COALITION STABILITY IN PJM: EXPLORING THE CONSEQUENCES OF STATE DEFECTION FROM THE WHOLESALE MARKET

Travis Dauwalter, Ali Daraeepour*, Bryan Higgins*, Seth Blumsack*, Brian Murray*, and Dalia Patino-Echeverri**

Synopsis: Using an electricity market simulation tool, we investigate the impacts of a U.S. state defecting from the PJM wholesale electricity market on the states that remain in the coalition. Generally, we find that the defection of a net electricity buyer increases the welfare of the remaining consumers and decreases the welfare of the remaining producers. If a net seller defects from the market, the opposite effect holds. Furthermore, the changes in generation caused by a state defection cause changes in emissions in the remaining states, affecting the ability of the remaining states to meet their climate incentives. However, the magnitude of these changes depends on the generation mix of each individual state. Our simulations suggest that, for state legislatures pursuing climate goals, the best strategy to adopt is to pass laws that are both geographically targeted and flexible. State and federal policymakers should also recognize the importance of an RTO's network effect on the achievement of state emission goals.

* Travis Dauwalter earned his Ph.D. in Economics and Public Policy from Duke University in 2021. He is now a consultant with Bain and Company in Atlanta.

* Ali Daraeepour is a senior data science manager for optimization and forecasting at Fluence Energy. Dr. Daraeepour has 15 years of experience in Market design, operations research, machine learning, and their applications to electricity market problems and electricity grid operation, planning, control, and regulation.

* Bryan Higgins is a PhD student studying energy systems at the Nicholas School of the Environment at Duke University.

* Seth Blumsack is Professor of Energy Policy and Economics and International Affairs, and Co-Director of the Center for Energy Law and Policy, at Penn State University. He also directs the RTO Governance Research Network, funded by private foundations and the U.S. National Science Foundation. Dr. Blumsack earned his Ph.D. in Engineering and Public Policy from Carnegie-Mellon University in 2006.

* Brian Murray is the interim director of the Nicholas Institute for Energy, Environment & Sustainability at Duke University, research professor at Duke's Nicholas School of the Environment and the Sanford School of Public Policy. His research focuses on the economics of energy policy, particularly as it relates to efforts to mitigate climate change risk.

* Dalia Patino-Echeverri is Associate Professor of Energy Systems and Public Policy at the Nicholas School of the Environment at Duke University. Her research assesses and proposes technological, policy, and market design approaches to pursue environmental sustainability, affordability, reliability, and resiliency in the electricity sector.

I. INTRODUCTION

Since the late 1990s, organized electricity markets in the United States have shown that a geographically broad and resource-diverse power grid can achieve efficiency and reliability improvements in electric power generation. PJM, a Regional Transmission Organization (RTO) in the eastern U.S., has become the largest organized electricity market in the western hemisphere (Figure 1). Although this large interconnected system offers important advantages, it also raises the possibility of conflict between the incentives of the various investor-owned utilities that are members of the coalition. If achieving the political and economic goals of an individual state is made difficult by RTO rules, its regulated utilities may leave the organization. This paper explores the impacts of a state's electric utilities and power producers leaving the wholesale electricity market of an RTO. Using an electricity market simulation tool, we model the operations of the remaining wholesale market under various state exit scenarios. Our analysis identifies the economic and emissions effects of state defection on the remaining electricity suppliers and consumers in the coalition.

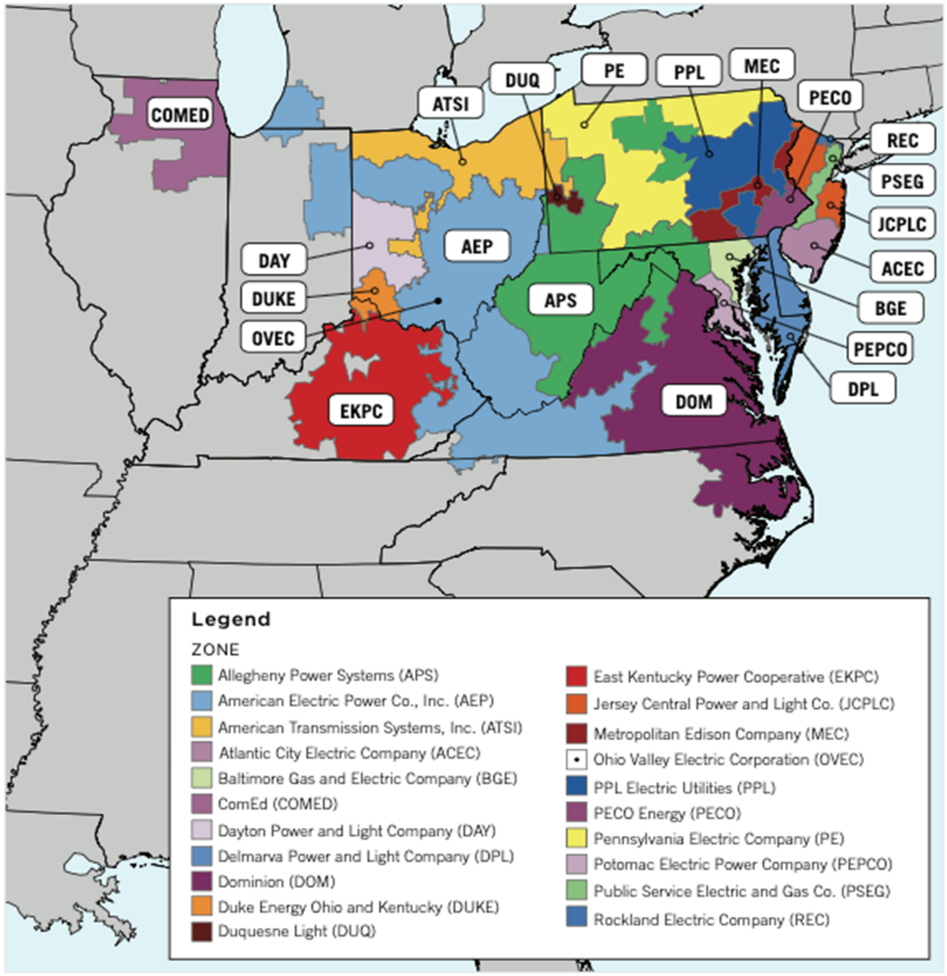


Figure 1: PJM Transmission zones.[1]

The notion of a state defecting from an RTO is not contrived. Recent proposed Minimum Offer Price Rule (MOPR) changes have caused states such as Maryland and New Jersey to threaten to withdraw from PJM's capacity market.[2] [3] Their arguments for leaving focus on discrepancies between the states' pursuits to

1. Travis E. Dauwalter, et al., *Coalition Stability in PJM: Exploring the Consequences of State Defection from the Wholesale Market* 1-38, 12 (Nicholas Inst. for Energy, Env't & Sustainability, Duke Univ., Working Paper, NI WP 22-02) (Nov. 2022), https://nicholasinstitute.duke.edu/publications/coalition-stability-pjm-exploring-consequences-state-defection-wholesale-market; PJM, *PJM Transmission Zones*, https://www.pjm.com/library/~/media/about-pjm/pjm-zones.ashx (last visited Oct. 8, 2023).

