Exactly how inefficient is the PJM capacity Market?

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ABSTRACT

A common feature of electricity markets is the need to assure an appropriate amount of generating capacity to satisfy demand at any given moment. Some regional markets hold a capacity auction which compensates generation facilities for providing power at some point in the future. These auctions are intended to efficiently price capacity via competitive bidding. However, the Pennsylvania-New Jersey-Maryland Interconnection (PJM) regional transmission organization (RTO) has been in litigation before the Federal Energy Regulatory Commission (FERC) over high prices and a lack of competition in their annual capacity market auctions. A peculiar feature of the PJM RTO is its segmented capacity market, where pivotal suppliers have successfully petitioned to separate from the larger market and create captive Locational Deliverability Areas (LDAs) in which they have a dominant market share. We analyze the competitiveness of the market, the growing capacity margins, as well as the PJM LDA market concentration via Hirschfield-Herfindahl Index (HHI), 4-Firm Concentration Ratio (CR_4) and Three-Pivotal-Supplier (TPS) test. We find that many LDAs do not operate competitively and have a pivotal supplier with market power, able to set prices unilaterally. In addition, we find that although reserve margins are inordinately high in the PJM market, they are rising along with prices, an outcome that is only seen in monopolistic markets.

1. Introduction

PJM's capacity market has frequently suffered from wild swings in capacity prices. The most recent auction saw a steep climb of 28 % although the North American Electric Reliability Corporation (NERC) is forecasting that PJM's capacity margin will reach 70 % in 2024. When a market has both high prices and a massive surplus, it is commonly described as inefficient.

2. Minimum offer price rule

On December 19, 2019, FERC finally issued an order in the lengthy Minimum Offer Price Rule (MOPR) case.[1] The debate concern was initiated in a filing by Calpine objecting to potentially low capacity bids in PJM's capacity market. December's order is unlikely to end the debate since FERC has already received over fifty rehearing requests.

In FERC's current order, they "protect" competition by placing a minimum bid requirement on resources who are receiving revenues under state sponsored Zero Emission Credit (ZEC) and Renewable Portfolio Standards (RPS) programs. For example, a nuclear plant owner receiving state level energy subsidies would be prevented from offering low prices in the capacity market. Application of the new rule may well extend to a variety of other state sponsored programs as well.

Commissioner Glick's dissent is well worth reading. His summary of the problem argues that the new order is designed to raise prices and delay the replacement of vintage generating units with more efficient technology:

3. The order amounts to a multi-billion-dollar-per-year rate hike for PJM customers, which will grow with each passing year. It will increase both the capacity price in the Base Residual Auction as well as the already extensive quantity of redundant capacity in PJM. It is a bailout, plain and simple.

4. The order will also ossify the current resource mix. It is carefully calibrated to give existing resources a leg up over new entrants and to force states to bear enormous costs for exercising the authority Congress reserved to the states when it enacted the Federal Power Act (FPA). States throughout the PJM region are increasingly addressing the externalities of electricity generation, including the biggest externality of them all, anthropogenic climate change. We all know what is going on here: The costs imposed by today's order and the ubiquitous

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preferences given to existing resources are a transparent attempt to handicap those state actions and slow—or maybe even stop—the transition to a clean energy future.[2]

The proposed order plans to keep capacity prices high in the face of new technologies and climate change policies. The order is based on a fundamental theory that capacity prices are lower when energy revenues increase. As renewables displace more expensive vintage technologies, capacity is becoming more valuable, not less. The two leading renewable technologies are non-dispatchable intermittent resources. To make them viable choices requires investments in battery backup systems and simple cycle gas turbines. The unsubstantiated assumption that they will lower the value of capacity needs to be examined closely by experts – a step that FERC has not addressed.

The last point is worth repeating since the assumptions in the order stand in stark contrast to the actual data. In spite of the adoption of a variety of state level programs, capacity prices in PJM have been increasing – sharply – in recent capacity auctions.

How has the PJM capacity market become so inefficient – combining rising prices with highly excessive reserve margins?

