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Why have PJM capacity markets decoupled from actual capacity bids?

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ABSTRACT

We analyze PJM's Reliability Pricing Model auction in the context of ongoing reform proposals that seek to address the perception that state subsidies for carbon free generation are depressing capacity prices. We show how PJM's clearing algorithm deviates from economic theory, and conclude that in fact the capacity market construct has been inflating prices rather than depressing them.

In June, FERC issued an order clearly establishing the relationship between market clearing prices and the market clearing bid.[1] The irony is that FERC assumed there was such a relationship. The evidence suggests the opposite – that, on average, PJM's capacity auction prices are 26% greater than the market clearing bid. The situation is exacerbated by the presence of substantial market power in PJM's increasingly fragmented capacity market.

Two months earlier, two PJM experts predicted that subsidies to nuclear and renewable resource would lead to a 2% reduction in capacity prices across PJM's footprint.[2,3] The following month, prices for 2021/2022 increased everywhere in PJM other than the EMAAC distribution zone. The increases were not insignificant – the largest single geographic area saw prices nearly double, compared to the previous auction.

In Table 1, areas where prices actually increased are highlighted in green. PJM's forecasted decreases are shown in red. There is not one case where the forecasted decrease actually took place.

This paper explains why PJM's capacity pricing methodology has departed so greatly from PJM's expectations.

1. Overview

Following the 1991 deregulation of the U.S. wholesale electric markets, the U.S. has developed seven "organized" markets where prices are set by independent auctions. PJM is the largest of these markets, providing 178,563 MW of capacity to thirteen states and the District of Columbia (Fig. 1).[4]

Annually PJM conducts a capacity auction to determine capacity prices three years into the future. This auction, named the Reliability Pricing Model, is unusually complex and opaque with many layers of adjustments. The basic calculations have been difficult to trace until recent debates at the Federal Energy Regulatory Commission (FERC) have provided additional data.[5]

In recent years, a variety of states have adopted programs designed to provide subsidies for nuclear and renewable resources. The subsidies are provided in a different market – the energy market – and have caused a debate at FERC over possible impacts in PJM's capacity market.

There are three reasons why PJM's forecasts were so far from the

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[1] "64. First, we find that it is unjust and unreasonable to separate the determination of price and quantity for the sole purpose of facilitating the market participation of resources that receive out-of-market support. PJM's Capacity Repricing proposal artificially inflates the capacity market clearing price to compensate for the participation of resources receiving out-of-market support in the PJM capacity market. PJM's Capacity Repricing proposal would allow such resources to impact the market, and disconnect the determination of price and quantity – a vital market fundamental. We agree with intervenors that, by setting a clearing price that is disconnected from the price used to determine which resources receive capacity commitments, the market clearing price under Capacity Repricing will send incorrect signals, leading to greater uncertainty with respect to entry and exit decisions." Order Rejecting Proposed Tariff Revisions, Granting in Part and Denying in Part Complaint, and Instituting Proceeding Under Section 206 Of the Federal Power Act, June 29, 2018, page 29.

[2] *Affidavit of Adam J. Keech of Behalf of PJM Interconnection, L.L.C.* April 9, 2018, pp. 6-9.

[3] *Affidavit of Dr. Anthony Giacomoni on Behalf of PJM Interconnection, L.L.C.* April 9, 2018, p. 6.

[4] PJM. *PJM – At a Glance,* April 24, 2018.

[5] ISO/RTO Council, http://isorto.org.

https://doi.org/10.1016/j.tej.2019.106640

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Table 1
Comparison of PJM nuclear subsidy scenario analysis with actual BRA results.[a,b,c]

Auction Results	2020/2021 BRA results	PJM subsidy scenario	% change	2021/2022 BRA results	% change
RTO	$76.53	$75.00	-2.00%	$140.00	82.93%
MAAC	$86.04	$85.00	-1.21%	$140.00	62.72%
EMAAC	$187.87	$187.87	0.00%	$165.73	-11.78%
SWMAAC	$86.04	$85.00	-1.21%	$140.00	62.72%
PSEG	$187.87	$187.87	0.00%	$204.29	8.74%
PS-NORTH	$187.87	$187.87	0.00%	$204.29	8.74%
DPL-SOUTH	$187.87	$187.87	0.00%	$165.73	-11.78%
PEPCO	$86.04	$85.00	-1.21%	$140.00	62.72%
ATSI	$76.53	$75.00	-2.00%	$171.33	123.87%
ATSI-C	$76.53	$75.00	-2.00%	$171.33	123.87%
COMED	$188.12	$170.01	-10%	$195.55	3.95%
BGE	$86.04	$85.00	-1.21%	$200.30	132.80%
PPL	$86.04	$85.00	-1.21%	$140.00	62.72%
DAY	$76.53	$75.00	-2.00%	$140.00	82.93%
DEOK	$130.00	$130.00	0.00%	$140.00	7.69%

[a] PJM. 2020/2021 Base Residual Auction Results, May 23, 2017.
[b] Attachment 2 to Affidavit of Adam J. Keech on Behalf of PJM Interconnection, L.L.C., April 9, 2018.
[c] PJM. 2021/2022 Base Residual Auction Results, May 23, 2018.