2. Catherine Morehouse, *Maryland taking a "serious look" at exiting PJM capacity market through FRR, says PSC Chair,* UTIL. DIVE, (Apr. 29, 2020), https://www.utilitydive.com/news/maryland-taking-a-serious-look-at-exiting-pjm-through-frr-says-psc-chair/576957/.

3. Robert Walton, *New Jersey looks to exit PJM capacity market, worried MOPR will impede 100% carbon-free goals*, UTIL. DIVE, (Mar. 31, 2020), https://www.utilitydive.com/news/new-jersey-looks-to-exit-pjm-capacity-market-worried-the-mopr-will-impede/575160/.

achieve net-zero carbon goals and regulatory actions from federal agencies, namely the Federal Energy Regulatory Commission (FERC). The discordance between state policy goals and federal market oversight in an RTO highlights the complex interactions between various stakeholders in the electricity sector. Our analysis considers the idea that a state may, as a matter of sovereignty, remove its electric utilities and power producers from an RTO market, thus causing spillover effects on the welfare of the remaining states.

We explore the defection of a state's utilities and power producers from the RTO's wholesale energy market as a means to simulate the potential (in)stability of the RTO network coalition to the departure of several members. We examine cases in which a state's utilities and power producers would cease to supply or purchase any electricity in PJM's real time market due to its defection. This is a somewhat extreme interpretation of what defection could mean – individual utilities could remain in the electricity market and only leave the capacity market or could leave the electricity market but engage in bilateral transactions with other PJM market participants. Also, the state's Independent Power Producers (IPPs) could continue selling in to PJMs markets. Determining which utilities would do what after their state's defection is an interesting question, but beyond the scope of this article. Instead, we focus on the distributional effects of the removal of all of a state's current electricity purchases and sales into PJM on prices, profits, generation, and emissions across the states that remain in the RTO to get a sense of the magnitude and geographic pattern of these spillover effects. From this we gain insights into the broader economic and environmental consequences of the simulated actions.

Our research focuses on wholesale market defection, expanding on previous literature that has assessed the impact of defection from a capacity market. Monitoring Analytics, the independent market monitor that oversees PJM, found that the threats by New Jersey and Maryland to leave the PJM capacity market could annually cost those states as much as $386.4 million and $206.6 million, respectively.[4] [5] Furthermore, they reported that a defection by either of these states would decrease the market-clearing prices in the remaining PJM capacity market. Intuition suggests that this would make the producers in the remaining states worse off while benefiting the remaining consumers. This study extends these lines of inquiry from PJM's capacity market to its wholesale energy market.

To investigate the implications of state defection from the PJM wholesale market, we simulate the operation of the wholesale market in 2019 under five different state-exit scenarios and compare them to the base case.[6] Each scenario involves the defection of a different state: New Jersey, Maryland, Virginia, Pennsylvania, and Illinois.[7] New Jersey and Maryland were selected due to their public

4. *Potential Impacts of the Creation of Maryland FRRs*, MONITORING ANALYTICS, (Apr. 6, 2020), http://www.monitoringanalytics.com/reports/R ports/2020/IMM_Potential_Impacts_of_the_Creation_of_Maryland_FRRs_20200416.pdf.

5. *Potential Impacts of the Creation of New Jersey FRRs*, MONITORING ANALYTICS, (May 13, 2020), http://www.monitoringanalytics.com/reports/Re- ports/2020/IMM_Potential_Impacts_of_the_Creation_of_New_Jersey_FRRS_20200513.pdf.

6. Dauwalter, *supra* note 1, at 4.

7. *Id.*

comments expressing "distaste for recent developments in PJM's market rules."[8] Virginia was chosen since "it is the largest importer of electricity in PJM."[9] Pennsylvania and Illinois were similarly chosen as the two largest net electricity sellers in the market.[10] In general, our findings indicate that when a net buyer state defects, the remaining states' producers are worse off, and the consumers are better off. The opposite effect occurs when a net seller defects. While this is not surprising, the magnitude of the changes in costs and CO_2 emissions provides insights into the economic and environmental benefits of a large Balancing Authority like PJM. We also explore the impacts of state defection on the remaining states' ability to pursue their environmental initiatives.

II. METHODS AND DATA

We simulate PJM's wholesale market hourly operation as it was in 2019 with generator offers, merit order, ancillary services, make-whole payments, and congestion-related effects all playing a role in which generators get dispatched and what price clears in each hour of the year.[11]

"To measure the impacts of a state defecting from the consortium, we also simulate the removal of a single state from the broader PJM organized market.[12] In those defection scenarios, we simulate PJM without the supply or demand of the defecting state."[13]

"We use the Electricity Market Simulation Tool (EMST) to simulate the day-ahead market operation outcomes in PJM."[14] "EMST is a reconfigurable tool that can integrate various unit commitment and dispatch models in different ways to represent various designs in energy and ancillary service markets."[15] The tool calculates dispatch and financial outcomes for all individual market players including out-of-market uplift payments.[16] EMST was first introduced by Daraeepour et al.[17] to simulate the operation of day-ahead and real-time markets for a year-long period under different market designs that account for the characterization of uncertainty in the day-ahead markets.[18] The tool initially explored load-following capability products, stochastic residual unit commitment, and stochastic market

8. *Id.*

9. *Id.*

10. Dauwalter, *supra* note 1, at 4.

11. *Id.*

12. *Id.*

13. *Id.* at 4. We assume that the utilities and independent power producers from the defecting state do not engage in any bilateral transactions with the remaining PJM members. Therefore, in the simulation we assume that imports and exports from/to other neighboring regions to/from PJM remain constant under all scenarios and are equal to observed hourly 2019 data.

14. Dauwalter, *supra* note 1, at 4.

15. *Id.*

16. Ali Daraeepour, et al., *Economic and environmental implications of different approaches to hedge against wind production uncertainty in two-settlement electricity markets: A PJM case study*, 80 ENERGY ECON. 336 (2019).

17. *Id.* at 342-343.

