Triennial Review of PJM's Variable Resource Requirement

Probabilistic Modeling Approach

PRESENTED TO

PJM Interconnection and Stakeholders

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Overview

Purpose

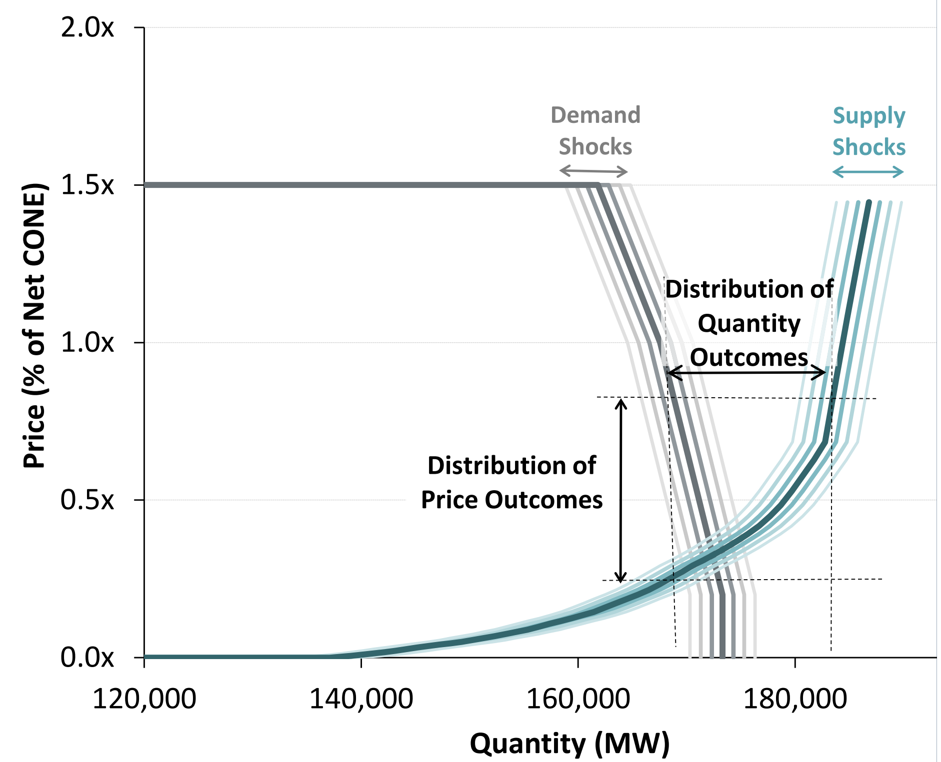
- Estimate average, range, and distribution of capacity market outcomes:
  - Price, quantity, and reliability
  - System-wide and in each location
- Compare results realized with different demand curve shapes

Approach

- Input locational supply curves, demand curves, and transmission parameters
- Use a locational clearing model to calculate prices and quantities
- Simulate a distribution of outcomes using a Monte Carlo analysis of realistic "shocks" to supply, demand, and transmission
- Average price over all draws converges to true Net CONE, consistent with long-run equilibrium in a merchant environment

Supply and Demand Shocks

(Illustrative)



Note:
Illustrative shocks are not intended to reflect exact shock magnitudes or locational clearing results.