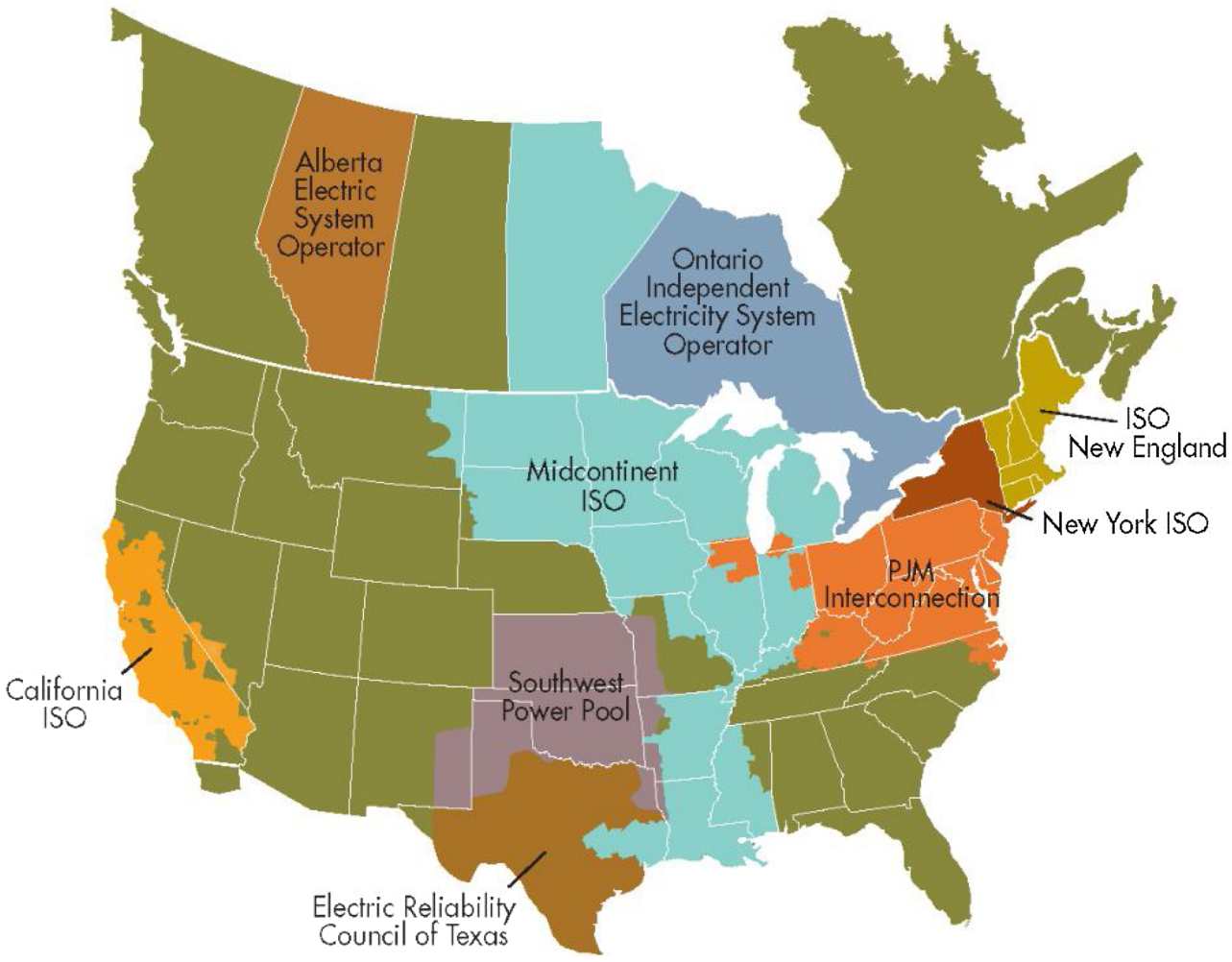

Fig. 1. Location of organized electric power market operators in North America.

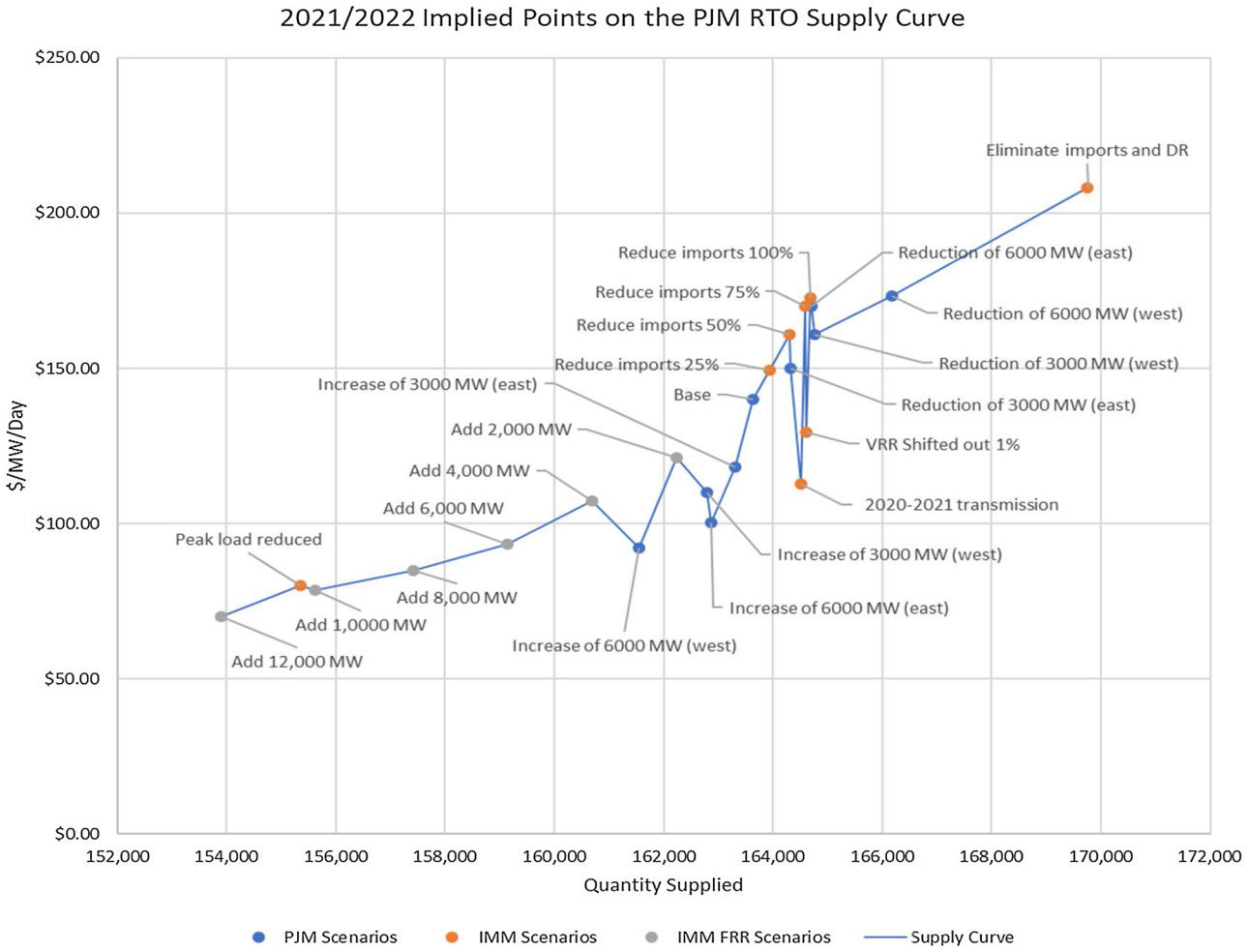

Fig. 2. Clearing Price-Quantity pairs from PJM, IMM scenario analyses.

actual results:

1 Economic theory does not agree with their basic assumption that subsidies reduce bids. In addition, the subsidies addressed by the PJM affidavits were for energy – not capacity.
2 A number of PJM's markets are characterized by strong degrees of market power. Northern Illinois, for example, is dominated by one bidder who comprises 42% of the market, and the top three generators together control 73% of the local generation.
3 The computer algorithm that sets capacity prices in PJM is deeply flawed and sets prices 26%, on average, above the market clearing bid.

The most surprising result of the studies prepared this summer by the Independent Market Monitor (IMM) and the PJM staff is the loose relationship between PJM's capacity supply and resource clearing prices in the RPM auction.

Supply curves slope upwards to the right, signifying that more supply is offered at higher prices. In PJM, increasing supply often increases the market clearing price. This leads to the somewhat sawtooth effect of PJM's capacity supply curve shown in Fig. 2.[6,7,8]

Overall, the materials provided in the course of the debate over and investigation into the Minimum Offer Price Rule (MOPR) provide an explanation for the wildly erratic changes in PJM capacity prices (Fig. 3).[9]

Logically, capacity prices should reflect the technology of new resources and relative scarcity or surplus of capacity relative to peak loads. In the case of PJM's ComEd zone, portions of the same power plant experience prices in PJM that are twenty times as high as the auction result for the neighboring ISO.[10]

2. Economic theory

The most basic chart used in the teaching of economics is the supply and demand chart drawn on the board by multitudes of professors over the past two hundred years. Fig. 4 below shows the chart from Alfred Marshall's *Principles of Economics* published in 1890.

Economic theory holds that the optimal market outcome is at point **A** in Alfred Marshall's graph above, where the amount supplied equals the amount demanded. PJM has largely dismissed this with an alternative theory – held, to the best of my research – only at PJM. In their formulation, **A** is dispensed with and the most efficient outcome is found by maximizing the area between the demand curve and the

[6] PJM. *2021/2022 RPM Base Residual Auction Results*, May 23, 2018.
[7] IMM. *Analysis of the 2021/2022 RPM Base Residual Auction*, August 24, 2018.
[8] IMM. *MOPR/FRR Sensitivity Analyses of the 2021/2022 RPM Base Residual Auction*, August 26, 2018.
[9] FERC Docket No. EL18-178.
[10] In the Midcontinent Independent System Operator auction, the Quad Cities nuclear station received a capacity price of $10/MW/Day. This compares to the PJM price for the remainder of the same unit at $195.55/MW/Day. Cook, Amanda. *MISO Clears at $10/MW-day in 2018/19 Capacity Auction* RTO Insider, April 12, 2018.