18. *Id.* at 341-342.

clearing.[19] EMST was later extended to include alternative pricing mechanisms, including primal approximations of convex-hull pricing.[20]

In this paper, the EMST simulates the day-ahead market operations for each hour of each day and uses its commitment and dispatch outcomes to initialize simulations of the subsequent day. Three models are used to simulate market operations (Figure 2). "First, EMST runs the Unit Commitment Model to determine the generating units' optimal on/off status and scheduled electrical power output."[21] This mixed-integer linear program takes generators' supply bids along with demand and wind generation forecasts for the next twenty-four hours as inputs to find the schedules that minimize electricity generation costs. The schedules are constrained by the technical characteristics of the power generators such as minimum and maximum power generation limits, ramping capabilities, and minimum up-time and down-time requirements. They are also constrained by the topology of the transmission network. The "second model is a linear program that performs Economic Dispatch, freezing the commitment variables to the optimal values found by the Unit Commitment and determining locational prices for energy and ancillary services."[22] The Economic Dispatch model abides the same technical constraints of the generators and transmission system.[23] After the day-ahead "market-clearing schedules and prices are determined, a third model calculates any out-of-market uplift payments that PJM" makes "to generators to ensure they do not operate at a loss when following the dispatch instructions."[24] The complete formulation of EMST's three models is available in Dauwalter et al.[25] In this paper we do not simulate a Real-Time market where electricity demand or production from variable energy resources is different from the day-ahead forecasts. This would require making assumptions about forecast errors -because the data is not available- and would not affect the comparison of outcomes across scenarios.

19. *Id.* at 343.

20. Ali Daraeepour et al., "*Enhancing Market Incentives for Flexible Performance: Alternative Market Designs to Enhance Market Incentives for Providing Operational Flexibility*" (presenting at the Institute for Operations Research and the Management Sciences (INFORMS) Annual Meeting) (Nov. 8-11, 2020), https://scholar.google.com/citations?view_op=view_citation&hl=en&user=RTEqkHIAAAAJ&citation_for_view=RTEqkHIAAAAJ:YOwf2qJgpHMC.

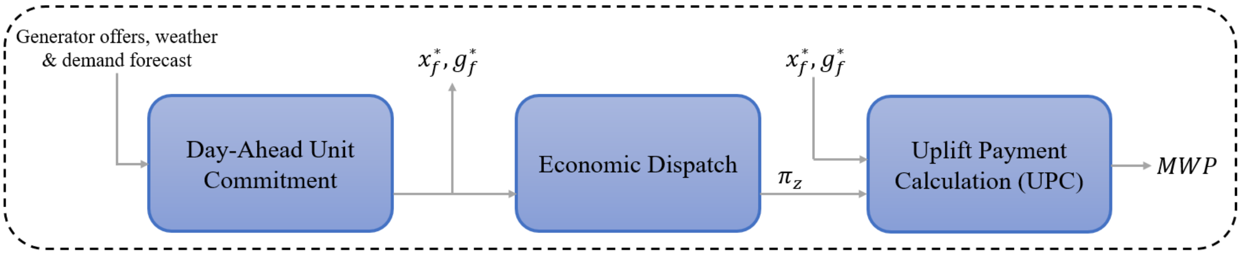
21. Dauwalter, *supra* note 1, at 4.

22. *Id.*

23. *Id.* at 9.

24. *Id.* at 4.

25. Dauwalter, *supra* note 1, at 7-9.



x_f^*, g_f^*: Welfare-maximizing commitment & generation variables for generator f
π_z: Locational marginal prices for zone z
MWP: Make-whole (uplift) payment for each generator

Figure 2: EMST configuration for simulating PJM dispatch outcomes.[26]

The models require detailed data on PJM's electricity demand, its power generation and energy storage assets, transmission constraints between the modeled PJM zones, and imports/exports between PJM and external grid systems. A full accounting of the data used in this study is available in[27] *Appendix A – Data*.

II. RESULTS

A. EMST Performance

To validate the data and modeling approach we compare EMST's base-case simulated prices and generation mix with historical data. The base case represents the actual operations of the PJM wholesale market during the year 2019. Table 1 shows descriptive statistics for all observed locational marginal prices in the PJM market in 2019 compared to EMST's simulated prices during the base case scenario. EMST is able to capture the average movements of the PJM energy market, with the mean and median from EMST being 1.7% and 6.9% higher than in the actual data.[28] Prices in real electricity markets are subject to a number of random events that can create large price spikes. These events include unplanned outages on power plants and transmission lines, as well as large errors in forecasts of electricity demand and wind and solar energy output. EMST, like most simulation models, is not able to completely capture these outlier prices.

Time Series	# of Obs	Mean ($/MWh)	Std Deviation ($/MWh)	Median ($/MWh)	Min ($/MWh)	Max ($/MWh)	Skewness	Kurtosis
Observed	8,760	25.99	9.26	24.36	8.8	160.36	3	20.74
EMST	8,760	26.43	4.94	26.05	14.23	55.67	0.96	2.03

26. *Id.* at 5.
27. *Id.* at 25.
28. *Id.* at 10.

Table 1: Descriptive statistics of PJM-wide prices in 2019 and EMST simulated prices.[29]

We also compare PJM's observed generation mix to EMST's simulated generation mix in Table 2, and note a few minor differences. EMST simulates higher nuclear generation than what was observed in 2019 because EMST assumes the nuclear generators run at full load for all hours in 2019, not accounting for any turndowns.[30] EMST also dispatches more natural gas units and less coal units compared to actual observations.[31] This is because EMST is designed to select the lowest cost asset, and although it factors in operational reliability constraints "it does not consider broader grid security/reliability concerns" as well as the choices that individual generator owners make to permit their assets to be dispatched based on economics.[32] In reality, PJM considers additional factors, occasionally dispatching units out of the merit order, like more expensive coal, trading lower costs for grid reliability. Our simulations do not include these 'must-run' conditions, thus opting to always dispatch the least expensive units. The simulated data also showed higher generation from renewables, particularly wind, due to not factoring day-ahead forecast errors nor curtailments that PJM occasionally makes to alleviate transmission congestion.

Fuel Type	% of observed mix	% of simulated mix
Coal	23.72%	17.73%
Gas	36.08%	38.70%
Hydro	1.99%	2.19%
Nuclear	33.64%	37.80%
Oil & Other fuels	1.38%	0.07%
Solar	0.29%	0.36%
Wind	2.90%	3.17%

Table 2: Actual vs simulated PJM generation mix, 2019.[33]

Due to limitations in available data between transmission zones, EMST divides PJM into 9 transmission regions, compared to PJM's twenty-one published transmission zones.[34] Hence why the model represents a larger number of available generators in each simulated transmission zone. Nevertheless, the simulated

29. Dauwalter, *supra* note 1, at 10.
30. *Id.*
31. *Id.*
32. *Id.*
33. Dauwalter, *supra* note 1, at 10.
34. *PJM Transmission Zones*, *supra* note 1.

well-centered prices, strong correlation, and accurate generation mixes when compared to observed data, speaks to the general quality of the simulation for the purposes of this paper – namely, to assess impacts on overall system performance rather than predicting specific shock events. Thus, we conclude that EMST can provide reliable estimates of PJM's generator profits, average cost to serve load, and emissions intensity and can be used to measure the impacts of various state defections on these metrics.

