imputed. In this particular example, each winning bid is uniquely mapped to an investor. In several instances, there may not be a unique mapping between the winning and cleared bids. Also, the identity of unsuccessful bidders can never be determined from the public data.

Investor A acquired 7.8 MW of the BGE → WESTERN HUB FTR for −$25,838 per MW in the first round of the auction. In the second round, the same investor acquired 10 MW of JCPL → BGE FTR for $15,656 per MW. The investor could earn a within auction arbitrage profit by acquiring the WESTERN HUB → JCPL FTR for any price less than $(25,838 − 15,656) = $10,182. The imputed information on Table 6 shows that investor A placed at least two bids for WESTERN HUB → JCPL FTR in the fourth round of the auction. The first bid is for 5 MW at $ 7,066 per MW and the second bid is for 5 MW at $ 6,611 per MW. Both bids are in the range that would generate positive profit for the offsetting portfolio if awarded. The bids cleared at $ 5,493 resulting in investor A earning a total arbitrage profit of $ (25,838 − 15,656 − 5,493) ×7.8 = $ 36,574.

This approach of imputing the identity of the bidders cannot be replicated for all possible cases of proactive bidding. The example described above, though only an anecdotal observation, suggests that investors may be aware of the profitable opportunity. Extending this line of

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[11] Names are omitted, even though this information is available in the public domain.

inquiry, in following sections we describe a tractable method to assess the extent to which investors were successful in exploiting the multi-round format to earn within auction arbitrage profits.

7. Isolating Offsetting Subsets of FTRs

A portfolio of FTRs acquired by an investor may include a subset of perfectly offsetting contracts. The investor realizes a arbitrage profit if this subset was bought for a net negative clearing price. To assess the size of the arbitrage profit (or loss) earned by each investor, we require a means to isolate offsetting FTRs from the larger pool of FTRs owned by the investor. Given that every offsetting subset of FTRs takes the form of a closed loop, one obvious approach would be to systematically isolate them. The obvious shortcoming of this approach is that the complexity grows exponentially as more FTRs are added to the pool. In addition, there may be more than one subset of FTRs forming a closed loop containing any given FTR. Because of this possibility, it becomes fundamentally difficult to avoid arbitrary selection. The following example heuristically demonstrates the general difficulty associated with isolating offsetting subsets of FTRs.

Consider a portfolio of FTRs shown in Table 7. There are two overlapping subsets of offsetting FTRs in this portfolio. The first offsetting subset is a closed loop formed by 2 MWs each of $FTR_{A\rightarrow B}$, $FTR_{B\rightarrow C}$, $FTR_{C\rightarrow D}$ and $FTR_{D\rightarrow A}$. The second offsetting subset is another closed loop made of 2 MWs each of $FTR_{A\rightarrow C}$, $FTR_{C\rightarrow D}$ and $FTR_{D\rightarrow A}$. As apparent, 2 MWs of $FTR_{C\rightarrow D}$ and 2 MWs of $FTR_{D\rightarrow A}$ could be either included as part of the first loop or the second loop exclusively.

We need an explicit criterion to choose which subsets to consider in such situations. Prior to the discussing the merits of suitable criteria, we introduce the following useful condition that every offsetting portfolio of FTR contracts – earning a deterministic zero-payoff every hour – need to satisfy. This condition greatly simplifies our effort to isolate offsetting subsets of FTRs.

7.1 Condition for Offsetting Portfolios

Proposition

Let Π denote a set of concurrent term FTRs. Let $\mathcal{F}_{ij}$ $(\forall\ (i,j), \mathcal{F}_{ij} \geq 0)$ represent the total offset capacity (MWs) of FTRs between a directed pair of nodes i (source) and j (sink). Π is an offsetting portfolio if,

$$\sum_{j|\mathcal{F}_{ij}\in\Pi} \mathcal{F}_{ij} = \sum_{j|\mathcal{F}_{ij}\in\Pi} \mathcal{F}_{ji} \qquad \forall\, i. \tag{7.1}$$

Proof

Following 3.1, the payoff, Φ_Π, earned by the portfolio Π reads as

$$\Phi_\Pi = \sum_{(i,j)|\,\mathcal{F}_{ij}\in\Pi} \mathcal{F}_{ij} \sum_{\mathrm{t}} \left(\beta_t CC_{t,j} - \beta_t CC_{t,i}\right). \tag{7.2}$$