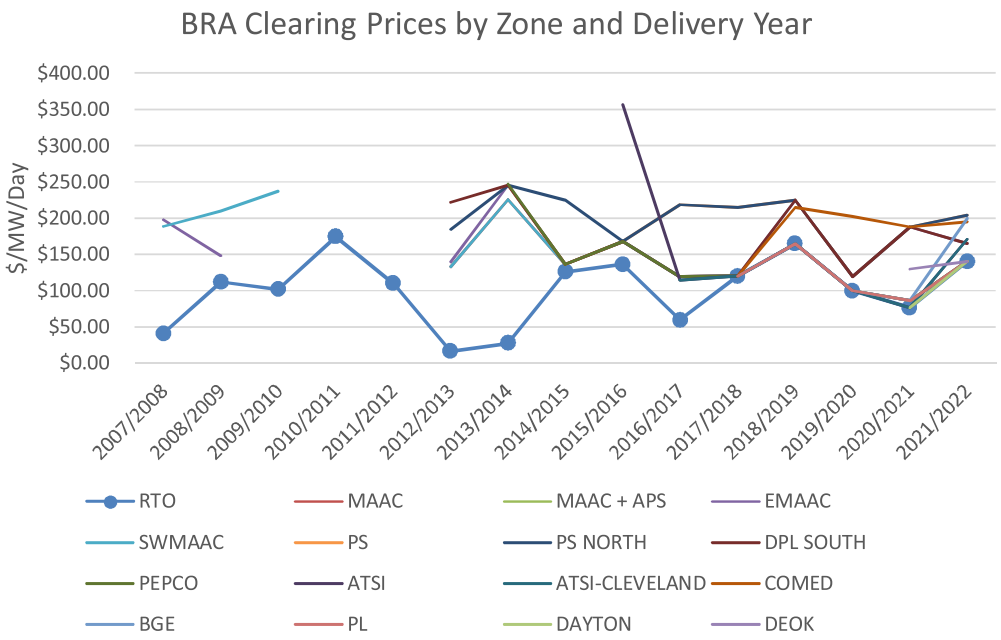

Fig. 3. History of BRA Prices.

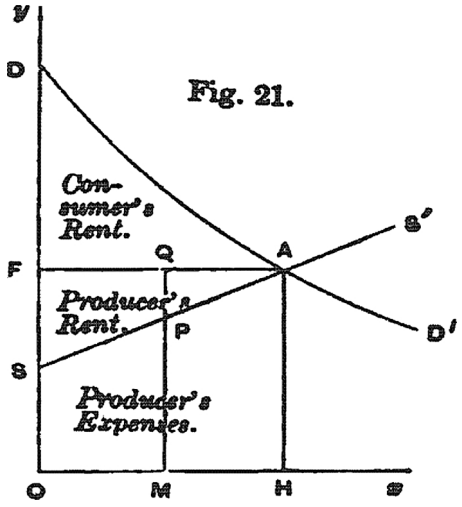

Fig. 4. Marshall's supply and demand curves in a competitive market.

supply curve. In the language of more modern texts, they are maximizing the producer and consumer surplus. In the simple example above, the outcome is the same – maximizing rents gives the same answer as adopting the standard rule that markets should settle where demand equals supply.[11],[12],[13]

Unfortunately, PJM did not stop there. PJM has allowed its algorithm to juggle components of the supply curve in order to find the largest producer and consumer surplus area. There is no easy proof that this is an efficient outcome. In fact, the juggling activity necessarily produces prices higher than **A** and quantities that may or may not be surplus or deficient to consumer needs.

As discussed below, important parts of the algorithm are undocumented. Two aspects of the algorithm can have a major impact on outcomes. First, if the algorithm determines that reaching point **A** is inappropriate, it will simply choose to stop at a point to the left of **A** which I have marked in red as **A′**.

In this case the algorithm has determined that stopping short of the standard economic solution is appropriate, leading to a smaller quantity supplied than consumers would prefer at a significantly higher price – **A′**. This is referred to as a "vertical line" solution since the price is determined by a vertical line drawn upwards from the last allowed bid (Fig. 5).

Alternatively, the algorithm can choose to purchase more capacity than required by the demand curve. In this case the algorithm determines that the best solution is to purchase more capacity than is required which I have marked in red as **A″**.

This adjustment is called "make whole". The price impact of "make whole" is the cost of the unneeded supply allocated over all of the consumers in the zone (Fig. 6).

Neither of these adjustments can be found in any textbook, nor are they consistent with any prevailing economic theories. The most recent PJM Capacity Market manual states:

> In the PJM Region, the basis for the Capacity Market design is the Reliability Pricing Model (RPM). The goal of RPM is to align

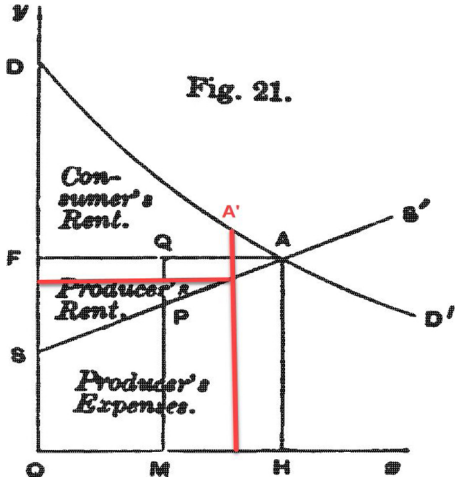

Fig. 5. The "vertical line" solution, adapted from Marshall, PJM.

[11] Alfred Marshall, *Principles of Economics*, 1890, p. 429.

[12] Please note that "Fig. 21" reflects the caption from Professor Marshall's original textbook.

[13] Professor Marshall used the term "consumer's rent" and "producer's rent" with same meaning as our current terminology.

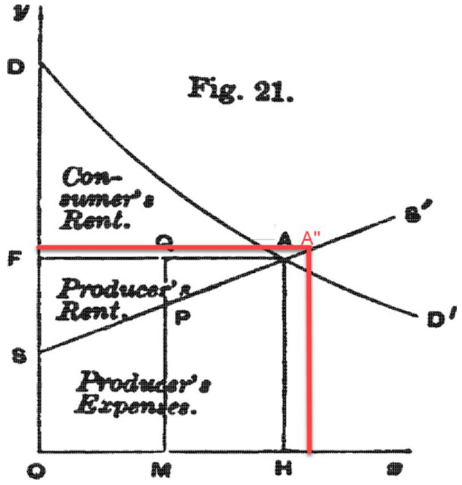

Fig. 6. The "make whole" solution, adapted from Marshall, PJM.

capacity pricing with system reliability requirements and to provide transparent information to all market participants far enough in advance for actionable response to the information.[14]

Economists would put this more simply. Price signals are used to guide future investment and consumption decisions. The current algorithm reflects a degree of the demand and supply information market participants need to guide future investment and operation decisions. Unfortunately, the RPM then veers from that goal by introducing extraneous factors in the attempt to solve bidding issues that are not germane to the basic goal, and that arise as artifacts introduced by RPM's designers.[15]

3. Market power

When one market participant has 42% of the zonal generation and the top three generators together control 73% of the local generation, as is the case in the ComEd zone, the local market is highly concentrated. The Hirschfield-Herfindahl Index (HHI) for the Northern Illinois capacity market is calculated at 2347.[16]

The PJM market monitor has identified potential market power and competition issues within the PJM capacity market yearly since the introduction of the Reliability Pricing Model in 2007.[17]

If market power was not present, we would have expected a significant decline in RPM prices in 2021/2022 given major changes in the Northern Illinois capacity market. The three major changes were: reduction in the federal corporate tax rate under the Tax Cuts & Jobs Act; the ICC Order 17-0333 dated 09/11/2017 implementing the Future Energy Jobs Act and approving "zero emissions credits" for two Exelon nuclear units in PJM; and the approval of several upgrades of transmission capacity into Northern Illinois, planned to be in service for the 2021/2022 delivery year.[18],[19],[20]

The outcome was actually the opposite to the forecasts from the PJM experts—in spite of significant cost reductions and the expansion of alternatives, the price in the ComEd zone increased from $188.12/MW/Day to $195.55/MW/Day.