B. Impacts of State Defection on Total Generation

After running the base case model, we separately model the defection of five different states from the PJM wholesale market. For each of the five state defection scenarios, PJM's 2019 market operations were simulated after removing both the electricity supply and demand of the defecting state. New Jersey and Maryland were selected due to threats they have made to exit PJM's capacity market in response to rule changes that would have made the states' renewable energy targets more difficult to achieve.[35] [36] An independent market monitor has already conducted analysis on the impacts of these states exiting the capacity market[37] [38] (ref, 2020a and 2020b).[39] We extend that analysis by considering the possibility of the state opting to leave the wholesale market altogether, which is not outside the realm of possibility as state objectives come into conflict with market designs.[40] Our analysis also allows us to evaluate the effects of defection on the remaining states in the PJM wholesale market. Virginia was selected due to its status as the largest net buyer of PJM's electricity, while Pennsylvania and Illinois were selected as the market's largest net sellers.[41]

An important result of state defection to note is the change in total generation of each state when one state leaves the market. The modeled changes in total generation for each member of PJM compared to the base case in each of the five defection scenarios are shown in Table 3.[42] As major PJM electricity sellers, when Pennsylvania or Illinois exit the market, the remaining states must make up for the supply shortage. These generation changes can be significant. For example, if Pennsylvania defects, "New Jersey and Ohio end up carrying 45% of the supply

35. Morehouse, *supra* note 2.

36. Walton, *supra* note 3.

37. *Maryland FRRs*, *supra* note 4.

38. *New Jersey FRRs*, *supra* note 5.

39. Dauwalter, *supra* note 1, at 1-38, ("A capacity market is intended to ensure resource adequacy to meet peak load demand at any time throughout the year. PJM specifies the demand for capacity three years out and bidders offer to ensure their capacity is available at that time at a given price per MW (technically a $/MW-month offer). These capacity payments accrue to the bidders and are paid by the customers of the utilities serving load in PJM. Withdrawing from the capacity market means that resource adequacy requirements must be met by other means (through utility-owned generation or through bilateral contracts between utilities and suppliers). They cannot be simply ignored by the utilities in the state defecting from the capacity market.").

40. In PJM, unlike in some other RTOs, the states do not have formal standing as "stakeholders," meaning that they lack a formal mechanism within PJM to influence or vote on specific market designs. States can attempt to influence market designs in PJM through the Organization for PJM States (OPSI, a liaison group), through FERC's regulatory process, or through actual or threatened defection as modeled in this article. *Id.* at 3.

41. *Id.*

42. *Id.* at 15.

deficit (on a MWh basis)."[43] Smaller states can also see dramatic changes.[44] In the Pennsylvania exit scenario, both Delaware and the District of Columbia must nearly double their electricity generation compared to the base case.[45]

Table 3: Changes in total generation after a state's producers and consumers leave PJM.[46]

State	State's electricity purchases from PJM's market (MWh)[a]	Net sales (+) or Net purchases (-) (MWh)[b]	Total state's generation sold to PJM's electricity market (MWh)	Percent change in total generation sold to PJM compared to Base Case simulation[c]				
			Base Case	NJ Exit	MD Exit	VA Exit	PA Exit	IL Exit
DC	8,772,540 (1.11%)	-8,718,198	54,343 (0.01%)	-0.76%	-8.82%	-19.17%	96.46 %	12.83%
DE	12,133,001 (1.54%)	-8,766,328	3,366,672 (0.44%)	-3.15%	-15.50%	-15.14%	88.04 %	4.72%
IL	96,511,187 (12.26%)	47,367,949	143,879,136 (19.01%)	-0.09%	-1.37%	-3.68%	0.87%	N/A
IN	21,194,371 (2.69%)	8,034,801	29,229,172 (3.86%)	-1.73%	-14.34%	-30.42%	14.43 %	18.63%
KY	25,082,353 (3.19%)	-17,991,769	7,090,584 (0.94%)	-2.88%	-5.74%	-12.65%	59.97 %	5.51%
MD	66,892,050 (8.50%)	-36,072,041	30,820,009 (4.07%)	0.15%	N/A	-9.17%	25.26 %	7.78%
MI	5,864,708 (0.75%)	21,820,652	27,685,361 (3.66%)	-0.39%	-2.40%	-6.42%	2.78%	2.78%
NC	3,565,230 (0.45%)	-604,507	2,960,723 (0.39%)	-0.21%	-0.85%	-2.58%	1.31%	0.99%
NJ	76,910,073 (9.77%)	-14,542,063	62,368,010 (8.24%)	N/A	-6.89%	-9.68%	31.21 %	1.67%
OH	155,915,008 (19.81%)	-38,733,399	117,181,608 (15.49%)	-0.74%	-10.37%	-21.48%	10.41 %	13.85%
PA	155,018,292 (19.69%)	105,720,286	260,738,578 (34.46%)	-0.84%	-2.02%	-5.59%	N/A	2.26%
TN	4,214,924 (0.54%)	-2,529,391	1,685,533 (0.22%)	0.01%	-1.16%	-3.86%	0.98%	0.84%
VA	123,462,023 (15.68%)	-75,048,248	48,413,776 (6.40%)	-0.21%	-6.98%	N/A	15.32 %	11.01%
WV	31,670,684 (4.02%)	-10,451,470	21,219,214 (2.80%)	-8.43%	-30.61%	-52.69%	45.55 %	45.03%
Change in remaining coalition's total generation:				-0.86%	-5.43%	-10.92%	14.13 %	7.71%

43. Dauwalter, *supra* note 1, at 16.
44. *Id.* 15-16.
45. *Id.*
46. *Id.* at 15.

[a] Sales figures are for the Base Case and are assumed to be unchanged under defection. Only the portion of state's 2019 demand served through purchases in PJM is represented. For example, Illinois' purchases correspond to ComEd zone demand which is the only state portion in PJMs service territory.

[b] Net PJM sales/purchases are for the Base Case and are calculated as Total Generation – Demand in PJM markets.

[c] The change in total generation is not modeled for the defecting state.

The opposite effect holds when a net buyer, such as Virginia, exits the market. With a net demand removed from the system, the remaining states reduce their generation. Despite sharing no borders with Virginia, suppliers in Indiana and Ohio must reduce their sales into PJM's market by 30.42% and 21.48%, respectively when Virginia defects.[47] This illustrates the extensive spillover effects caused by leaving a large interconnected system like PJM.