In 7.2, the outer summation is over every directed pair of nodes represented by for which there is at least one FTR contract within the portfolio, Π. If Π is a set of offsetting FTRs, then its payoff, Φ_Π, is zero in every hour regardless of the realized levels of the congestion components of the nodal prices. Given that $\forall\, t, \beta_t > 0$, we have,

$$\sum_{(i,j)|\,\mathcal{F}_{ij}\in\Pi} \mathcal{F}_{ij}\left(CC_{t,j} - CC_{t,i}\right) = 0 \qquad \forall\, t. \tag{7.3}$$

After breaking the summation operator and rearranging, we obtain,

$$\sum_{i|\mathcal{F}_{ij}\in\Pi} \left(CC_{t,i} \sum_{j|i,\mathcal{F}_{ij}\in\Pi} \left(\mathcal{F}_{ji} - \mathcal{F}_{ij}\right) \right) = 0 \qquad \forall\, t. \tag{7.4}$$

Since 7.4 should hold for all i and all $CC_{t,i} \in \mathbb{R}$, we therefore require,

$$\sum_{j|\mathcal{F}_{ij}\in\Pi} \mathcal{F}_{ji} - \sum_{j|\mathcal{F}_{ij}\in\Pi} \mathcal{F}_{ij} = 0 \qquad \forall\, i. \tag{7.5}$$

Q.E.D

The above condition applies to every subset of offsetting FTR contracts. However, as shown by the heuristic example, there may be no unique decomposition of the portfolio into offsetting and non-offsetting groups of FTRs. Consequently, within a given portfolio of FTRs acquired by an investor, there may be no unique assessment of the size of offsetting FTRs.

In the absence of a firm basis for identification, we consider profitability as a reasonable guiding measure for assessing the size of offsetting FTRs within the investor's portfolio. The measure is consistent with the broader objective of finding the magnitude of arbitrage profits earned by each investor. It is also consistent with the goals of profit oriented investors who are allowed to progressively plan their bidding strategies as the multi-round auction unfolds. An added advantage, perhaps the most important of all, is that this criterion combined with the linear condition facilitated by the proposition above allows us to formulate a linear optimization problem for the task of finding offsetting portfolio of FTRs.

7.2 Linear Optimization Problem

We formulate two linear optimization problems. The first problem is structured to isolate the most profitable subset of offsetting FTRs within a portfolio of FTRs bought by an investor. The second linear optimization problem is identical in all respects to the first problem except that in this problem the FTRs are not distinguished on the basis of their ownership. This problem treats all FTRs cleared in the auction as if they were purchased by one large investor. The solution of this problem is good indicator of the potential (an upper bound) for within auction arbitrage profits given the participants' revealed choice of nodes and clearing prices. The importance of this problem is due to the fact that investor-investor transactions after all of the auction rounds have been completed are not observed. Hence, additional offsetting FTRs may be acquired post-auction, but we have no way to identify final ownership. Thus, the second problem allows us to determine the maximum level of arbitrage profits given the set of FTRs that cleared.

Let, Π_p denote a portfolio of concurrent term FTR contracts owned by a investor p, the capacity (MW) of each is represented by $\overline{\mathcal{F}_{ij}^k}$ $(k \ni \mathcal{F}_{ij}^k \in \Pi_p)$ where i denotes the source node and j denotes the sink node and k is an index to distinguish FTRs with identical source-sink combination. (For any given p, $\mathcal{F}_{ij}^k \in \Pi_p$ for only some k – that is, different investors may own FTRs with the same source-sink nodes.) In addition, $\mathcal{F}_{ij}^k$ denotes the capacity (MW) of the FTR contract that is offset by other FTRs in the portfolio. Further, let MCP_{ij}^k denote the clearing price ($/MW) of the FTR with capacity $\overline{\mathcal{F}_{ij}^k}$. The solution of the following linear optimization problem represents the most profitable allocation of offsetting FTRs contained within the portfolio Π_p.