Exelon's 10,168 MW of unforced capacity are pivotal to the market.[21] It is impossible for Northern Illinois to meet its reliability requirements without Exelon's fleet of nuclear plants. Most importantly, the specific cost of any one of the plants is effectively irrelevant since four to five of those plants are required to meet the zone's reliability requirements. In a case like this, the impact of the ZEC revenues on the Quad Cities units is irrelevant to the outcome, because Quad Cities' bids are set in reference to a revenue maximizing, portfolio bidding strategy and not based on the marginal costs or individual revenues of each plant in isolation.

The chart in Fig. 7 below shows my reconstruction of the ComEd Zone supply curve in the 2021/2022 Base Residual Auction.

The demand curve in Fig. 7 has been taken from the market monitor's revised Analysis of the 2021/2022 RPM Base Residual Auction.[22] Transfers from other PJM zones have been netted from the demand curve, following the approach taken by the Independent Market Monitor. Specific bid prices and quantities have been inferred from materials published by Exelon, PJM, and the Independent Market Monitor.[23],[24],[25]

Exelon, being the pivotal supplier, submits bids from its Illinois portfolio of 10,168 MW.[26] Exelon's May 24, press release identified the marginal plant as Byron. Absent other adjustments, the clearing price in the auction would reflect the Byron bid. Since Exelon's portfolio determines the market price, the actual bid for Quad Cities has no impact on the outcome. Quad Cities' capacity revenues will be set by the marginal Exelon resource. Exelon can also determine which plants will clear and which will not. In the 2020/2021 auction, Byron and Dresden cleared at a lower price.[27] In the current auction, Quad Cities cleared

[14] PJM. *Manual 18: PJM Capacity Market Revision: 40, PJM Capacity Market Operations*, February 22, 2018, p. 15.

[15] We have been unable to find source documents supporting these artifacts as the next section discusses in detail

[16] The U.S. Department of Justice Antitrust Division website states: "agencies generally consider markets in which the HHI is between 1,500 and 2,500 points to be moderately concentrated, and consider markets in which the HHI is in excess of 2,500 points to be highly concentrated." https://www.justice.gov/atr/herfindahl-hirschman-index.

[17] Independent Market Monitor for PJM (IMM): IMM, *PJM State of the Market 2007*, p. 228; IMM, *PJM State of the Market 2008*, p. 249; IMM, *PJM State of the Market 2009*, p. 299; IMM, *2010 State of the Market Report for PJM*, p. 351; IMM, *2011 State of the Market Report for PJM,* p. 85; IMM, *2012 State of the Market Report for PJM,* p. 129; IMM, *2013 State of the Market Report for PJM*, p. 157; IMM, *2014 State of the Market Report for PJM,* p. 179; IMM, *2015 State of the Market Report for PJM,* p. 185; IMM, *2016 State of the Market Report for PJM,* p. 213; IMM, *2017 State of the Market Report for PJM,* p. 233; & IMM, *PJM State of the Market 2018*, p. 258.

[18] Tax Cuts and Jobs Act of 2017, Pub L. No. 115-97, 131 Stat. 2054.

[19] PJM Transmission Expansion Advisory Committee Market Efficiency Update, August 10, 2017 https://www.pjm.com/-/media/committees-groups/committees/teac/20170810/20170810-teac-market-efficiency-update.ashx.

[20] Illinois Power Agency, Petition for Approval of the IPA's Zero Emission Standard Procurement Plan pursu-ant to Section 1-75(d-5)(1)(C) of the Illinois Power Agency Act, ICC Docket 17-0333, available at: https://www.icc.illinois.gov/docket/files.aspx?no=17-0333&docId=256557; see also https://www2.illinois.gov/sites/ipa/Pages/Prior_Approved_Plans.aspx.

[21] Unforced capacity or UCAP is the commodity transacted in the RPM Auctions. UCAP is an adjustment to ICAP or installed (nameplate) capacity that is defined by the PJM Glossary as UCAP = ICAP * (1 – EFORd) where EFORd is the Equivalent Forced Outage Rate for a specific generating unit based on its historical performance, or a class average such rate when unit-specific data is unavailable. The stated value has been inferred from PJM's 2021-2022 RPM Resource Model dated February 1, 2018, and from class average EFORd rates published online through PJM's Data Miner 2 (Equivalent Forced Outage Rates – Monthly) for years 2014-2017.

[22] Analysis of the 2021/2022 RPM Base Residual Auction, Independent Market Monitor for PJM, August 24, 2018, page 131.

[23] Exelon Announces Outcome of 2021/2022 PJM Capacity Auction, Exelon, May 24, 2018.

[24] 2021/2022 RPM Base Residual Auction Results, PJM, May 23, 2018.

[25] Analysis of the 2021/2022 RPM Base Residual Auction, Independent Market Monitor for PJM, August 24, 2018.

[26] The stated value has been inferred from PJM's 2021-2022 RPM Resource Model dated February 1, 2018, and from class average EFORd rates published online through PJM's Data Miner 2 (Equivalent Forced Outage Rates – Monthly) for years 2014-2017.