3. Capacity auctions

On July 25, 2019, FERC prevented PJM from running their annual capacity market auction in August of 2019. The issue of the 2019 auction (known officially as the 2022–2023 Auction, as the capacity is bid ahead three years) has been unaddressed by FERC for the past seven months. The decision that PJM should not run their auction in August was probably a relief to all participants – since those who wanted the auction feared lower prices and those who opposed the auction feared a continuation of rising prices.

FERC concluded:

In rendering this determination, we take into account considerations such as the magnitude of the tariff process at issue–the BRA, a major feature of the PJM market–and the corresponding interest of market participants who make resource investment and retirement decisions based on price signals. We recognize the importance of sending price signals sufficiently in advance of delivery to allow for resource investment decisions. However, we believe that in the circumstances presented here, on balance, delaying the auction until the Commission establishes a replacement rate will provide greater certainty to the market than conducting the auction under the existing rules.[3]

The specter of lower prices was raised in two PJM studies authored by Adam Keech and Dr. Anthony Giacomoni.[4],[5] Their argument in a nutshell was that nuclear and coal subsidies in the energy market would reduce the bids of the subsidized units in PJM's capacity market. The economic logic of their prediction was not borne out in the following auction where the overall level of capacity prices increased significantly for the majority of the sub-zones.

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

Overall, PJM capacity prices increased 28 % between the 2020/ 2021 the 2021–2022 Auctions, but some areas increased by as much as 132.8 %.

The PJM market is complicated. The basic structure starts with

secret bids, a secret and undocumented algorithm for resolving the bids, and a multitude of adjustments.

We have previously discussed the basic foundational problems – market power and the undocumented market algorithm.[6] We also authored a paper in Electricity Journal that discussed these issues in more detail.[7] Simply stated, the algorithm that sets market prices is idiosyncratic. Depending on the bids from major market participants, increased supplies can (and do) increase prices. Decreased supplies can (and do) decrease prices.

4. Reserve margins

A more fundamental problem exists, however. PJM is responsible for administering the capacity auction. The North American Electric Reliability Corporation (NERC) is responsible for guaranteeing the reliability of the electric system for the U.S. as a whole and the footprint of PJM, in particular.

The following chart shows NERC's forecast of reserve margins for PJM. According to NERC, prospective reserve margins will reach 70 % by 2024 – approximately four times the required level of reserves (Table 2).

While PJM's capacity auction indicates an increasing level of scarcity, NERC's studies indicate a massive surplus. In fact, the surplus is so massive that it is unprecedented in NERC's footprint (Fig. 1).

The combination of rapidly increasing reserve margins and rapidly increasing prices indicates that PJM's capacity market is inefficient – it is setting non-competitive prices at an increasingly frequent rate (Fig. 2):

The prospective reserve margin, calculated by NERC, has increased from 30 % in the 2015/2016 margin to 70 % in 2023/2024. The reference margin set by NERC is just over 15 %, less than a quarter of the 2023/2024 prospective margin. While everyone benefits from the additional reliability, the additional cost has increased significantly.

5. Market power

At the heart of the problem is the increasingly segmented capacity market. Every few years, PJM has permitted a pivotal supplier to separate from the larger RTO market and build a captive market in which it has a dominant market share.

Determining market captivity is relatively simple. A reasonably accurate analysis of market share can be calculated by cross-referencing the generating plants in PJM's RPM auction Resource Model with EIA Form 860 data, financial reports and trade press releases, to determine each facility's parent company.[8],[9] From that information, a number of industry standard metrics for market concentration can be calculated.

Below is a table of each Locational Deliverability Area (LDA) and the year they separated from the market. In addition, the market's current HHI and the concentration ratio of the largest 4 firms (CR$_4$) are calculated for each LDA (Table 3).

Herfindahl-Hirschman Index (HHI) is an industry standard measure for market concentration. HHI is calculated as the sum of the squared market share of each competing firm. Values above 1800 suggest a highly concentrated market, potentially impeding competitive behavior.[10]

HHI is a newer method of measuring concentration of the entire

[2] FERC, *Order Establishing Just and Reasonable Rate: Commissioner Glick Dissent.* Issued December 19, 2019, pg. 2.