<u>L.P. 1</u>

$$z_p = \min_{\mathcal{F}_{ij}^k \in \Pi_p} \sum_{(i,j,k) \ni \mathcal{F}_{ij}^k \in \Pi_p} MCP_{ij}^k \times \mathcal{F}_{ij}^k \tag{7.6}$$

Subject to:

$$\sum_{(j,k) \ni \mathcal{F}_{ij}^k \in \Pi_p} \mathcal{F}_{ij}^k = \sum_{(j,k) \ni \mathcal{F}_{ij}^k \in \Pi_p} \mathcal{F}_{ji}^k \qquad \forall\, i, \tag{7.7}$$

$$0 \leq \mathcal{F}_{ij}^k \leq \overline{\mathcal{F}_{ij}^k} \qquad \forall\, (i,j,k) \ni \mathcal{F}_{ij}^k \in \Pi_p. \tag{7.8}$$

The objective (7.6) is to minimize the total price[12] paid by the investor to acquire the offsetting

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[12] The investor earns a arbitrage profit if the net marginal clearing price is negative.

portfolio. The first set of constraints (7.7) follows from the condition that needs to be satisfied by every offsetting subset of FTRs (proposition 7.1) and the last set of conditions (7.8) require that the capacity of the offsetting FTRs to be within that of that of their respective purchased FTRs in the portfolio. The objective z_p represents the arbitrage profit earned by the investor p.

Now consider the *potential* arbitrage profit earned by all investors. Let Π $(\Pi = \bigcup_p \Pi_p)$ denote the set of all FTRs cleared in the auction.

L.P. 2

$$z = \min_{\mathcal{F}_{ij}^k \in \Pi} \sum_{(i,j,k) \ni \mathcal{F}_{ij}^k \in \Pi} MCP_{ij}^k \times \mathcal{F}_{ij}^k \tag{7.9}$$

Subject to:

$$\sum_{(j,k) \ni \mathcal{F}_{ij}^k \in \Pi} \mathcal{F}_{ij}^k = \sum_{(j,k) \ni \mathcal{F}_{ij}^k \in \Pi} \mathcal{F}_{ji}^k \qquad \forall\, i, \tag{7.10}$$

$$0 \leq \mathcal{F}_{ij}^k \leq \overline{\mathcal{F}_{ij}^k} \qquad \forall\, (i,j,k);\ \mathcal{F}_{ij}^k \in \Pi. \tag{7.11}$$

The objective (7.9) is to minimize the total price paid by investors as a group to acquire the larger offsetting portfolio. All other constraints have the same interpretation as those of L.P. 1.

7.4 PJM Annual FTR Auctions (2005-2009)

The auction results data published by the PJM Interconnection show that every year since 2005, on average 72 investors (after accounting for affiliate relationships) participated in the FTR auction. Among the FTRs bought by each participant, the most profitable subset of FTRs is isolated by solving (7.6)-(7.8). This is repeated once for both On-Peak and Off-Peak classes of FTRs. A summary of the results are shown in Table 8A and 8B. The first three columns show the total of profitable offsetting capacity in MWs (On-Peak, Off-Peak and the total) owned by each investor. The last three columns of the table show the corresponding maximum within auction arbitrage profit earned by each investor. The results confirm that there are a few investors every year, who have profitably acquired offsetting portfolios.

The year 2007 marks an abrupt break in the trend with regard to the volume of FTRs cleared in the auction. There was nearly a 100% increase in the total volume of cleared MWs compared to 2005 and 2006 (Table 8A). This trend continued in 2008 with a slight increase in the volume of MWs cleared compared to that of 2007 (Table 8A and 8B). The year 2009 saw a considerable drop, perhaps due to the economic recession. The sizeable increase in the volume of cleared FTRs observed in 2007 is followed by a substantial increase in the total volume of profitable offsetting FTRs acquired by the investors. In 2005 and 2006, a mere 568 and 257 MWs of offsetting portfolios were acquired by investors, respectively. However in 2007 and 2008, 4,223 and 1,725 MWs of offsetting portfolios were acquired by the investors, respectively.

Summing across firms, the greatest aggregate certain profit (nearly $1.12 million) was earned in 2007, which was also the year with the highest potential profit (about $17.87 million). The sum of within auction arbitrage profit across all investors in 2009, which recorded lower participation compared to the general trend, was only $558 thousand (Table 8B). Despite the fact that the 2008 auction registered the largest sales volume of FTR contracts in MWs, a comparatively low $845 thousand was earned as within-auction arbitrage profits by individual firms (Table 8B).