[27] Exelon Announces Outcome of 2020/2021 PJM Capacity Auction, Exelon,

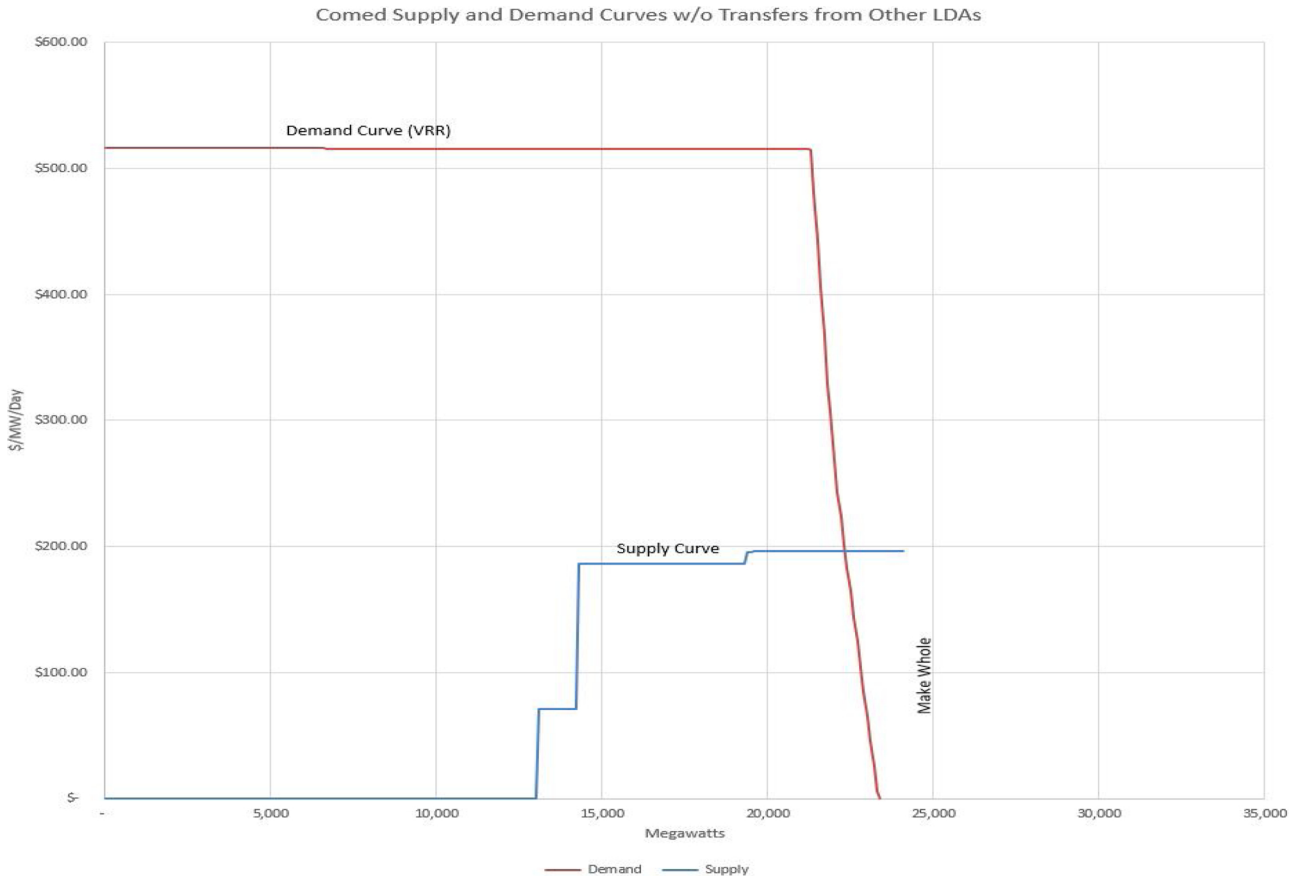

Fig. 7. ComEd Supply and Demand.

but Dresden did not clear even though the market clearing price increased in the most recent auction, and again, a portion of Byron cleared.

Exelon could have submitted bids based on its net Avoidable Cost Rate. This was analyzed by the Independent Market Monitor who concluded that the market clearing price would have fallen to $130.04/MW/Day had their offers been capped at net ACR.[28] This would not have been a rational choice for Exelon since a very small increase in its quantity cleared in the auction would not have offset the significantly lower clearing price.

4. PJM's computer algorithm

The PJM web site contains an eleven-year-old description of the algorithm lacking significant structural components and lacking updates for the past eleven years of regulatory changes approved by the FERC.[29] The document admits its deficiencies at the outset:

> Some of the logic employed in the optimization such as Flexible Self-Scheduling, Tie-Breaking, and Make-Whole, is not discussed in this document as the intent is to explain the core formulation.[30]

After several discussions with PJM, it is apparent that the PJM staff do not have a copy of the full specification of the algorithm. Moreover, there is some evidence that their understanding of the algorithm may be inconsistent with a detailed review of the scenarios released by PJM and the Independent Market Monitor.[31,32]

Although the 2007 summary is missing a number of critical details, the single most important missing component is the section that would explain how and when the algorithm "skips over" components of the supply curve. In submitting a bid, each resource can be entered as one to ten independent parts of the resource. Each part can be entered as "flexible" or "inflexible". This bidding process only involves a decision by a bidder today to break a single indivisible power plant into random components and label some parts as normal bids (flexible) and label other parts as "take it or leave it" (inflexible).

The determination that a specific bid's quantity is inflexible is not a true market signal. This determination provides no guidance for investors trying to determine the location of a new factory or a new power plant. In three years, when the auction prices take effect, investment decisions can be sized efficiently in the real world to meet a variety of requirements – fuel, location, transmission and others, if accurate market signals are given.

How does the algorithm determine which bids should clear and which should not? This important issue is not specified in PJM's filings. Normally, we would return to standard economic theory and make a determination based on the concepts of producer and consumer surplus:

In the chart above, a bid is considered by the algorithm that has the correct price for inclusion in the solution, but it has been marked as "inflexible". The algorithm would normally consider the gains to the producer – the green triangle – versus the costs to consumers – the red

(*footnote continued*)
May 24, 2017.

[28] Analysis of the 2021/2022 RPM Base Residual Auction, Independent Market Monitor for PJM, August 24, 2018, page 118.

[29] PJM. *Base Residual Auction Optimization Formulation*, December 12, 2007.

[30] PJM. *Base Residual Auction Optimization Formulation*, December 12, 2007.

[31] PJM. *Scenario Analysis for 2021/2022 Base Residual Auction*, September 4, 2018.

[32] IMM. *MOPR/FRR Sensitivity Analyses of the 2021/2022 RPM Base Residual Auction*, September 26, 2018.

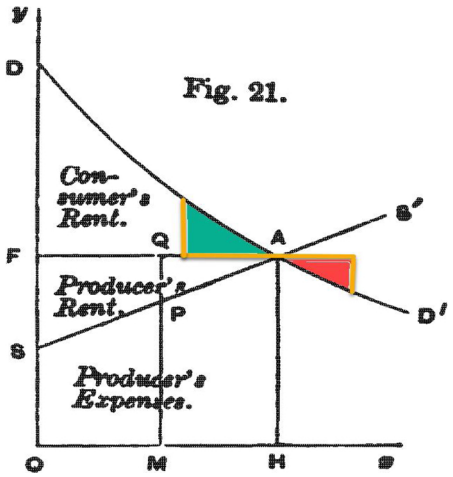

Fig. 8. The decision rule used when the marginal resource is an "inflexible" sell offer.

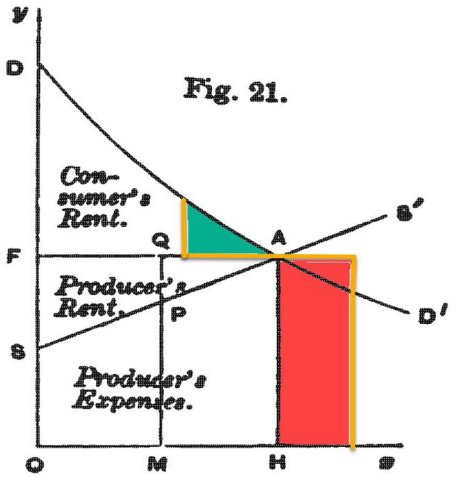

Fig. 9. Alternative decision rule for a marginal inflexible sell offer, as described by PJM.

triangle. If the costs to the consumer are greater than the gains to the producer, then the bid is rejected and the supply curve considers alternative bids that the algorithm finds more attractive. If the cost to the consumer is less than the benefit to the producer, the bid is accepted (Fig. 8).

This approach is the approach that the staff at McCullough Research considered most consistent with economic theory. In deconstructing the various scenarios, we found that this formulation provided the closest match to the reported results. We were surprised to find that in our discussions and emails with PJM that they have an alternative approach (Fig. 9).

The PJM alternative turns out to be very important.[33] This has a dramatic impact on clearing prices determined by the algorithm – increasing them from 11% to 26%. The mainstream economic approach roughly will reject inflexible bids one half of the time and accept inflexible bids the rest of the time. PJM's approach will almost always reject the inflexible bid because the cost to the consumer is overstated. If the bid is rejected, then the prices are determined by "clearing the auction at the higher-priced point on the Variable Resource Requirement Curve that corresponds to the Unforced Capacity provided by all Sell Offers located entirely below the Variable Resource Requirement Curve."[34] The tariff language describes the point where a vertical line drawn from the last acceptable bid intersects the demand curve, as shown in Fig. 5 above.[35]

Like many other undocumented features of the PJM algorithm, this would seem to reflect a programmer's decision that has not been presented to or approved by FERC.[36] We have modeled both options using the Monte Carlo method of random experiments. This approach was pioneered at the Manhattan Project during the Second World War in order to model nuclear reactions using the relatively primitive computers of the era. Today, it is easy to build a Monte Carlo model of the capacity market in Northern Illinois.