[3] FERC, *Order on Motion for Supplemental Clarification.* Issued July 25, 2019.

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

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

[6] McCullough Research, *Why Have PJM Capacity Markets Decoupled from Actual Capacity Bids*, Dec 10, 2018

[7] Robert McCullough et al., *Why Have PJM Capacity Markets Decoupled from Actual Capacity Bids, Electricity Journal, Nov 2019.*

[8] PJM, *Capacity Market (Reliability Pricing Model)*, Delivery Years 2022/2023, https://www.pjm.com/markets-and-operations/rpm.aspx.

[9] EIA, *Form EIA-860 detailed data with previous form data (EIA-860A/860B)*, 2018, https://www.eia.gov/electricity/data/eia860/.

[10] Monitoring Analytics, LLC, 2020.

Table 1

Comparison of PJM nuclear subsidy scenario analysis with actual BRA results. (For interpretation of the references to colour in this Table legend, the reader is referred to the web version of this article)

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%

Source: Constructed using PJM, 2020/2021 Base Residual Auction Results, May 23, 2017 - Attachment 2 to Affidavit of Adam J. Keech on Behalf of PJM Interconnection, L.L.C., April 9, 2018 - PJM. 2021/2022 Base Residual Auction Results, May 23, 2018.
Description: Areas where prices increased are highlighted in green. PJM's forecasted decreases are shown in red in column four. There is not one case where the forecasted decrease actually took place.

Table 2

Reserve Margin Forecast for PJM.

Demand, Resources and Reserve Margins (MW)										
Quantity	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Total Internal Demand	150,870	151,547	152,253	152,854	153,435	153,988	154,494	155,107	155,891	156,689
Demand Response	9,127	9,118	9,178	9,198	9,243	9,280	9,315	9,343	9,387	9,433
Net Internal Demand	141,743	142,429	143,075	143,656	144,192	144,708	145,179	145,764	146,504	147,256
Additions: Tier 1	13,694	17,907	19,180	19,180	19,180	19,180	19,180	19,180	19,180	19,180
Additions: Tier 2	15,253	23,657	41,021	46,570	50,133	50,379	50,800	50,878	51,042	51,042
Additions: Tier 3	0	0	0	0	0	0	0	0	0	0
Net Firm Capacity Transfers	1,412	1,3601360	0	0	0	0	0	0	0	0
Existing-Certain and Net Firm Transfers	183,935	180,439	174,429	174,429	174,429	174,429	174,429	174,429	174,429	174,429
Anticipated Reserve Margin (%)	39.43 %	39.26 %	35.32 %	34.77 %	34.27 %	33.79 %	33.36 %	32.82 %	32.15 %	31.48 %
Prospective Reserve Margin (%)	50.19 %	55.87 %	64.94 %	68.14 %	69.98 %	69.55 %	69.29 %	68.66 %	67.92 %	67.06 %
Reference Margin Level (%)	15.90 %	15.80 %	15.70 %	15.70 %	15.70 %	15.70 %	15.70 %	15.70 %	15.70 %	15.70 %

Source: NERC, 2019 Long-Term Reliability Assessment, December 2019, pg. 74.
Description: This table shows NERC's forecast of reserve margins for PJM. According to NERC, prospective reserve margins will reach 70 % by 2024 – nearly five times the required level of reserves.

market. CR_4 is the classic method which measures only the market share of four firms. Higher values are considered Oligopolistic.

In this case, HHI values for each individual LDA are above 2000, the average is over 2500, and two are nearly 3000. The CR_4 for each is similarly high. This indicates that by separating these LDAs from RTO, PJM has created highly concentrated sub-markets.

Another simple metric for market power is whether any one supplier has over 20 % market share. The chart below shows the concentration of market share in the Northern Illinois LDA, ComEd.[11] One company, Exelon, is the dominant entity with 42 % market share (Fig. 3).

Similarly, one parent company, FirstEnergy, holds the majority of the market share for ATSI with 50 % of the market under their control; five (5) times the next largest firm, and as much market share as all other competitors combined.