Now consider the arbitrage profit that could be captured through post-auction trading. Among all the FTRs that have cleared the auction each year, the most profitable subset of FTRs is isolated by solving (7.9)-(7.11). This represents an upper-bound on the total arbitrage profits that could be earned given the cleared FTRs and their clearing prices. The results are shown in Table 9. Since 2005, every year between 3% and 5% of cleared FTRs complete a profitable offsetting combination. The year 2007 is an exception with offsetting FTRs at 9% of the cleared FTRs. The potential for arbitrage profits is approximately 1% of the total value of FTRs sold in the auction. For 2006, 2007, 2008 within auction arbitrage profits summed across firms were roughly 6 percent of the potential reported from the solutions of (7.9)-(7.11) displayed in Table 9. However in the years 2005 and 2009, the within auction arbitrage profits summed across firms were 11 percent and 16 percent of the potential including post-auction trading. In the year 2005, one investor accounts for nearly 95 percent of all the within auction arbitrage profits earned.

Another noticeable trend is that few of the roughly 72 investors acquire offsetting portfolios of FTRs in the multi-round auction – only 5 in 2005 rising steadily to 12 in 2009. In addition, the bulk of the within auction arbitrage profits are earned by a subset of these investors. This is especially true in the last three years, when five investors account for the majority of the within auction arbitrage profits earned. This may be because those investors were better positioned in terms of their network assets or simply ahead of other investors in strategizing to profitably acquire offsetting FTRs.

8. Additional Remarks

The PJM Interconnection L.L.C., the pioneer of FTR auctions, has stated "Price Discovery" as the main objective behind the choice of multi-round format (PJM Interconnection L.L.C., 2003). According to PJM's Federal Electricity Regulatory Commission filing, "Price discovery will prevent windfall bids from capturing significant levels of FTRs for an inappropriately low price" (PJM Interconnection L.L.C., 2003).

PJM's claim that the multi-round format will prevent bidders from acquiring FTRs at a too low price, suggests a belief that the information revealed in a multi-round auction format will result in higher FTR valuations than a single-round FTR auction. The information acquisition afforded by a multi-round auction is commonly offered as an explanation for its popularity in selling assets, especially for those characterized by costly value assessments (Engelbrecht-Wiggans, 1988). Olivier Compte et al. (2007) showed that the multi-round auctions, affording endogenous information pooling within the auction, generally yield higher expected seller revenue. For instance, the Federal Communications Commission (FCC) has adopted a multi-round ascending format to auction spectrum licenses (see Milgrom, 2004). At the end of every round, bids are revealed and bidders are given an opportunity to *raise* their previous bids or make new bids. Unlike FTR auctions, no licenses are sold until the end of the auction which occurs when all bidding activity ceases. Cramton (1998) argued that the success of FCC spectrum auctions is partly due to the flexibility given to the bidders to adjust bids on the basis of information revealed within the auction process. The clearing prices posted by the ISO at the end of every round in the FTR auction similarly allows the participants in the following round to refine their strategies. However, in contrast to most auctioned objects, the FTR contracts with their unique payoff and pricing structure allow for deterministic profitable trading possibilities, which may undermine any benefits possibly gained from employing a multi-round format.

9. Conclusions

A shortcoming of multi-round FTR auctions is described. The structure of payoffs associated with FTR contracts allows for the persistence of a particular within auction arbitrage profit making opportunity. An examination of PJM auction data reveals that some investors are benefiting from transactions that result in arbitrage profit. It is debatable if the size of the profits earned by investors and the potential for such profits observed in the auctions conducted by the PJM are large enough to warrant regulatory adjustments. However, it is hard to ignore the possibility that this shortcoming could be further exploited in the future. At the least, it may be beneficial to have some level of oversight to detect strategic bidding to acquire offsetting portfolios.

In addition, the potential for arbitrage profits could also be seen as an opportunity to earn profits post-auction. If the winners of the auction are willing to resell their FTRs after the auction, additional arbitrage profits could be extracted.

By modifying the auction format to a single-round, the ISO can eliminate these opportunities. However, the multi-round format is not without its benefits. As described earlier, a multi-round auction format provides an opportunity for bidders to learn about their opponents' valuations. The bidders, who positively value this opportunity, are more likely to participate in a multi-round auction compared to a single round auction. A logical progression of research in this area could be to carefully weigh the benefits associated with a multi-round format against the loss of efficiency due to the persistence of these profit-making opportunities. This analysis may require data that is currently not available in the public domain.