The first step is to estimate the likely bid quantities based on data provide by PJM. There is some uncertainty in this approach which is one of the reasons why a Monte Carlo model is appropriate. Our Monte Carlo model runs 100,000 different simulations (commonly referred to as "games") of the ComEd zone using random bid prices. Once the bid quantities and prices are arranged in a supply curve, the first candidate bid is analyzed to see whether it will be accepted as a "make whole" resource or rejected and the next most optimal resource should be considered. If a "make whole" resource is not selected, then the model calculates the "vertical line" solution.[37,38]

Our Monte Carlo results indicate that application of traditional economic theory produces results that are 12% higher than results that would be obtained if the clearing prices was simply set to the price where the supply curve intercepts the demand curve. Alternatively, if PJM's assumptions concerning the optimal decision to skip over the marginal resource and revert to the vertical line are used, this results in substantially higher prices – 26% higher than the price where the demand curve crosses the supply curve.

The optimization approach consistent with economic theory shows that PJM's clearing method results in a margin over competitive prices of 12.9% with a 95% confidence interval between 12.79% and 13.08% (Fig. 10).

It is easy to run the same 100,000 set of simulations with PJM's alternate theory of how the algorithm decides which bids are "make whole" or "vertical line" clearing-price solutions. The results from our model of Northern Illinois indicate that if PJM's description of the model is correct, capacity prices on average are 26% higher than the offer prices of the marginal resource meeting the demand curve, due primarily to the "vertical line" solutions (Fig. 11).

The Monte Carlo model also allows us to evaluate the relevance of a minimum offer on the distribution of prices in the ComEd Zone. The probability that market clearing prices will ever fall low enough to be affected by minimum offer rules is itself minimal, as can be seen in the histogram of results (Fig. 12).

A reconstruction of the supply and demand curves in RPM and their

[33] Email from PJM to McCullough Research dated October 18, 2018.

[34] Conduct of RPM Base Residual Auctions, PJM Open Access Transmission Tariff, Attachment DD.5.12(a).

[35] The problems do not stop here. The process is intrinsically iterative – one exclusion may well trigger another and so on. Normal optimization techniques handle such problems poorly and frequently fail to find optimal solutions. There is some evidence from the IMM and PJM scenarios that this is the case with the RPM algorithm.

[36] In attempting to understand the algorithm we started with Sections 5.12, Conduct of RPM Auctions, and Section 5.14, Clearing Prices and Charges, of the PJM tariff. We also searched the seventy-nine documents referenced in the web site for these sections. We also reviewed the PJM Capacity Market Manual and the 2007 description of the PJM algorithm.

[37] It should be noted that if the marginal bidder selects inflexible bids – an optimal choice in almost all cases – the clearing prices are always equal to or higher than the prices that would be calculated if bids were "flexible."

[38] A third alternative where the demand curve intersects the supply curve between two steps in the supply curve occurs approximately 5% of the time. In this case, we have followed standard economic theory and set the price equal to the intersection between the demand curve and the vertical line connecting the two bids. It is unknown what the PJM algorithm does in this case.

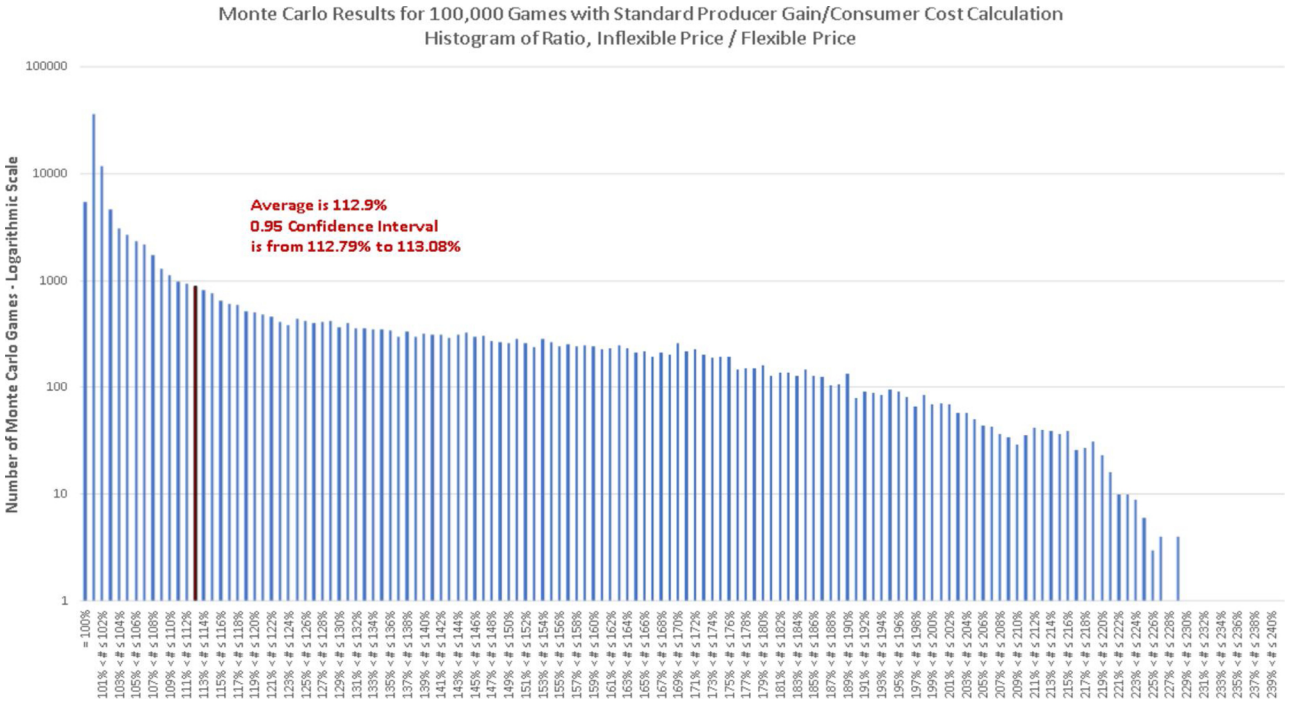

Fig. 10. Monte Carlo results under standard inflexible offer decision rule.