In general, high market concentration does not bode well, but it doesn't necessarily mean there is no competition. However, capacity

auctions operate differently than many markets. If the reserve capacity is not filled, the auction does not clear, and the entire system risks losing power in times of high demand. This implies that if there exists any one supplier, or combination of suppliers that can pull out of the auction and cause the reserve capacity to not be met, they are considered "pivotal suppliers" and have an amount of market power. They are price makers instead of price takers.

In practice, this means that in the ComEd LDA, Exelon is assured that some portion of their capacity will be accepted in the auction regardless of how high their bid is. A corollary of the situation is that no possible combination of bids by smaller competitors can dislodge Exelon's capacity from being included in the auction's result.

The conventional industry standard metric for determining if there exists a pivotal supplier is the Three Pivotal Supplier (TPS) test.[12] PJM uses the TPS test in their energy markets as a way of determining whether market mitigation is necessary, but also uses the test for

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[11] Not to be mistaken for Commonwealth Edison, a subsidiary of Exelon, often shortened to ComEd

[12] Page 5. https://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2018/2018-som-pjm-volume2.pdf.
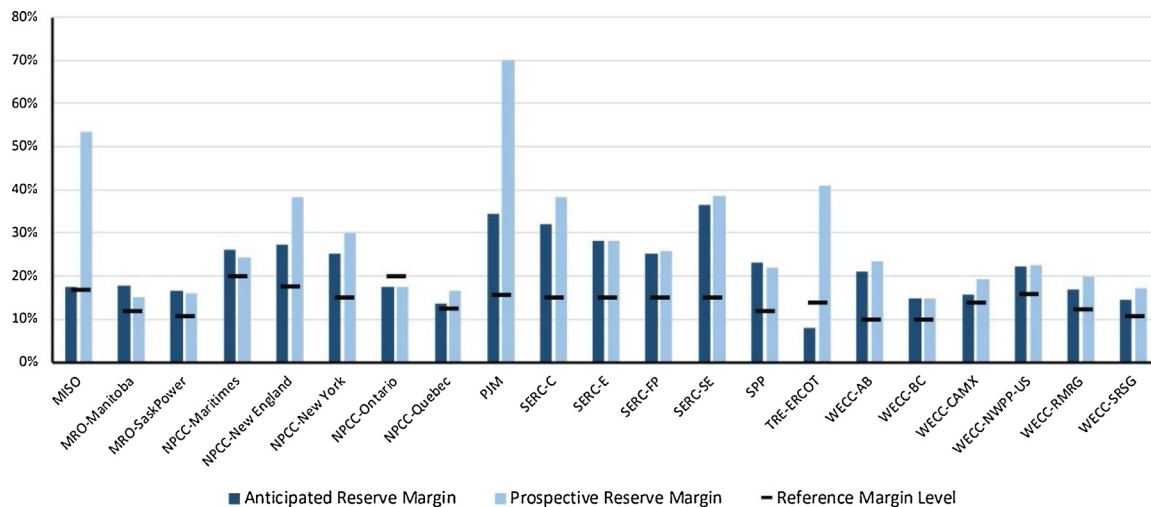
Fig. 1. Anticipated and Prospective Reserve Margins for 2023 Peak by Assessment Area.
Source: NERC, *2019 Long-Term Reliability Assessment,* December 2019, pg. 11
Description: NERC's studies indicate a surplus of prospective capacity for the PJM market. The reference margin determined by NERC is 15 %, prospective margins are 70 %.
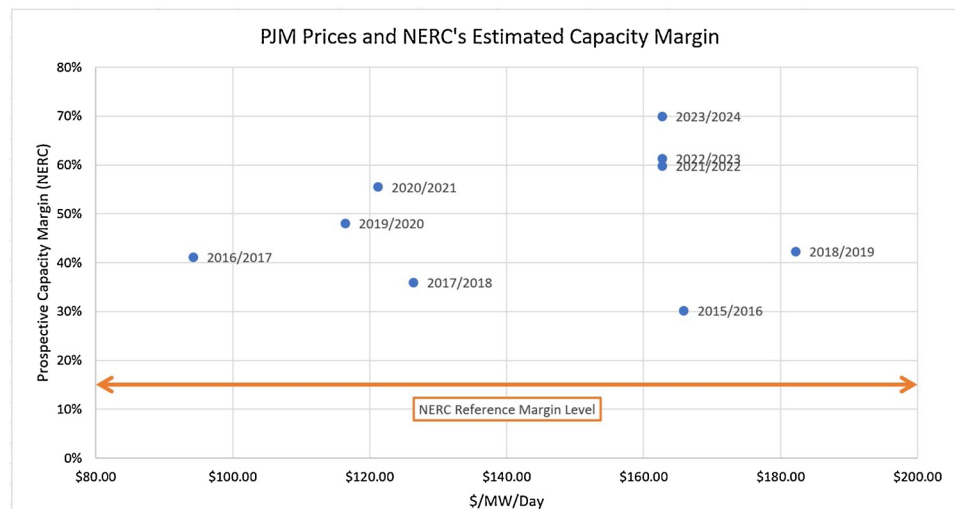