An alternative solution would be to allow sequential bidding, with winners declared only at the end of the auction, similar to the FCC's simultaneous multiple round auctions. In this format, the bidders would quote source, sink, MWs and prices for their choices of FTRs. The ISO would post tentative clearing prices after solving the auction revenue maximization problem subject to simultaneous feasibility condition. Unlike the current format, no sales would take place at the end of intermediate rounds. The bidders would be allowed to refine their strategies by placing a new set of bids, perhaps only bids greater than or equal to the last round's clearing prices. The process would continue for a pre-specified number of rounds or until all bidding activity ceases. All FTRs would be sold at the clearing prices emerging from the last round of the auction. Since all FTRs would be bought at a single consistent set of clearing prices, any portfolio of offsetting FTRs would clear for a total net price of $0. Similar to FCC auctions, an "activity rule," which conditions current bidding to be conditional on participation in prior rounds, could be a requirement for participation in subsequent rounds to ensure that bidders bid throughout the auction. This format, while preventing the participants from earning arbitrage profits within the auction, allows for the pooling of information, thus facilitating the PJM and other ISO's stated objective of "price discovery".

There is substantial literature regarding FTR based congestion management for conducting wholesale electric power markets, and these contracts are becoming the dominant approach to providing network users a means to hedge congestion charges. However, the auctions used to sell these contracts have not been studied to the same extent. Currently, ISOs choose a simultaneously feasible subset of FTR bids that maximize the net auction value. A thorough analysis involving the strategic behavior of the auction participants will greatly improve our understanding of these markets and potentially improve their overall efficiency.

References

Ashenfelter, O. 1989. "How Auctions Work for Wine and Art." *Journal of Economic Perspectives* 3(3):23-36.

Bonbright, J.C., A.L. Danielsen, and D.R. Kamerschen. 1961. *Principles of public utility rates*: Columbia Univ. Press.

Chao, H.-P., and S. Peck. 1996. "A Market Mechanism for Electric Power Transmission." *Journal of Regulatory Economics* 10(1):25-59.

Compte, O., and P. Jehiel. 2007. "Auctions and Information Acquisition: Sealed Bid or Dynamic Formats?" *RAND Journal of Economics* 38(2):355-372.

Cramton, P. 1998. "The Efficiency of the FCC Spectrum Auctions." *Journal of Law and Economics* 41(2):727-736.

Engelbrecht-Wiggans, R. 1988. "On a possible benefit to bid takers from using multi-stage auctions." *Management science* 34(9):1109-1120.

Hogan, W.W. 1992. "Contract Networks for Electric Power Transmission." *Journal of Regulatory Economics* 4(3):211-242.

ISO/RTO Council. 2007. *Progress of Organized Wholesale Electricity: A Summary of 2006 Market Data from 10 ISOs & RTOs*.

Market Monitoring Unit (PJM) (2008) Financial Transmission and Auction Revenue Rights, P.J.M. Interconnection L.L.C., pp. 359-404.

Milgrom, P. 2004. *Putting auction theory to work*: Churchill Lectures in Economics. Cambridge; New York and Melbourne: Cambridge University Press.

PJM Interconnection L.L.C. 2003. *Amended and restated Operating Agreement to create an annual Financial Transmission Rights auction (Docket: ER03-406-000)*: Federal Energy Regulatory Commission.

Schweppe, F.C. 1988. *Spot pricing of electricity*. Boston: Kluwer Academic.