As the largest net sellers and buyers in the market, Pennsylvania, Illinois, and Virginia represent the extremes of the defection scenarios.[48] Naturally, the results of the New Jersey and Maryland defection scenarios fall in between those of the extreme cases.[49] Both states are net buyers, but Maryland generally buys more power than New Jersey. As a result, the spillover impacts on generation in the remaining states are larger in the Maryland exit scenario than the New Jersey exit scenario.[50]

C. Impacts of State Defection on Electricity Prices

Table 4 "reports the impact of state defection from PJM on the average cost to serve load."[51] Here, the annual cost to serve load is defined as the sum of each hour's in-state purchases multiplied by each state's wholesale market clearing price in that hour.[52] The average is calculated by dividing this wholesale cost by the total number of MWhs consumed in the year.[53] It represents the cost retailers incur to purchase power from the wholesale market before ultimately selling it to consumers.[54] This can be taken as a "proxy for consumer welfare, with higher values" corresponding to higher consumer electricity bills (and thus lower consumer welfare).[55]

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47. Dauwalter, *supra* note 1, at 16.
48. *Id.* at 15.
49. *Id.*
50. *Id.* at 16.
51. Dauwalter, *supra* note 1, at 17.
52. *Id.*
53. *Id.*
54. *Id.*
55. Dauwalter, *supra* note 1, at 17. In general, higher wholesale costs will translate to higher retail bills so this assumption is fair for the purposes of this article. The mechanism by which higher wholesale costs translate into higher retail bills will, in reality, vary by state. In states with active retail competition (like Pennsylvania, for example), competitive suppliers may have mechanisms to hedge volatility or otherwise shift risk when wholesale costs rise. This may mean that changes in wholesale costs may not be directly passed on to consumer bills in a dollar-for-dollar fashion. *Id.*

The implications of the results in Table 4 are tied to the balance of supply and demand in PJM's system. "The average cost to serve load" in the base case reflects the co-optimization of generation and reserves in the entire system.[56] When a net seller exits, the rest of the system must make up for the supply deficit, causing the market to clear with more expensive units.[57] Conversely, when a net buyer exits, fewer units need to be dispatched in the remaining system, causing the most expensive units to fall out of the merit order and the market clearing price to decrease.[58]

Table 4: Average cost to serve load after state defection.[59]

State	Net sales (+) or Net purchases (-) (MWh)[b]	Avg cost to serve load ($/MWh)	Percent change in average cost to serve load compared to Base Case simulation[c]				
		Base Case	NJ Exit	MD Exit	VA Exit	PA Exit	IL Exit
DC	-8,718,198	$27.76	-0.52%	-4.28%	-10.12%	7.26%	4.75%
DE	-8,766,328	$27.75	-4.53%	-3.95%	-4.53%	8.04%	1.13%
IL	47,367,949	$25.44	-0.52%	-2.23%	-6.39%	-0.03%	N/A
IN	8,034,801	$27.61	-0.48%	-4.19%	-10.14%	1.76%	4.72%
KY	-17,991,769	$25.93	-0.16%	-2.60%	-6.31%	12.48%	2.98%
MD	-36,072,041	$27.83	-0.88%	N/A	-9.64%	7.38%	4.42%
MI	21,820,652	$27.61	-0.48%	-4.19%	-10.14%	1.76%	4.72%
NC	-604,507	$27.78	-0.53%	-4.28%	-10.21%	6.78%	4.75%
NJ	-14,542,063	$27.58	N/A	-3.99%	-4.52%	7.68%	1.08%
OH	-38,733,399	$27.70	-0.49%	-4.20%	-10.12%	1.70%	4.73%
PA	105,720,286	$25.95	-1.23%	-2.62%	-5.02%	N/A	2.13%
TN	-2,529,391	$27.81	-0.50%	-4.24%	-10.27%	1.63%	4.74%
VA	-75,048,248	$27.78	-0.54%	-4.27%	N/A	5.99%	4.73%
WV	-10,451,470	$27.80	-0.49%	-4.23%	-10.24%	4.19%	4.73%
Full Coalition:		$27.04	-0.97%	-3.82%	-7.98%	5.45%	4.46%

[a] Demand figures are for the Base Case and are assumed to be unchanged under defection.

56. *Id.*

57. *Id.* This generally holds for all states that remain after a net-exporter exits with one exception: when Pennsylvania defects, the average cost to serve load in Illinois decreases. However, the magnitude of this change is very small. Dauwalter, *supra* note 1, at 17.

58. *Id.* at 1-38, 18.

59. *Id.* at 17.

[b] Net exports/imports are for the Base Case and are calculated as Total Generation - Demand.

[c] The change in average cost to serve load is not modeled for the defecting state.

Table 5 reports the changes in state-level generators' profits (in $ per MWh) compared to the base case after a state defection.[60] Profits are estimated as the difference between wholesale revenues minus the costs of production represented in the EMST's Unit Commitment and Economic Dispatch models which include start-up costs, shut-down costs, no-load costs and fuel costs.[61] The varied impacts of state defection on profits are likely tied to variations in generation mix between states. Like generators generally have like costs, meaning that generators of the same technology will be clustered close to one another in the supply curve, and thus will be close to one another in the merit order. As demand shifts after a state defection, the cost optimization of the new system may shift each state's merit order enough to include or exclude these 'fuel/technology' clusters, impacting the overall profitability of all generators in the system.[62]

Table 5: Generators' sales profits after state defection.[63]

State	Net sales (+) or Net purchases (-) (MWh)[b]	Generators' sales Profits ($/MWh)	Percent change in generators' sales profits compared to Base Case simulation[c]				
		Base Case	NJ Exit	MD Exit	VA Exit	PA Exit	IL Exit
DC	-8,718,198	$3.76	4.97%	2.45%	4.42%	-0.83%	3.55%
DE	-8,766,328	$5.22	-42.58%	-20.72%	-7.50%	-49.26%	3.19%
IL	47,367,949	$12.03	-0.79%	-2.76%	-7.92%	-0.81%	N/A
IN	8,034,801	$6.95	0.01%	4.39%	11.69%	-8.57%	-2.72%
KY	-17,991,769	$4.10	2.24%	2.24%	7.07%	41.96%	0.25%
MD	-36,072,041	$16.25	-1.81%	N/A	-4.90%	-9.86%	-0.73%
MI	21,820,652	$12.81	-0.64%	-6.12%	-13.94%	1.24%	6.99%
NC	-604,507	$23.59	-0.47%	-4.25%	-9.86%	6.13%	4.55%
NJ	-14,542,063	$9.92	N/A	-3.20%	-0.47%	-4.98%	1.22%
OH	-38,733,399	$5.64	-1.19%	-4.26%	-13.05%	-3.59%	4.24%
PA	105,720,286	$6.60	0.64%	-3.17%	-6.50%	N/A	3.79%

60. *See* Table 5.
61. *See* Dauwalter, *supra* note 1, at 6, 11, 13, 37.
62. *Id.* at 18.
63. *Id.*

TN	-2,529,391	$8.66	-1.36%	-12.04%	-27.93%	5.44%	14.26%
VA	-75,048,248	$13.37	-0.80%	-1.07%	N/A	-2.72%	-1.01%
WV	-10,451,470	$5.97	6.46%	26.48%	60.67%	-13.15%	-17.38%
Full coalition:		$8.85	-0.22%	-1.85%	-4.48%	-4.64%	1.20%

[b] Net exports/imports are for the Base Case and are calculated as Total Generation - Demand.