Fig. 2. PJM Capacity Reserve Margins and Prices – 2015-2022.
Source: Data Sourced from *NERC-Long Term Reliability Assessment-2019*
Description: The reference margin set by NERC is just over 15 %. The PJM reserve margin has increased from 30 % in the 2015/2016 margin to 70 % in 2023/2024, nearly five times the reference margin.

Table 3
LDAs, Capacity Price, HHI and 4-Firm Concentration Ratio.

PJM Capacity Price Auction				
LDA	**Entered Auction**	**Current HHI**	**Capacity Price**	**Top 4 CR**
PSEG	2009 − 2010	2999.11	$204.29	87.03
BGE	2014	2539.02	$203.89	98.00
ComEd	2014	2284.22	$195.55	76.01
ATSI	2012 − 2013	2873.90	$171.33	76.34
EMAAC	2009	2179.96	$165.73	64.95

Source: Constructed from Form EIA-860 (2018) and PJM Capacity Market (RPM), Delivery Years 2022/2023.
Description: This table shows PJM Locational Deliverability Areas (LDA) and the year they separated from the RTO market and entered the auction as independent sub-markets. In addition, the current Herfindahl-Hirschman Index (HHI) and the concentration ratio of the largest 4 firms (CR_4) are calculated for each LDA.

capacity markets.[13] If any one firm fails the test, it is automatically subjected by PJM to price caps due to its potential for exercising market power. Monitoring Analytics provides the TPS calculation procedure in their publication, *Overview of the Three Pivotal Supplier Test.*[14]

The formula is below (Fig. 4).

The TPS calculation takes the total quantity offered by all suppliers, subtracts the largest suppliers, then divides by the demand in the market served.[15]