Table 1. Independent System Operators in United States

ISO	Territory
Pennsylvania Jersey Maryland Interconnection	Pennsylvania, New Jersey, Maryland, Delaware, District of Columbia, Virginia, West Virginia and Ohio and parts of Illinois, Michigan, Indiana, Kentucky, North Carolina and Tennessee
Midwest ISO	North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Wisconsin, Illinois, Indiana, Michigan and parts of Montana, Missouri, Kentucky, and Ohio
California ISO	Most of California
ISO New England	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont
New York ISO	State of New York
ERCOT (Texas)	Most of Texas

Source: Federal Energy Regulatory Commission

Table 2. Hedging Instrument Nomenclature and Auction Format Adopted by ISOs

ISO	Current System	Hedging Instruments	Auction Format (One Year Term Contracts)
Pennsylvania Jersey Maryland Interconnection	Nodal System	Financial Transmission Right Obligations Financial Transmission Right Options	Multi-Round (4 Rounds, 25 % each round)
Midwest ISO	Nodal System	Financial Transmission Right Obligations	Multi-Round (3 Rounds, 33 % each round)
California ISO	Nodal System (since April, 1st 2009)	Congestion Revenue Right	Single Round
ISO New England	Nodal System	Financial Transmission Right	Single Round
New York ISO	Nodal System	Transmission Congestion Credit	Multi-Round (A minimum of 4 Rounds, could be reduced to fewer rounds if transmission owners agree unanimously)
ERCOT (Texas)	Zonal, (Expected switch to nodal system in 2010)	Congestion Revenue Right (in future)	

Sources: PJM Interconnection LLC. (www.pjm.com); Midwest ISO (www.mdwestiso.org); California ISO (www.caiso.com); ISO New England (www.iso-ne.com); New York ISO (www.nyiso.com); ERCOT (www.ercot.com).

Table 3. Bid Schedules Placed by a Participant for the Same FTR in PJM 2007-08 Annual FTR Auction

FTR's Source Node Name: Western Hub

FTR's Sink Node Name: Eastern Hub

Class: On-Peak

Round1		Round2		Round3		Round4	
MW	Bid ($/MW)	MW	Bid ($/MW)	MW	Bid ($/MW)	MW	Bid ($/MW)
5.0	28,606.61	5.0	28,606.61	3.5	27,906.61	5.0	26,561.02
5.0	27,761.02	5.0	27,761.02	5.0	27,761.02	7.5	25,916.02
7.5	27,011.02	7.5	27,011.02	5.0	26,561.02	7.5	25,366.02
		7.5	26,136.02	7.5	25,916.02	10.0	24,516.21
				7.5	25,366.02	10.0	23,812.02
				10.0	24,516.21	15.0	23,161.02
				10.0	23,812.02	15.0	22,506.02

Table 4. Imputing the Investor for Bids Received by the ISO for *BGE – to – WESTERN HUB – Off Peak FTR* in Round 1 of the PJM 2007-08 FTR Annual Auction

Cleared Quantities and Prices (Auction Results)				**Bids**		**Imputed**	
Cleared Bid Identity	Qty (MW)	MCP ($/MW)	Investor	Qty (MW)	Bid ($/MW)	Possible Matches	Investor
R1-1	7.8	-25,837.79	Invst. A	12.5	-25,837.8	R1-1	Invst. A
				12.5	-26,318.4		
				15	-26,783.4		
				15	-27,263.8		
				15	-27,688.4		
				15	-28,183.4		
				12.5	-28,668.4		
				12.5	-29,143.4		
				12.5	-29,843.4		
				12.5	-30,543.8		
				10	-31,338.4		
				10	-32,083.4		
				10	-32,888.4		

Source: PJM Interconnection LLC. (www.pjm.com). The bid information is released six months after the completion of the auction. The cleared information is released at the end of each round.

Table 5. Imputing the Investor for Bids Received by the ISO for *JCPL – to – BGE – Off Peak FTR* in Round 2 of the PJM 2007-08n FTR Annual Auction

Cleared Quantities and Prices (Auction Results)				**Bids**		**Imputed**	
Cleared Bid Identity	Qty (MW)	MCP ($/MW)	Investor	Qty (MW)	Bid ($/MW)	Possible Matches	Investor
R2-1	5	15,655.84	Invst. A	5	16,516.02	R2-1; R2-2	Invst. A
R2-2	5	15,655.84	Invst A	5	15,711.21	R2-1; R2-2	Invst. A
				5	14,906.02		
				7.5	14,131.02		
				7.5	13,336.21		
				7.5	12,606.02		
				10	11,811.21		
				10	11,016.02		
				10	10,211.21		
				15	9,436.21		

Source: PJM Interconnection LLC. (www.pjm.com). The bid information is released six months after the completion of the auction. The cleared information is released at the end of each round.