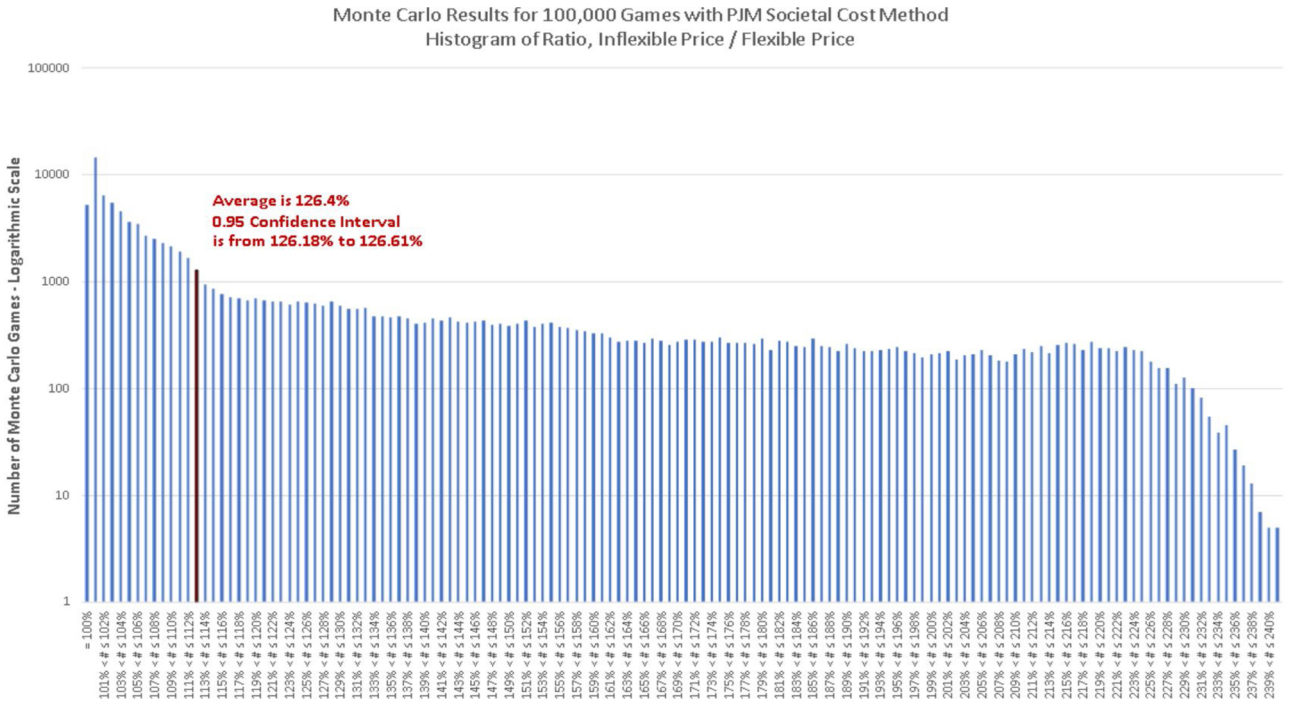

Fig. 11. Monte Carlo results under PJM alternative inflexible offer decision rule.

relation to auction clearing prices further illustrates the problem with PJM's approach. The chart in Fig. 13 shows our reconstruction of the supply and demand curves in the 2021/2022 Base Residual Auction, compared to the same set of scenarios from the previous Fig. 2.

There is an old Enron exploit designed to raise payments to reliability must-run plants. Originally practiced in Texas, it has been rediscovered (or perhaps simply reemployed by traders moving from one employer to another) in other areas. The exploit is relatively simple. The owner of the reliability must-run unit issues bids or dispatch instructions designed to place the unit offline just before it will be needed in the next period. Bringing the unit from standby to full operation triggers additional payments to the unit when it is actually needed to preserve system stability.

The inflexible option can be utilized in a roughly parallel fashion. Even if a specific bidder may not control a large percentage of the total market, any sufficiently large percentage can allow the bidder to set the marginal bid. If the bid is not selected by the algorithm, the bidder will lose the marginal bid but gain the benefit of the vertical line up to the demand curve for other units it owns that did clear the auction. In the previous example above, the marginal bid would have been rejected by

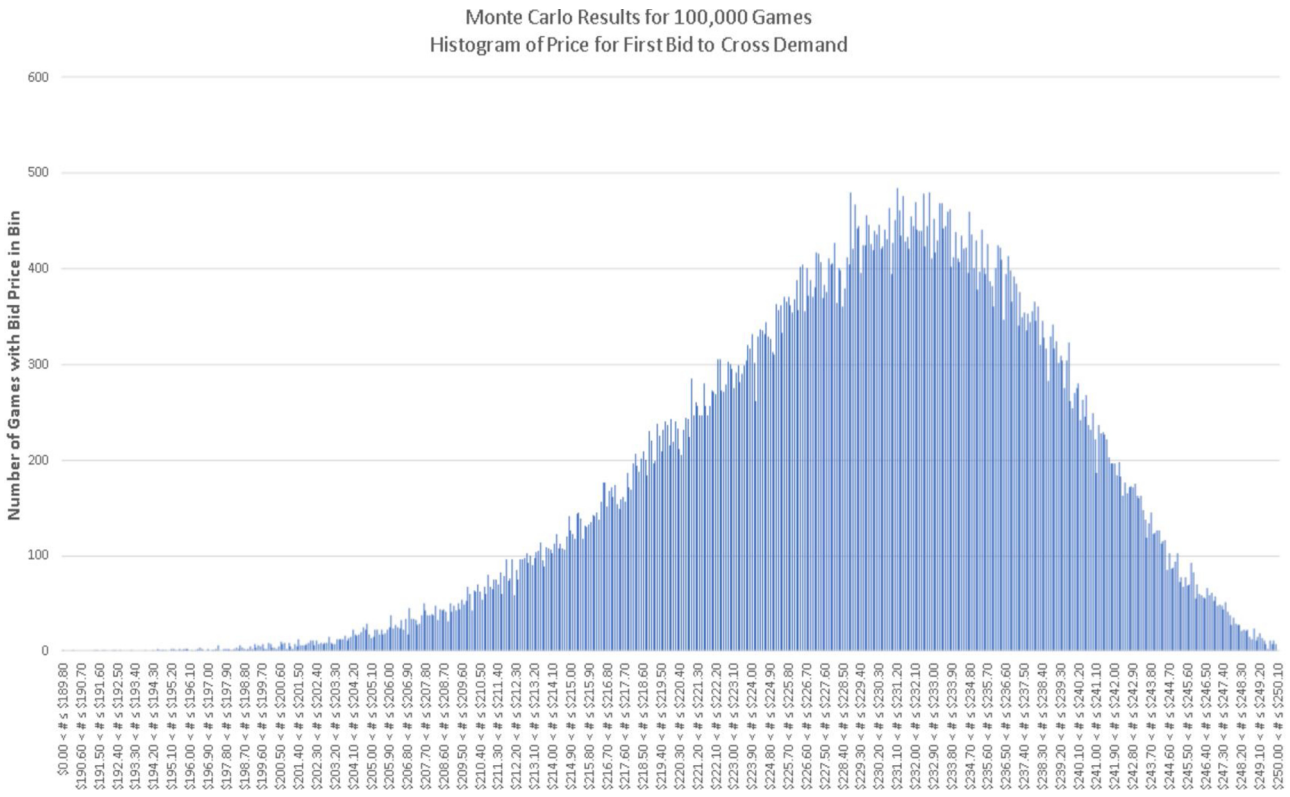

Fig. 12. Monte Carlo distribution of marginal resource offer prices.

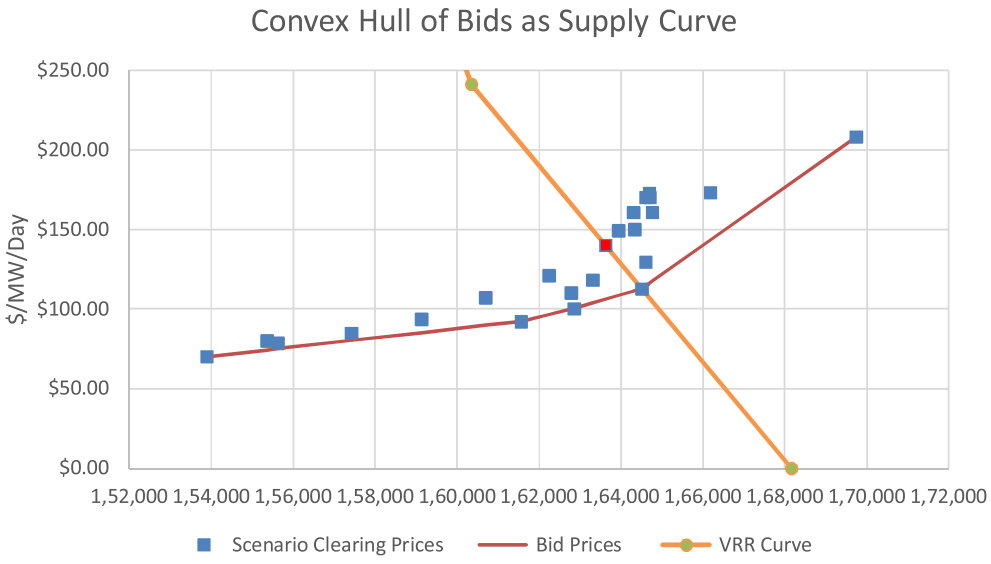

Fig. 13. Scenario analyses of PJM, IMM compared to imputed supply curve.

the PJM calculation of net benefits. Once rejected, the price increases to **A′** (Fig. 14).