The table below shows the results of a TPS test for each LDA. Results

[13] Page 118 https://www.pjm.com/~/media/documents/manuals/m18.ashx.
[14] Monitoring Analytics, Overview of the Three Pivotal Supplier Test, 2015. https://www.pjm.com/~/media/committees-groups/task-forces/gofstf/20150722/20150722-item-02-imm-tps-education.ashx.
[15] As previously noted, capacity markets are slightly different. For this metric, demand is the reliability requirement, but supply must incorporate CETL, DR and EE. CETL is the transmission limit for imported energy. DR is Demand Response resources, metered load that can be reduced on demand (offered into RPM auctions as capacity). EE is Energy Efficiency resources, projects which reduce load demanded due to efficiency increases (also offered in the RPM auction as capacity).
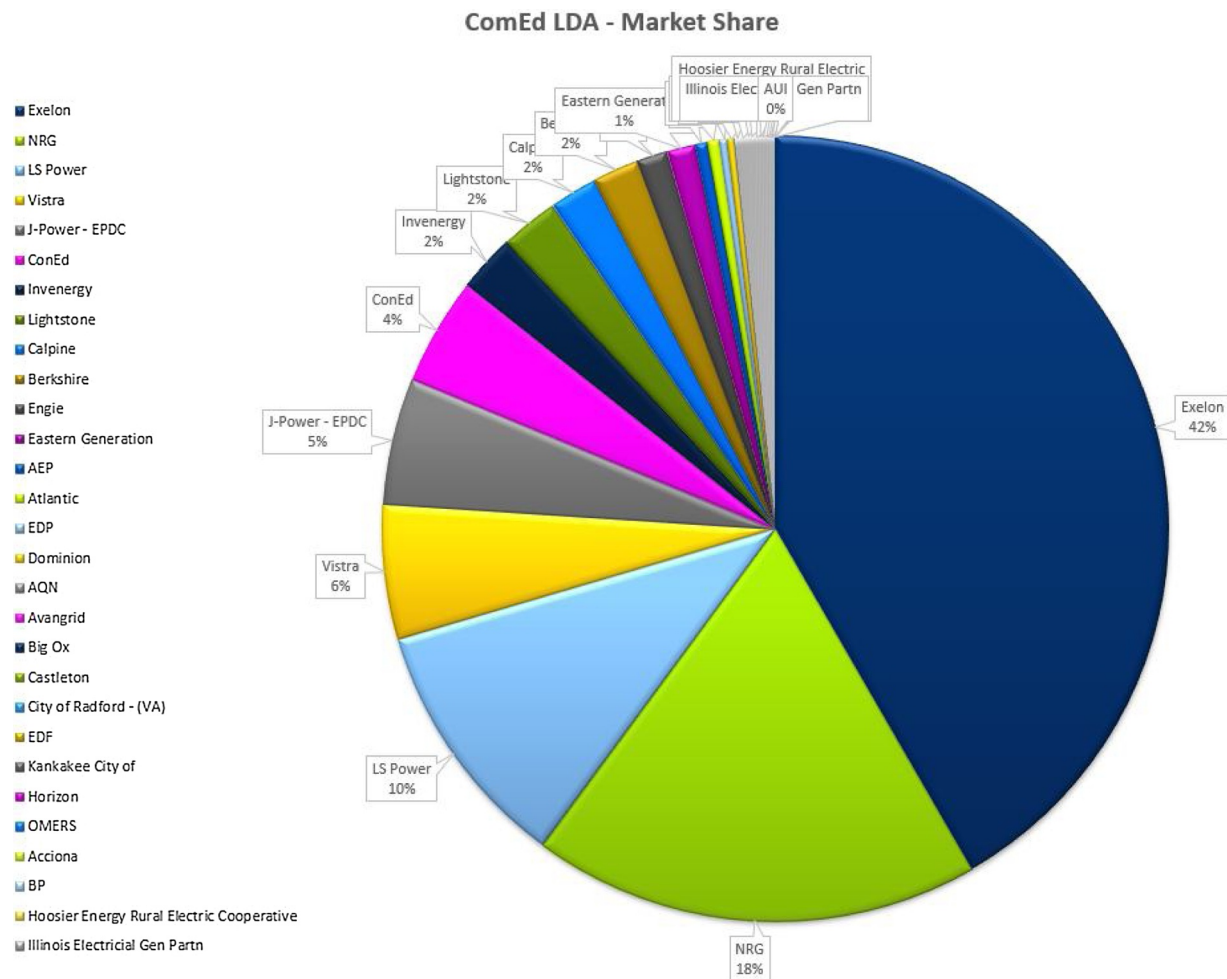
ComEd LDA - Market Share

Fig. 3. Market Share of ComEd Parent Companies.
Source: Constructed using data sourced from *Form* EIA-860 (2018) and *PJM Capacity Market (RPM), Reliability Pricing Model.*
Description: Depicts the concentration of market share in the Northern Illinois LDA, ComEd. One company, Exelon, is the dominant entity with 42 % market share.
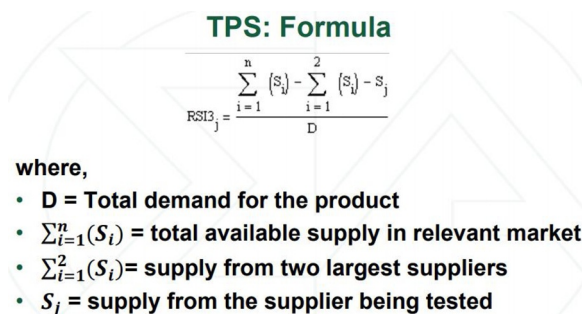
TPS: Formula