Table 6. Imputing the Investor for Bids Received by the ISO for *WESTERN HUB – to – JCPL – Off Peak FTR* in Round 4 of the PJM 2007-08 FTR Annual Auction

Cleared Quantities and Prices (Auction Results)				**Bids**		**Imputed**	
Cleared Bid Identity	Qty (MW)	MCP ($/MW)	Investor	Qty (MW)	Bid ($/MW)	Possible Matches for Bids	Investor
R4-1	1	5,493.41	Invst. B	100	9,480.26	R4-9; R4-10	Invst. C
R4-2	1	5,493.41	Invst. B	1	7,116.00	R4-1; R4-2	Invst. B
R4-3	7.5	5,493.41	Invst. A	5	7,066.02	R4-5; R4-5	Invst. A
R4-4	7.5	5,493.41	Invst. A	5	6,611.02	R4-5; R4-5	Invst. A
R4-5	5	5,493.41	Invst. A	1	6,404.00	R4-1; R4-2	Invst. B
R4-6	5	5,493.41	Invst. A	7.5	6,136.02	R4-3; R4-4	Invst. A
R4-7	50	5,493.41	Invst. C	50	6,115.20	R4-7; R4-8	Invst. C
R4-8	50	5,493.41	Invst. C	50	5,880.00	R4-7; R4-8	Invst. C
R4-9	100	5,493.41	Invst. C	7.5	5,661.02	R4-3; R4-4	Invst. A
R4-10	100	5,493.41	Invst. C	100	5,577.84	R4-9;R4-10	Invst. C
				10	5,211.61		
				10	4,731.02		
				50	4,704.00		
				15	4,261.61		
				50	3,897.96		
				15	3,816.02		
				50	3,528.00		
				20	3,316.02[13]		

Source: PJM Interconnection LLC. (www.pjm.com). The bid information is released six months after the completion of the auction. The cleared information is released at the end of each round.

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[13] To conserve space, other bids lower than $ 3,000, which did not clear, are not shown.

Table 7. Heuristic Example

FTR	Capacity (MW)
$FTR_{A \rightarrow B}$	3
$FTR_{B \rightarrow C}$	3
$FTR_{C \rightarrow D}$	2
$FTR_{D \rightarrow A}$	2
$FTR_{A \rightarrow C}$	2

Table 8A: Results of Applying L.P. 1: Offsetting Portfolio of Each Investor

Investor	Capacity (MW)			Profit ($)		
	Off-Peak	On-Peak	Total	Off-Peak	On-Peak	Total
2005						
Constellation Energy Group, Inc.	30	37	67	5,745	6,898	12,643
DC Energy Mid-Atlantic, LLC	207	263	470	220,053	382,640	602,692
Pepco Holding Inc.		8	8		7,500	7,500
RBS Sempra Commodities	16	6	22	2,713	1,925	4,638
Shell Energy North America (US), LP	2		2	315		315
Total	**254**	**314**	**568**	**228,826**	**398,963**	**627,789**
Auction Total	**70,656**	**78,724**	**149,380**	**344,857,358**	**497,922,773**	**842,780,131**
2006						
Black Oak Capital, LLC	2		2	13,281		13,281
Constellation Energy Group, Inc.	50	22	72	5,967	19,286	25,254
DC Energy Mid-Atlantic, LLC	26	35	60	61,113	27,577	88,690
JPMorgan Ventures Energy Corporation		2	2		89	89
PPL Energy Plus, L.L.C.	20	20	40	46,795	13,849	60,644
RBS Sempra Commodities	32	46	78	14,663	39,988	54,651
SIG Energy, LLLP	2		2	264		264
Total	**132**	**125**	**257**	**142,083**	**100,790**	**242,874**
Auction Total	**81,955**	**88,843**	**170,799**	**561,285,604**	**825,022,454**	**1,386,308,057**
2007						

330 Fund I, L.P.	138	128	266	50,167	32,800	82,967
American Electric Power Company, Inc.	617	733	1,350	79,619	152,922	232,541
Constellation Energy Group, Inc.	16	45	61	17,078	93,443	110,521
DC Energy Mid-Atlantic, LLC	22	12	34	20,858	6,761	27,619
Dominion Energy	397	734	1,132	21,134	145,664	166,798
Edison International	100		100	3,029		3,029
Galt Power Inc.	5	5	10	335	13	347
JPMorgan Ventures Energy Corporation	316	454	770	117,842	127,960	245,802
PPL Energy Plus, L.L.C.	10	10	20	2,557	4,610	7,168
Saracen Energy, LP	226	264	491	96,646	141,871	238,517
Total	**1,847**	**2,386**	**4,233**	**409,264**	**706,045**	**1,115,310**
Auction Total	**163,377**	**185,116**	**348,493**	**630,050,203**	**1,005,556,828**	**1,635,607,031**