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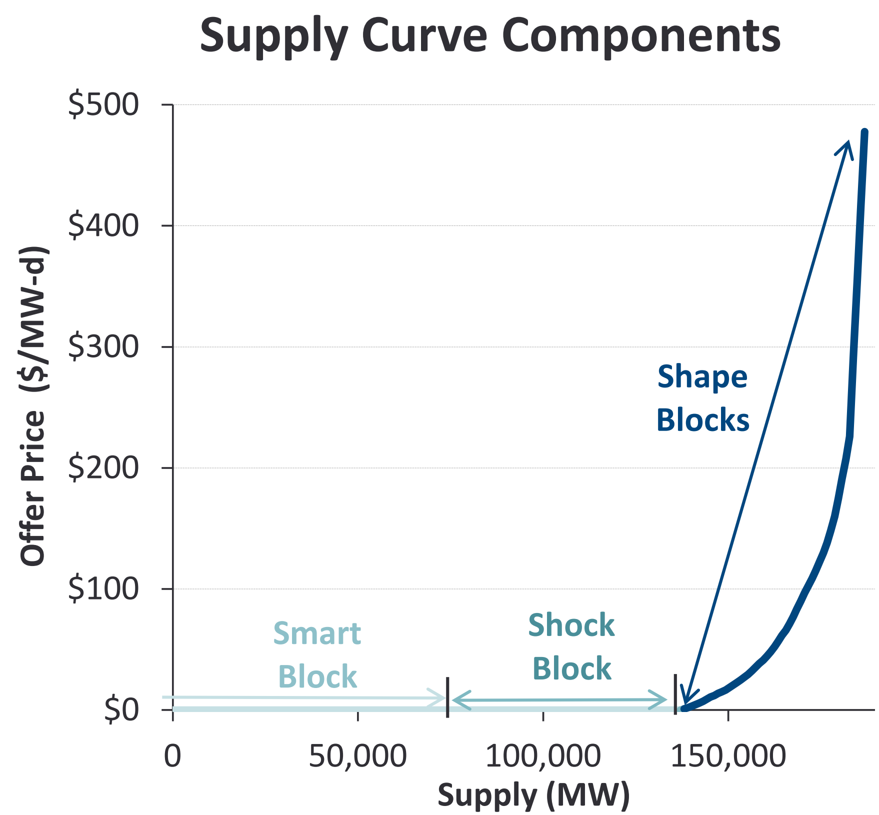
Supply Curve Components

Model Supply in Three Components:

1. **Shape Blocks**
   - Supply offers at prices above zero
   - Shape based on historical PJM offer curves (select one of the historical years' shapes)
   - Lumpiness based on size of individual RPM resources in each location
   - Independent of demand curve shape
2. **Shock Block**
   - Zero-priced supply block
   - Quantity in each zone varies with each draw to generate "shocks" to the supply curve
3. **Smart Block (for Long-Run Equilibrium)**
   - Zero-priced supply block
   - Quantity adjusted such that the average price equals Net CONE
   - Quantity is constant across draws, but may be slightly different across demand curves
   - Plays the role of long-run supply elasticity (i.e. entry when prices are above Net CONE; exit when prices are below Net CONE)

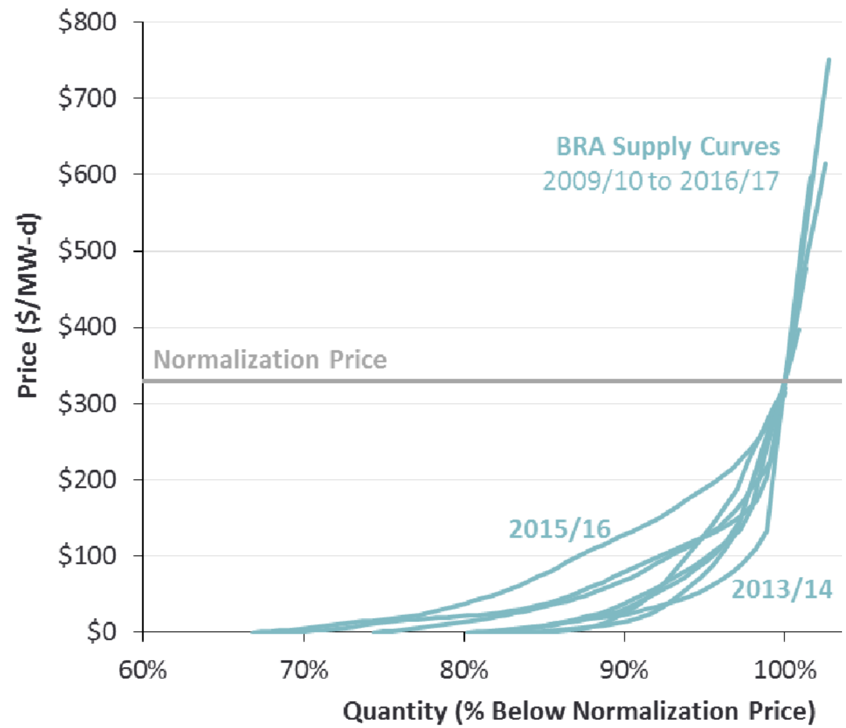


Sources and Notes:
Smart block and shock blocks both represent quantities of supply that are offered at zero-price, and are used as adjustable parameters in our model.
Shape blocks represent the supply that is offered at non-zero prices, and is based on historically observed supply as shown the next slide.