$$RSI3_j = \frac{\sum\limits_{i=1}^{n} (S_i) - \sum\limits_{i=1}^{2} (S_i) - S_j}{D}$$

where,

- **D = Total demand for the product**
- $\sum_{i=1}^{n}(S_i)$ = **total available supply in relevant market**
- $\sum_{i=1}^{2}(S_i)$= **supply from two largest suppliers**
- S_j = **supply from the supplier being tested**

Fig. 4. Three-Pivotal Supplier (TPS) formula.
Source: Monitoring Analytics, *Overview of the Three Pivotal Supplier Test*, 2015, Page 4. https://www.pjm.com/~/media/committees-groups/task-forces/gofstf/20150722/20150722-item-02-imm-tps-education.ashx
Description: The TPS calculation takes the total quantity offered by all suppliers, subtracts the largest suppliers, then divides by the demand in the market served.

Table 4
Pivotal Supplier Test Results. (For interpretation of the references to colour in this Table legend, the reader is referred to the web version of this article)

TPS Test	Three Pivotal	One Pivotal
PSEG	0.79	0.96
BGE	0.09	1.13
ComEd	0.64	0.93
ATSI	0.97	1.09
EMAAC	0.66	0.80

Source: Constructed from Form EIA-860 (2018) and PJM Capacity Market (RPM), Delivery Years 2022/2023.
Description: The test statistic is a ratio of how much capacity is offered to what is demanded. Offered capacity excludes the three firms with the most market share, and the firm with the highest market share respectively. Thus, values over one (1) indicate there is a surplus of capacity offered (PASS), while values below one (1) indicate there is a shortage of capacity offered (FAIL). A shortage of capacity gives pivotal suppliers market the power to set prices.

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[16] The test statistic is a ratio of what is offered and what is demanded, thus values over one (1) indicate there is a surplus of capacity offered (PASS), while values below one (1) indicate there is a shortage of capacity offered (FAIL).

[17] The largest four (4) suppliers provide 98% of the electricity in BGE. The remaining 2% is generated by three (3) additional suppliers.

highlighted in red indicate the existence of pivotal suppliers (Table 4).[16]

All LDAs fail the Three Pivotal Supplier test, with BGE failing by an astonishing amount.[17] Additionally, COMED, EMAAC and its sub-LDA, PSEG, fail the One Pivotal test when only the single largest supplier is removed from the auction, indicating that supplier is pivotal. In this case, the pivotal supplier for those three LDAs is the same company, Exelon, with market shares of 42 %, 44 % and 48 %, respectively.[18]

While all suppliers must submit a bid in the capacity market, a pivotal supplier can structure its bid to exercise economic withholding by simply pricing some of its capacity out of the market. Without their capacity the auction would not clear, so their bid automatically becomes the auction clearing price.

6. Conclusion

The bottom line is clear. The balkanization of the PJM capacity market has increased market concentration over the past decade by removing the majority of PJM's capacity from competition. Instead of a competitive market where supplies across PJM are used to meet capacity needs, a variety of smaller auction areas have been created where one supplier has massive market power as measured by a simple market share analysis, the Herfindahl-Hirschman Index, and the TPS test. In at least three of these areas, a single market participant is pivotal and able to set the market price directly by economic withholding.

The result is the astonishing situation where NERC is forecasting a 70 % reserve margin while auction prices continue to increase. Such a result runs contrary to a competitive marketplace and is indicative of malfunctioning price signals. In a competitive market, surplus capacity would cause prices to fall and signal firms to exit the market. In PJM's LDAs, not only is more and more capacity being built, market prices continue to rise. The only markets in which both surplus and prices rise, are monopolistic.

Declaration of Competing Interest

The authors report no declarations of interest.