[c] The change in average cost to serve load is not modeled for the defecting state.

D. Welfare Calculations

The calculations of producer and consumer welfare follow from the findings of the previous section. Producer surplus is the sum of the total annual wholesale profits for each state (also equal to the per MWh of generation multiplied by each state's total electricity sales in the PJM market).[64] The calculation results are shown in Table 6.[65] Green values represent increases in producer surplus, while red values represent decreases.[66] These results vary from the generation profit results from Table 5 because they reflect both the change in average per MWh of generation and the change in generation itself. (*Consult Table 3*).)[67]

In general, these results suggest that if a net buyer exits the PJM wholesale market, the producer surplus decreases in the remaining states, while producer surplus increases when a net seller exits.[68] There are two exceptions to this rule: Delaware and Washington, D.C. Delaware's producer surplus decreases by 4.59% when Pennsylvania exits from the energy market.[69] We can see from Table 3 that Delaware must increase generation by 88.04% to help make up for the supply deficit caused by Pennsylvania's departure.[70] However, the profitability of Delaware's generating fleet decreases by 49.26% under the same scenario (Table 5).[71] The effect of the drop in profitability dominates the effect of the increased generation, resulting in a net loss of producer surplus.[72] Conversely, Washington, D.C.'s increased profitability dominates the reduction in generation when New Jersey defects, causing a net increase in producer surplus.[73]

Table 6: Producer surplus by state after state defection.[74]

64. *See* Table 6.
65. *Id.*
66. *Id.*
67. *See* Table 5; *see* Table 6.
68. *See supra* Table 5.
69. *Id.*
70. *Id.*
71. *Id.*
72. *See generally supra* Tables 3 and 5, *see generally* Table 6.
73. *See generally supra* Tables 3 and 5, *see generally* Table 6.
74. Dauwalter, *supra* note 1, at 19.

State	Producer Surplus ($)	Percent change in producer surplus compared to Base Case simulation				
	Base Case	NJ Exit	MD Exit	VA Exit	PA Exit	IL Exit
DC	204,448	4.17%	-6.59%	-15.60%	94.84%	16.84%
DE	17,582,294	-44.39%	-33.01%	-21.50%	-4.59%	8.06%
IL	1,730,433,535	-0.88%	-4.09%	-11.31%	0.06%	N/A
IN	203,084,173	-1.73%	-10.58%	-22.28%	4.63%	15.41%
KY	29,033,448	-0.71%	-3.62%	-6.47%	127.09%	5.77%
MD	500,707,376	-1.66%	N/A	-13.63%	12.92%	7.00%
MI	354,759,876	-1.03%	-8.37%	-19.47%	4.06%	9.97%
NC	69,846,394	-0.69%	-5.06%	-12.19%	7.52%	5.58%
NJ	618,661,033	N/A	-9.87%	-10.10%	24.68%	2.91%
OH	661,264,989	-1.92%	-14.18%	-31.73%	6.45%	18.67%
PA	1,720,955,038	-0.20%	-5.13%	-11.73%	N/A	6.14%
TN	14,593,773	-1.35%	-13.06%	-30.71%	6.47%	15.22%
VA	647,413,157	-1.01%	-7.97%	N/A	12.18%	9.89%
WV	126,666,334	-2.52%	-12.23%	-23.99%	26.41%	19.83%
Full coalition:		-1.07%	-7.18%	-14.91%	8.84%	9.01%

We also make a proxy calculation for consumer surplus using wholesale energy payments. The true consumer surplus would require a willingness-to-pay measure for electricity by individuals in each state. Since we are primarily interested in directional effects, we argue that the payments made to wholesale generation are a sufficient measure for capturing changes in consumer surplus under different defection scenarios. To calculate this value, we multiply the average cost to serve load (Table 4) by the state's purchases in PJM's market.[75] This is the amount of money that would be conveyed to retailers to provide generation services to electricity consumers.[76]

The literature suggests our approach for understanding changes in true consumer surplus is viable. First, electricity consumers are relatively unresponsive to

75. *See supra* Tables 3 and 4.
76. *See supra* Tables 3 and 4.

marginal price fluctuations.[77] [78] [79] Rather, the average cost of delivered electricity consumers face has a greater influence on consumption decisions.[80] Furthermore, it has been demonstrated that, as with most goods, long run demand for residential electricity is more elastic than short run demand.[81] We argue, then, that consumers would measure their welfare based on the average cost they are paying for electricity and would maintain their current consumption in the short run even under average price changes on their electric utility bill. In sum, decreased average price levels will have salience to consumers and reflect an increase in consumer welfare.

We are left, then, with determining how retailers may or may not change their pricing behavior based on changes to the wholesale pricing. Here, again, the literature suggests that fluctuations in the marginal costs of producers are often absorbed by the retailers or can be hedged using various mechanisms.[82] [83] [84] That is, retail suppliers will likely not pass-through high frequency marginal cost fluctuations like short-lived price spikes. Instead, we claim that changes in levels (i.e., average cost) will trigger pricing adjustments.

So, under a state defection, if the retailers in a remaining state experience a lower average cost of supply, we expect it would trigger a downward adjustment to retail utility bills, directly increasing consumer welfare. Similarly, an increase in average cost of supply would result in an analogous decrease in consumer welfare. As we assume that electricity demand in the remaining states remains constant in the short run, the calculated changes in consumer surplus directly mirror the changes in average cost to serve load from Table 4.[85] A decrease in a state's average cost to serve load in Table 4 translates to an equivalent increase in consumer surplus for the state's consumers, and vice versa.[86]

These results illustrate the tradeoffs between producers and consumers in the wholesale electricity market. In nearly all scenarios, an increase in producer surplus corresponds to a decrease in consumer surplus and vice versa. Whether a

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77. Severin Borenstein, *To What Electricity Price do Consumers Respond? Residential Demand Elasticity Under Increasing-Block Pricing* 1 (Ctr. for the Study of Energy Mkts., Working Paper Series CSEM WP 195, 2009), https://haas.berkeley.edu/wp-content/uploads/csemwp195.pdf.

78. Severn Borenstein & James B. Bushnell, *Do Two Electricity Pricing Wrongs Make a Right? Cost Recovery, Externalities and Efficiency* 1 (Nat'l Bureau of Econ. Rsch., Working Paper 24756, 2018), https://www.nber.org/papers/w24756.

79. Jeong-Shik Shin, *Perception of Price When Price Information is Costly: Evidence from Residential Elasticity Demand*, 67 REV. OF ECON. & STAT. 591, 591 (1985). https://www.jstor.org/stable/1924803.

80. Koichiro Ito, *Do Consumers Respond to Marginal or Average Price? Evidence From Nonlinear Electricity Pricing,* 104 AM. ECON. REV. 537, 560, (2014).