Supply Curve Shapes

- Model relies on smoothed supply curve shapes, consistent with 2009/10-16/17, excluding transition period before full three-year forward auctions
- Cycle through each of the eight shapes
- "Lumpiness" reflected in local curves:
  - Use resources size and location from 2016/17 offer curve
  - Randomly shuffle the order of the offer blocks to create 1,000 different curves
  - Re-state prices consistent with the smoothed supply curve shape
- Effect is a relatively elastic supply curve at the system level, but small LDAs are more greatly affected by the impact of lumpy investments

Smoothed Supply Curves
2009/10 – 2016/17



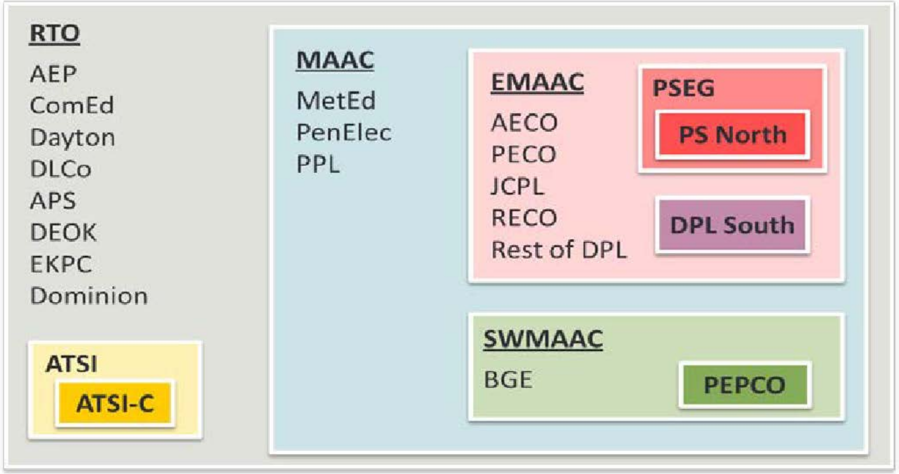
Sources and Notes:
Smoothed supply offer curves developed from raw data provided by PJM staff.
Offer curves normalized by quantities offered below $330/MW-d and inflated to 2016/17 dollars.

Model Mechanics

Demand, Transmission, and Clearing

- Reflect nested zonal LDA structure and planning parameters from 2016/17
- Input expected values for locational auction parameters:
  - Demand curve price points as a % of administrative Net CONE
  - Demand curve quantity points as a % of Reliability Requirement
  - Capacity emergency transfer limit expected value
- Auction clearing:
  - Selects lowest-cost supply to meet demand curve given transmission constraints
  - Determine cleared price and quantity in each location

Modeled LDAs from 2016/17



Model Mechanics
Shocks

- Parameters consistent with year 2016/17 parameters in Base Case
- Shocks to supply, reliability requirement, CETL, and administrative Net CONE create volatility that depends on LDA size and level of import-dependence
- Magnitude of each type of shock developed from historical auction and administrative parameter data (see Appendix)