Table 8B: Results of Applying L.P. 1: Offsetting Portfolio of Each Investor

Investor	Capacity (MW)			Profit (MW)		
	Off-Peak	On-Peak	Total	Off-Peak	On-Peak	Total
2008						
330 Fund I, L.P.	13	14	27	725	3,477	4,202
American Electric Power Company, Inc.	363	327	689	77,205	18,030	95,235
Constellation Energy Group, Inc.	29	17	46	32,816	10,861	43,676
DC Energy Mid-Atlantic, LLC	84	94	178	6,593	24,367	30,959
Dominion Energy	291		291	80,700		80,700
EPIC NJ/PA, LP	43		43	12,745		12,745
LDH Energy Funds Trading, Ltd.		90	90		15,224	15,224
Merrill Lynch Commodities, Inc.		142	142		115,914	115,914
Saracen Energy, LP	82	81	163	115,296	327,973	443,270
Solios Power LLC	40	16	56	2,939	271	3,210
Total	**944**	**781**	**1,725**	**329,019**	**516,117**	**845,136**
Auction Total	**170,074**	**178,711**	**348,784**	**1,008,420,648**	**1,411,340,098**	**2,419,760,746**
2009						
American Electric Power Company, Inc.	310	470	780	98,409	63,887	162,296
Borough of Pitcairn, Pennsylvania	2	4	6	38	376	414
City of Dowagiac, Michigan	6	5	12	717	640	1,356
DC Energy Mid-Atlantic, LLC	102		102	4,342		4,342
Dominion Energy	957	954	1,910	129,647	90,705	220,352

Galt Power Inc.	13	20	33	101	3,066	3,167
Harrison REA, Inc.	1	2	3	195	982	1,177
JPMorgan Ventures Energy Corporation	123	161	284	22,594	52,148	74,742
NRG Energy, Inc.	10	25	35	5,687	6,595	12,282
PPL Energy Plus, L.L.C.	6	6	11	9,416	4,109	13,525
Saracen Energy, LP	63	52	114	30,460	30,571	61,032
Solios Power LLC	18	14	31	792	2,988	3,780
Total	**1,615**	**1,711**	**3,325**	**302,398**	**256,066**	**558,464**
Auction Total	**138,326**	**148,313**	**286,639**	**552,415,482**	**743,771,289**	**1,296,186,772**

Table 9: Results of Applying L.P. 2: Offsetting Portfolio of All FTRs Cleared in the Auction

	Off-Peak	On-Peak	Total
2005			
Total MWs Cleared	70,656	78,724	149,380
Total Value Cleared	344,857,358	497,922,773	842,780,131
Profitable MWs	1,921	5,094	7,015
Potential for arbitrage profits	1,808,146	3,837,147	5,645,293
2006			
Total MWs Cleared	81,955	88,843	170,799
Total Value Cleared	561,285,604	825,022,454	1,386,308,057
Profitable MWs	1,922	3,139	5,061
Potential for arbitrage profits	1,777,498	2,602,966	4,380,464
2007			
Total MWs Cleared	163,377	185,116	348,493
Total Value Cleared	630,050,203	1,005,556,828	1,635,607,031
Profitable MWs	12,352	17,697	30,049
Potential for arbitrage profits	5,406,680	12,462,874	17,869,553
2008			
Total MWs Cleared	170,074	178,711	348,784
Total Value Cleared	1,008,420,648	1,411,340,098	2,419,760,746
Profitable MWs	6,392	7,771	14,163
Potential for arbitrage profits	4,726,365	9,556,546	14,282,911
2009			
Total MWs Cleared	138,326	148,313	286,639
Total Value Cleared	552,415,482	743,771,289	1,296,186,772
Profitable MWs	4,845	4,687	9,532
Potential for arbitrage profits	1,925,247	1,542,809	3,468,057