81. Xing Zhu et al., *A Meta-Analysis on the Price Elasticity and Income Elasticity of Residential Electricity Demand*, 201 J. OF CLEANER PROD. 169, 169-177 (2018).

82. Lucas W. Davis & Erich Muehlegger, *Do Americans Consume Too Little Natural Gas? An Empirical Test of Marginal Cost Pricing*, 41 RAND J. OF ECON. 791, 808 (2010).

83. Lee S. Friedman, *Energy Utility Pricing and Customer Response in Energy Policy*, *in* REGULATORY CHOICES: A PERSPECTIVE ON THE DEVELOPMENTS IN ENERGY POLICY 10, 17-18, 39, 41 (Richard J. Gilbert ed., 1991).

84. Steven L. Puller & Jeremy West, *Efficient Retail Pricing in Electricity and Natural Gas Markets*, 103 AM. ECON. REV. 350, 351-52, 354 (2013).

85. *See supra* Table 4.

86. *Id*.

state is better or worse off after a defection is a broader welfare question that must include how a state prioritizes consumer and producer surplus as well as some equity considerations. Our simulations predict two distinct exceptions to this producer/consumer tradeoff: Delaware is unambiguously worse off if Pennsylvania defects (both producers and consumers lose), and DC is unambiguously better off if New Jersey defects (both producers and consumers gain).[87]

E. Emissions

Table 7: Annual CO_2 emissions after state defection.[88]

State	CO_2 Emissions (tons)	Percent change annual CO_2 emissions compared to Base Case simulation[c]					CO_2 Emissions Intensity (tons/ MWh)	Percent change in annual CO_2 emissions intensity compared to Base Case simulation[c]				
	Base Case	NJ Exit	MD Exit	VA Exit	PA Exit	IL Exit	Base Case	NJ Exit	MD Exit	VA Exit	PA Exit	IL Exit
DC	9,696 (0.00%)	-0.85%	-27.74%	-42.08%	41.06%	44.04%	0.178	-0.09%	-20.75%	-28.34%	-28.20%	27.66%
DE	2,352,029 (0.87%)	-36.60%	-44.10%	-9.92%	23.62%	3.34%	0.699	-34.54%	-33.85%	6.15%	-34.26%	-1.32%
IL	38,408,952 (14.19%)	-0.18%	-3.94%	-10.30%	3.06%	N/A	0.267	-0.09%	-2.61%	-6.87%	2.17%	N/A
IN	16,065,906 (5.94%)	-2.58%	-21.47%	-42.49%	21.87%	28.25%	0.55	-0.86%	-8.32%	-17.35%	6.50%	8.11%
KY	5,585,576 (2.06%)	-3.40%	-5.70%	-13.32%	78.10%	4.72%	0.788	-0.54%	0.04%	-0.77%	11.33%	-0.75%
MD	9,774,654 (3.61%)	0.16%	N/A	-12.76%	36.34%	11.24%	0.317	0.01%	N/A	-3.95%	8.85%	3.21%
MI	3,472,462 (1.28%)	-1.27%	-7.79%	-20.26%	9.01%	9.01%	0.125	-0.88%	-5.52%	-14.79%	6.06%	6.06%
NC	15,649 (0.01%)	-1.04%	-4.13%	-12.52%	6.37%	4.81%	0.005	-0.83%	-3.31%	-10.20%	4.99%	3.78%
NJ	13,145,484 (4.86%)	N/A	-14.52%	-19.18%	66.31%	3.53%	0.211	N/A	-8.19%	-10.52%	26.75%	1.83%
OH	62,074,508 (22.94%)	-1.32%	-17.96%	-34.85%	18.76%	24.73%	0.53	-0.58%	-8.47%	-17.03%	7.56%	9.56%
PA	95,672,023 (35.36%)	-1.30%	-4.41%	-11.97%	N/A	5.48%	0.367	-0.46%	-2.44%	-6.76%	N/A	3.15%
TN	744,770 (0.28%)	0.01%	-1.16%	-3.86%	0.98%	0.84%	0.442	0.00%	0.00%	0.00%	0.00%	0.00%
VA	6,319,909 (2.34%)	-0.65%	-24.28%	N/A	54.95%	39.41%	0.131	-0.44%	-18.60%	N/A	34.37%	25.58%

87. Dauwalter, *supra* note 1 (technically, our simulations also show that Illinois is unambiguously better off under a Pennsylvania defection but the changes in producers surplus and consumer wholesale costs are 0.06% and -0.03%, respectively).

88. *Id.* at *16*.

WV	16,950,714 (6.26%)	-10.96%	-38.37%	-66.04%	57.34%	56.90 %	0.799	-2.76%	-11.18%	-28.22%	8.10%	8.18%
Total	270,592,332	-2.15%	-12.24%	-22.91%	26.89%	17.01 %	0.358	-1.30%	-7.20%	-13.46%	11.18%	8.63%

[a] Demand figures are for the Base Case and are assumed to be unchanged under defection.

[b] Net sales/purchases are for the Base Case and are calculated as Total Generation – Demand within PJM.

[c] The change in the annual CO_2 emissions is not modeled for the defecting state.

Conflict between state policy goals and RTO market designs represent one motivation for states to consider defection from regional electricity markets. The RTO, in principle, provides robustness and stability by expanding supply to meet market load demand. But participation in an RTO may also hamper state policy levers to encourage new renewable generation investments or to restrict a state's utilities from contracting with high-emissions generators.[89] It also introduces complexity to projections of any one state's generation level and mix as part of the regional supply network meeting regional demand.[90] The latter can imply substantial spillover effects in emissions arising from state RTO defection.[91] These spillover effects are similar in nature to the "leakage" effects that arise from incomplete environmental regulation, where the regulation simply shifts emissions from one location to another.[92] By evaluating the CO_2 emissions before and after different defection scenarios, we get a sense of the impacts that one state's actions can have not only on another state's production, but also on its ability to meet its climate initiatives. This also shows the importance of state policymakers considering the interstate market network in which its utilities operate in setting broader environmental and economic policy goals – and federal policymakers too as FERC regulates RTOs.

Table 7 reports the total annual CO_2 emissions for each state compared to the base case under each of the defection scenarios.[93] The red values represent negative changes in emissions.[94] These results are closely related to the changes in total generation from Table 3.[95] In general, if a state experiences an increase in generation, it also experiences an increase in emissions, though the magnitude of

89. North Dakota v. Heydinger, 835 F.3d 912 (8th Cir. 2016) (a group of power generators in North Dakota challenged Minnesota's Next Generation Energy Act (NGEA), which would have prohibited Minnesota utilities from contracting with high-emissions power plants in other states. With utilities in both states participants in the markets operated by the Midcontinent Independent Systems Operator (MISO), the NGEA would have effectively placed MISO-dispatched power plants in North Dakota under regulatory control of the Minnesota commission).