Model Inputs in Base Case

Parameter	RTO	ATSI	ATSI-C	MAAC	EMAAC	SWMAAC	PSEG	DPL-S	PS-N	PEPCO
Average Parameter Value										
Administrative Net CONE ($/MW-d)	$331	$363	$363	$277	$330	$277	$330	$330	$330	$277
True Net CONE ($/MW-d)	$331	$363	$363	$277	$330	$277	$330	$330	$330	$277
CETL (MW)		7,881	5,245	6,495	8,916	8,786	6,581	1,901	2,936	6,846
Reliability Requirement (MW)	166,128	16,255	6,164	72,299	39,694	17,316	12,870	3,160	6,440	9,012
Standard Deviation of Simulated Shocks										
Administrative Net CONE ($/MW-d)	$26	$23	$23	$37	$34	$37	$34	$34	$34	$37
Reliability Requirement (MW)	1,499	259	164	794	492	279	215	76	131	220
Reliability Requirement (% of RR)	0.9%	1.6%	2.7%	1.1%	1.2%	1.6%	1.7%	2.4%	2.0%	2.4%
CETL (MW)		965	662	771	1,055	1,008	793	230	364	844
Supply Excluding Sub-LDAs (MW)	624	507	157	532	1,132	315	136	97	226	328
Supply Including Sub-LDAs (MW)	4,054	663	157	2,767	1,591	644	363	97	226	328

Model Mechanics

Net System Supply minus Demand Shocks

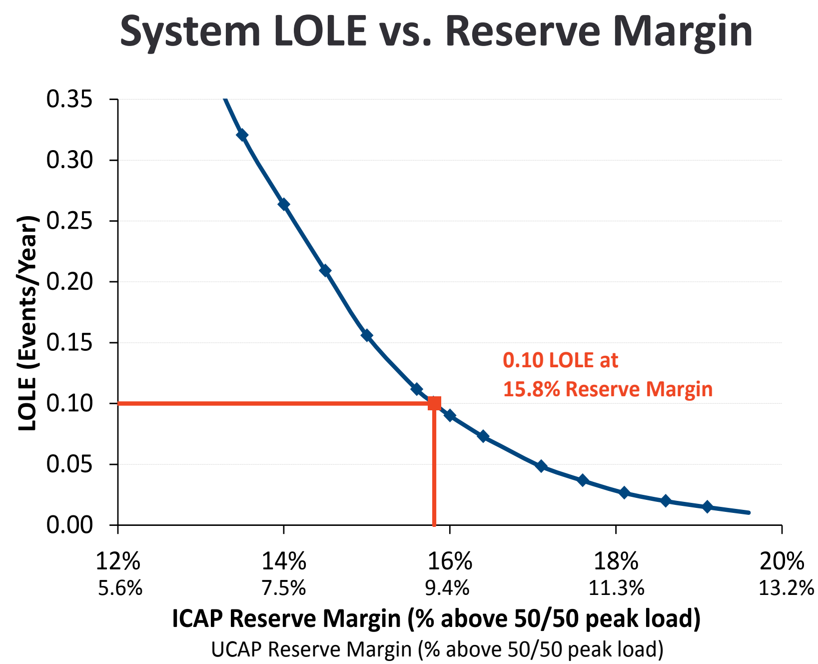
- Most important driver of realized price and quantity volatility is net supply minus demand
- Our simulation shocks (bottom panel) reflect shocks between two methods for calculating historical shocks (top panels):
  - Standard deviation of absolute values of net supply
  - Standard deviation of differences from time trend
- Consistent with goal of representing levels of volatility consistent with historical observation in RPM