References

McCullough, R., Shierman, E., Weisdorf, M., Howard, B.M., 2019. Why have PJM capacity markets decoupled from actual capacity bids? Electr. J. 32 (9) 106640.

Monitoring Analytics, 2015. Overview of the Three Pivotal Supplier Test. https://www.pjm.com/~/media/committees-groups/task-forces/gofstf/20150722/20150722-item-02-imm-tps-education.ashx.

Monitoring Analytics, LLC State of the Market Report for PJM, Volume 2: Detailed Analysis. https://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2018/2018-som-pjm-volume2.pdf.

NERC, 2019. Long-Term Reliability Assessment. December 2019. https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2019.pdf.

PJM RPM Resource Model. Delivery Years 2022/2023. https://www.pjm.com/markets-and-operations/rpm.aspx.

Further reading

EIA, 2018. Form EIA-860 detailed data with previous form data (EIA-860A/860B). https://www.eia.gov/electricity/data/eia860/.

FERC, Order on Motion for Supplemental Clarification, Docket Nos. EL16-49-000 and EL18-178-000 (Consolidated). Issued July 25, 2019. https://www.ferc.gov/CalendarFiles/20190725135527-EL16-49-000.pdf.

FERC, Order Establishing Just and Reasonable Rate. Docket Nos. EL16-49-000 and EL18-178-000 (Consolidated). Issued December 19, 2019. https://www.ferc.gov/whats-new/comm-meet/2019/121919/E-1.pdf.

PJM, 2020/2021 Base Residual Auction Results. May 23, 2017. https://www.pjm.com/~/media/markets-ops/rpm/rpm-auction-info/2020-2021-base-residual-auction-report.ashx.

PJM, Affidavit of Adam J. Keech on Behalf of PJM Interconnection, L.L.C. April 9, 2018, pp. 6–9. https://www.pjm.com/~/media/documents/ferc/filings/2017/20170508-el17-62-000.ashx.

PJM, Affidavit of Dr. Anthony Giacomoni on Behalf of PJM Interconnection, L.L.C. April 9, 2018. https://pjm.com/-/media/documents/ferc/filings/2018/20180212-el18-34-000.ashx.

PJM, 2021/2022 Base Residual Auction Results. May 23, 2018. https://www.pjm.com/-/media/markets-ops/rpm/rpm-auction-info/2021-2022/2021-2022-base-residual-auction-report.ashx.

PJM, Manual 18: PJM Capacity Market. Revision: 44. Effective Date: December 5, 2019. https://www.pjm.com/~/media/documents/manuals/m18.ashx.

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Jean-Carl Ende is a graduate student at Portland State University pursuing a Master's degree in Urban Economics along with a graduate certificate in econometrics and data analysis. His interests include institutional economics and the history of economic thought, quantitative and spatial analysis, environmental resource management, urban economics and public policy, and the effects of climate change on population geography. He holds Bachelor's degrees in Quantitative Economics and Social Science with minors in Geography and Political Economy.

Aiman Absar holds a B.A. in Economics and Mathematics from Reed College. His interests include Behavioral and Experimental Economics, Market development in emerging economies, Game Theory and it's applications in computer science.

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[16] The test statistic is a ratio of what is offered and what is demanded, thus values over one (1) indicate there is a surplus of capacity offered (PASS), while values below one (1) indicate there is a shortage of capacity offered (FAIL).

[17] The largest four (4) suppliers provide 98% of the electricity in BGE. The remaining 2% is generated by three (3) additional suppliers.

[18] The remaining LDAs, BGE and ATSI, pass the TPS test with the largest two suppliers removed, but not the largest three. These suppliers a considered to be "jointly pivotal". The iterative TPS calculation to determine which suppliers are jointly pivotal can continue, removing the largest two and the fourth, then the largest two and the fifth, and so on, until the result is a PASS. That supplier, and all other suppliers below them are considered to PASS the TPS test and are not considered jointly pivotal. For BGE, the largest two and the fifth PASS, indicating the largest four are considered jointly pivotal. For ATSI, the largest two and the ninth PASS, indicating each of the largest eight are jointly pivotal with the largest two.