90. Dauwalter, *supra* note 1, at 10-11.

91. *Id*.

92. *Id*.

93. *Id*.

94. *See* Dauwalter, *supra* note 1, at 16.

95. *Id*.

the change depends on the emissions intensity of the generation fleet.[96] For example, when any net buyer defects, Ohio reduces its total generation less than the amount that its CO_2 emissions drops.[97] In other words, "the more CO_2 intensive generators in Ohio begin to fall out of the merit order post defection."[98] This effect arises not because of any particular policy related to CO_2 emissions but because high-emissions power plants are generally less efficient and therefore more expensive to operate. The opposite takes place when a net seller defects. "Under Pennsylvania and Illinois defect scenarios, Ohio increases its generation by 10.41% and 13.85%, respectively, while CO_2 emissions jump by 18.76% and 24.73%."[99] "Indeed, the fleet of plants that are on the margin throughout the year produce more CO_2 per MWh than the inframarginal plants.[100]"

As illustrated by Table 7, the emissions intensity of generation of each state in the PJM region varies under each defection scenario as different types of generators fall into or out of the merit order.[101] These changes often, though not always, follow the changes in each state's total generation (Table 3).[102] One notable exception is Delaware. Under the net-exporter scenarios where Pennsylvania and Illinois exit the market, Delaware's generation increases by 88.04% and 4.72% respectively to make up for the generation shortfall.[103] The resulting emissions increases are smaller than the generation increases, leading to reductions in overall carbon intensity of 34.26% and 1.32%.[104] This result indicates that for this particular state, the generators often just outside of the merit order in the Base Case are lower emitting than the average generator inside the merit order. This is different from most other states in PJM, in which the less frequently dispatched peaker plants are often more emissions intensive than the more commonly dispatched generators.

IV. DISCUSSION

Our analysis suggests a general tradeoff between producer and consumer welfare in the remaining states if an individual state were to exit the PJM wholesale electricity market. How the net impact would be valued by a state would depend on that state's relative weighting of producer and consumer welfare. We believe this is a distinctly political question. We foresee a state's total welfare calculation taking the form:

$$W_{i,k} = (1 - \lambda_i)PS_{i,k} + \lambda_i v_i CS_{i,k}$$

Where $W_{i,k}$ is the total welfare of state i under scenario k, PS is producer surplus, CS represents our proxy for consumer surplus (consumer wholesale

96. *Id*.
97. *Id*.
98. *See* Dauwalter, *supra* note 1, at 16.
99. *Id*. at 16-17.
100. *Id.* at 17.
101. *Id.* at 16.
102. *See* Dauwalter, *supra* note 1, at 16.
103. *Id*.
104. *Id*.

costs), v_i is a scaling measure converting the proxy consumer surplus value to true consumer surplus for state i, and $\lambda_i \in [0,1]$ represents the political preference for producer or consumer welfare. For example, $\lambda_i = 1$ means that state i only considers consumer welfare in its total welfare measure, and thus the state would consider any scenario in which a net buyer defects as a benefit. If a net exporter were to defect, consumer welfare would decrease and the state would consider itself negatively impacted.

We also find that state defection has substantial spillover effects, affecting both producer and consumer welfare in remaining states. This introduces an interesting question of coalition dynamics into organizations like PJM, as spillover effects could cause remaining states to reconsider their participation in this market. Even if state defection threats are purely strategic, with the goal of influencing market design or FERC regulation, the threats themselves may affect how market participants in remaining states view the benefits and costs of market design decisions. If a large net buyer or net seller state, such as Virginia or Pennsylvania, were to defect, it is not implausible that other states could choose to exit the market to avoid experiencing significant changes to their own electricity producers and consumers. It is also possible that the conditions created by a state defection could make it more appealing for other states to join PJM. (A Pennsylvania defection, for example, could create an opportunity for another net supplier with sufficient transmission interconnection.) Additional modeling, including analysis of impacts on the defecting state itself, could help determine the types of conditions that could lead to a cascading effect of state defections. Understanding the landscape that could bring about an unraveling of the PJM coalition would be valuable to both state and federal regulators.

In addition to the producer and consumer welfare effects, state defection from the PJM wholesale market also has important climate policy implications for the remaining coalition. In general, when a net seller leaves the market, the remaining states are left to make up for the shortfall, leading to increased reliance on more expensive and higher emitting generators. This could place additional strain on the remaining coalition in a time when states are working to reduce emissions to meet climate goals. Although the changes in emissions of the state exiting the market are also needed to fully understand the climate impacts of state defection, this analysis highlights the importance of interstate cooperation and coordination for maximizing efficiency and grid decarbonization.

We note that this analysis focuses on defection from wholesale markets rather than capacity markets. Furthermore, our results do not account for other benefits of participating in an RTO, including shared investment in transmission infrastructure, grid reliability, and resiliency. A model that considers these factors would lead to more thorough welfare calculations. Such a complete analysis is beyond the scope of this paper.

V. CONCLUSION

This study investigates the welfare effects on market participants that remain in an RTO following a state defection from the wholesale energy market. While previous reports investigated the effects of a state defection from the PJM capacity market, our efforts give a fuller picture of the complex relationships between coalition members and the instability that would be introduced by state defection from the wholesale market. We find, generally, that if a net buyer defects from the wholesale energy market, the remaining states' producers are worse off while the remaining states' consumers are better off. The opposite effect holds true if the defecting state is a net-seller. The overall welfare ramifications depend on how a state values producer surplus relative to consumer surplus. Furthermore, state defection can have important impacts on electricity sector emissions in the remaining states, impacting those states' ability to meet their climate goals. However, as mentioned before, the possibility remains that both utilities and power producers of the defecting state buy and sell electricity from/to PJM market participants not in the electricity market but through bilateral transactions, therefore mitigating all the effects discussed here.[105]

It is unclear how serious state defection threats from PJM were when they were issued in 2020.[106] There have been cases of individual transmission owners moving from one RTO to another (as Duquesne Light did when it left MISO to join PJM in 2005), but as of the time of this writing, no state defections have occurred. Some of the policy concerns underlying state defection threats (e.g., the MOPR) were diminished by subsequent softening of the terms, which allowed for the possibility that state-subsidized generation sources could qualify for capacity payments in PJM auctions.[107] That said, the prospect of state defection from an RTO, especially one covering as many states as PJM, raised some important questions about the strength of the complex connections within an RTO coalition that affect costs, prices, and environmental performance in subtle and profound ways. By examining these interactions, this article underscores the importance of policymakers at the state and federal levels recognizing the effects of an RTO's structure and rules on the size and distribution of the economic welfare and environmental performance of its constituents.

105. *Id*.

106. Dauwalter, *supra* note 1.

107. Dan R. Skowronski, *PJM Revisions to MOPR Go Into Effect*, SAUL EWING, (Oct. 11, 2021), https://www.saul.com/insights/alert/pjm-revisions-mopr-go-effect.