LDA	Standard Deviation (MW)				Standard Deviation as % of 2016/17 LDA Size			
	Supply (MW)	CETL (MW)	Reliability Requirement (MW)	Net Supply (MW)	Supply	CETL	Reliability Requirement	Net Supply (%)
Historical Absolute Value								
RTO	20,040	n/a	14,783	5,894	12.1%	n/a	8.9%	3.5%
MAAC	3,549	811	931	3,480	4.9%	1.1%	1.3%	4.8%
EMAAC	1,900	721	645	2,451	4.8%	1.8%	1.6%	6.2%
SWMAAC	907	910	335	1,652	5.2%	5.3%	1.9%	9.5%
PS	820	352	288	832	6.4%	2.7%	2.2%	6.5%
PS NORTH	534	252	101	585	8.3%	3.9%	1.6%	9.1%
DPL SOUTH	112	206	57	282	3.5%	6.5%	1.8%	8.9%
PEPCO	423	1,060	233	1,673	4.7%	11.8%	2.6%	18.6%
ATSI	717	1,742	38	2,421	4.4%	10.7%	0.2%	14.9%
ATSI-Cleveland	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Historical Deviation from Trend								
RTO	4,816	n/a	4,850	2,147	2.9%	n/a	2.9%	1.3%
MAAC	1,229	808	792	2,208	1.7%	1.1%	1.1%	3.1%
EMAAC	1,102	717	578	2,091	2.8%	1.8%	1.5%	5.3%
SWMAAC	409	378	283	792	2.4%	2.2%	1.6%	4.6%
PS	657	329	96	759	5.1%	2.6%	0.7%	5.9%
PS NORTH	338	222	84	401	5.3%	3.4%	1.3%	6.2%
DPL SOUTH	70	172	48	193	2.2%	5.4%	1.5%	6.1%
PEPCO	234	236	166	585	2.6%	2.6%	1.8%	6.5%
ATSI	557	n/a	n/a	n/a	3.4%	n/a	n/a	n/a
ATSI-Cleveland	473	n/a	n/a	n/a	7.7%	n/a	n/a	n/a
Simulation Shocks								
RTO	4,054	n/a	1,499	4,277	2.4%	n/a	0.9%	2.6%
MAAC	2,767	771	794	2,984	3.8%	1.1%	1.1%	4.1%
EMAAC	1,591	1,055	492	1,954	4.0%	2.7%	1.2%	4.9%
SWMAAC	644	1,008	279	1,214	3.7%	5.8%	1.6%	7.0%
PS	363	793	215	908	2.8%	6.2%	1.7%	7.1%
PS NORTH	226	364	131	446	3.5%	5.7%	2.0%	6.9%
DPL SOUTH	97	230	76	259	3.1%	7.3%	2.4%	8.2%
PEPCO	328	844	220	935	3.6%	9.4%	2.4%	10.4%
ATSI	663	965	259	1,186	4.1%	5.9%	1.6%	7.3%
ATSI-Cleveland	157	662	164	699	2.5%	10.7%	2.7%	11.3%

Model Mechanics

Reliability Outcomes

- Calculate realized reliability in each location as a consequence of the cleared quantity
- PJM staff provided estimates of system and local loss of load events (LOLE) for system and each LDA consistent with reliability requirements study



Model Mechanics
Draws and Price Convergence

Each simulation run outputs based on10,000 Monte Carlo draws

Convergence Draws:

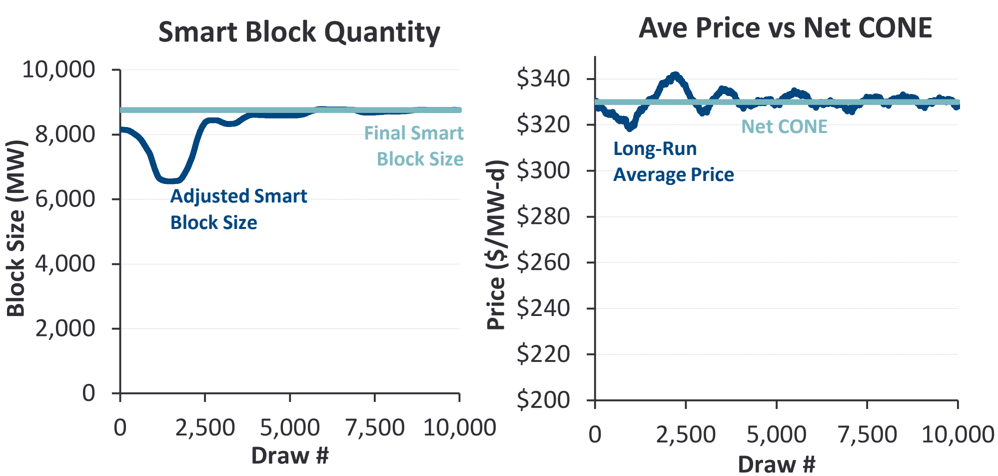
- 9,000 convergence draws to estimate final "smart block" quantity in each location
- Determines total average quantity of supply that can be supported in each location by a particular demand curve (e.g. a curve right-shifted by 100 MW should attract 100 MW more supply on average)

Production Draws:

- Fix the smart block size
- 1,000 draws to illustrate distribution of supply, demand, and reliability results