The bidder will lose the revenues from the marginal bid, but will gain the difference between **A′** and **A** on all of its remaining resources. Since the slope of the demand curve is often quite steep, this is a profit-maximizing strategy in many cases.

This strategy is not available to all participants. First, the bidder must have the technical resources to accurately forecast the supply curve. This may be difficult for the large RTO Zone, but it is not terribly difficult for the smaller zones – especially when individual bidders comprise a larger share of the entire supply curve. Second, there is enough uncertainty in the supply curve that the inflexible bid must be large enough to fail the algorithm optimization regardless of possible errors in their forecast. Luckily for the possible bidder, the remote chance that the bid is actually accepted still confers benefits since in that case the bidder will receive "make whole" payments from PJM.

Price leadership has both rewards and penalties. Currently, Saudi Arabia has been forced to curtail oil production to offset burgeoning supplies from U.S. and Canadian producers. This is an optimal strategy for Saudi Arabia since keeping high prices on part of its capacity is better than lower prices on all of its oil production capacity. Like Saudi Arabia, Exelon can limit its participation in the market to maintain higher prices on some of its capacity rather than accept lower prices on all of its capacity.

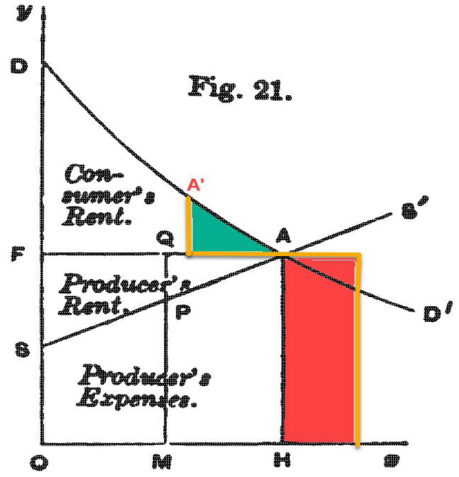

Fig. 14. An inflexible marginal offer gives rise to a "vertical line" solution and price increase.

The FRR option set out by FERC poses similar risks. Northern Illinois currently has one supplier whose market share is more than sufficient to set the clearing price. If the current dominant bidder retires from the capacity market using the FRR option, it is not at all clear that the remaining market participants will make the same bids and that prices will fall.

Notwithstanding other issues, the reality of the PJM capacity market is that market power is not the exception. While Northern Illinois is a worst-case location for competitive outcomes, a number of major companies possess substantial market power in specific PJM capacity zones. PJM's willingness to continue to "calve off" portions of their region into smaller Locational Delivery Areas, or zones, reduces the technical obstacles to forecasting specific supply curves. It also magnifies the influence of specific companies in ever smaller regions.

In the case of the ComEd Zone, elimination of Exelon's market power – either through the Fixed Resource Requirement (FRR) option for all of Exelon's nuclear units or through a ceiling on nuclear bids low enough to reduce imports of capacity from the RTO Zone – does not reduce the problem of market power.

The IMM has an interesting scenario in its August analysis where all of PJM's nuclear units are bid at $0/MW/Day in the 2021/2022 Auction. In Scenario 20, prices crash in the ComEd Zone, falling from $195.55/MW/Day to $71.48/MW/Day (Fig. 15).

The flaw in this optimistic analysis is the assumption that the elimination of the market leader would leave all other bids unchanged. The removal of the pivotal bidder and the potential crash of capacity prices by $124.07/MW/Day would be a life and death market event for the remaining market participants. It is unlikely – very unlikely – that the loss of the market price leader would not affect the remaining market participants' bidding strategy.

If Exelon were removed from the market through an FRR or some other mechanism, three firms would control 70% of the remaining capacity in Northern Illinois. They would face exactly the same decision that Exelon faced in the 2021/2022 auction:

Option A: Act jointly or individually as market leaders; or,

Option B: Lower their bids to displace imports from the RTO Zone.

Their decision will depend on the value of market bid cap adopted

		Actual Auction Results		All Nuclear Offers at $0 per MW-day	
LDA	Product Type	Clearing Prices ($ per MW-day)	Cleared UCAP (MW)	Clearing Prices ($ per MW-day)	Cleared UCAP (MW)
RTO	Annual	$140.00	162,911.8	$71.48	165,256.7
	Summer	$140.00	715.5	$71.48	587.6
	Winter	$140.00	715.5	$71.48	587.6
RTO Total			163,627.3		165,844.3
ATSI	Annual	$171.33	8,007.3	$71.48	8,603.4
	Summer	$171.33	6.3	$71.48	6.2
	Winter	$171.33	0.0	$71.48	0.0
ATSI Total			8,007.3		8,603.4
EMAAC	Annual	$165.73	29,287.5	$125.94	29,597.6
	Summer	$165.73	88.0	$125.94	86.7
	Winter	$165.73	1.0	$125.94	1.0
EMAAC Total			29,288.5		29,598.6
PSEG	Annual	$204.29	5,366.6	$204.29	5,366.6
	Summer	$204.29	9.3	$204.29	9.2
	Winter	$204.29	1.0	$204.29	1.0
PSEG Total			5,367.6		5,367.6
BGE	Annual	$200.30	1,937.7	$200.30	1,937.7
	Summer	$200.30	85.0	$200.30	83.5
	Winter	$200.30	0.0	$200.30	0.0
BGE Total			1,937.7		1,937.7
ComEd	Annual	$195.55	22,083.6	$71.48	24,345.0
	Summer	$195.55	274.5	$71.48	154.4
	Winter	$195.55	274.5	$71.48	268.2
ComEd Total			22,358.1		24,499.4
DEOK	Annual	$140.00	2,733.3	$128.47	2,636.3
	Summer	$140.00	25.4	$128.47	24.9
	Winter	$140.00	0.0	$128.47	0.0
DEOK Total			2,733.3		2,636.3

Fig. 15. IMM Analysis of 2021/2022 BRA.

by PJM (currently Net CONE x B) and the market participants' sense of the tolerance of FERC, anti-trust authorities, and the IMM to accept "counter intuitive" market outcomes. As in the 2021/2022 Auction, it is quite possible that prices would increase if Northern Illinois capacity sellers pursue Option A. The one thing that would not enter their calculations would be the existence of an expanded MOPR.

5. Conclusion

When PJM predicted state subsidies for energy would lower capacity prices and the opposite happened, this forecasting error presented a teachable moment about the role these kinds of organized markets have played in the organized capacity markets.

PJM's assumptions about the effects of these subsides deviates from economic theory. Therefore, PJM does not provide a true competitive market. PJM's markets are characterized by strong degrees of market power. The computer algorithm that sets capacity prices in PJM is deeply flawed, setting prices 26%, on average, above the market clearing bid.

Rather than worrying about prices being too low, FERC should open the window into PJM's opaque capacity auctions and illuminate the troubling peculiarities that bias the results against the interests of consumers.