Steps in Each Monte Carlo Draw
1. Draw Shocks
2. Create Local Supply and Demand Curves
3. Clear Auction
4. Tabulate Price, Quantity, and Reliability

Example Calibration: EMAAC



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Interpreting Results

Simplifications

- This model approach is intended to:
  - Estimate distributions of supply, demand, and reliability that might be realized under long-run equilibrium market conditions
  - Reflect realistic shocks to supply, demand, and transmission on a fleet-wide basis
  - Capture locational interactions under PJM's nested zonal structure
  - Compare results with different demand curves
- Need to interpret results understanding what it does not do:
  - Reflect invest/retire decisions for individual resources or resource classes
  - Consider short-run conditions between now and a long-run equilibrium
  - Reflect time-sequential results (e.g. duration of boom-bust cycle)
  - Model sub-annual resource constraints

Comparison to Hobbs Model

- Like Hobbs model developed in 2005 and used to evaluate the VRR curve in prior RPM reviews, the current model is a stylized depiction of supply and demand dynamics
- Biggest differences in revised approach are to: (a) model supply entry/exit based on actual supply curve shapes (not possible to know as of 2005); (b) reflect historical observation on size of shocks under actual RPM performance; and (c) capture locational dynamics

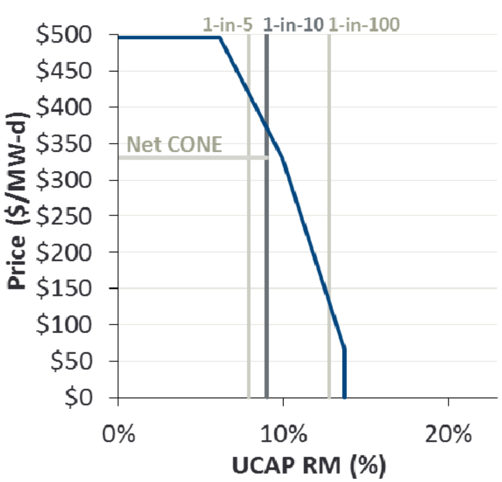
	Brattle	Hobbs
Supply	• Supply curve shape based on history • Long-run entry/exit so prices equal Net CONE on average (no excess profits under any curve shape) • Unexpected shocks to supply (bigger supply uncertainties than in Hobbs)	• Vertical supply curve (also scenarios where new supply offers at a fixed above-zero price) • Quantity of new supply offering depends on recently-realized energy and capacity prices, and a risk aversion parameter (excess profit required for entry in volatile market) • Max entry in any one year is limited • No additional supply shocks
Demand	• Demand curve varies around a fixed average value with shocks (similar, but slightly smaller demand uncertainties than Hobbs)	• 100 years of time-sequential load growth • Load growth uncertainty causes deviations from the trend
Transmission	• Nested zonal LDA structure	• Not modeled
Reliability	• Estimated as result of individual draws	• Not modeled

Interpreting Results

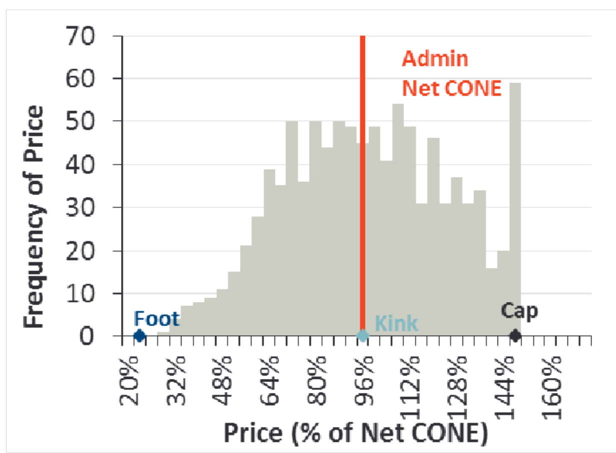
Base Results with Current VRR Curve

- Simulate a distribution of price, quantity, and reliability outcomes with any one curve
- Current curve:
  - Does not meet 1-in-10 on average (LOLE = 0.121)
  - High proportion of events below 1-in-5 (20%)
  - Moderate price volatility
- Translate into summary statistics for comparing across curves

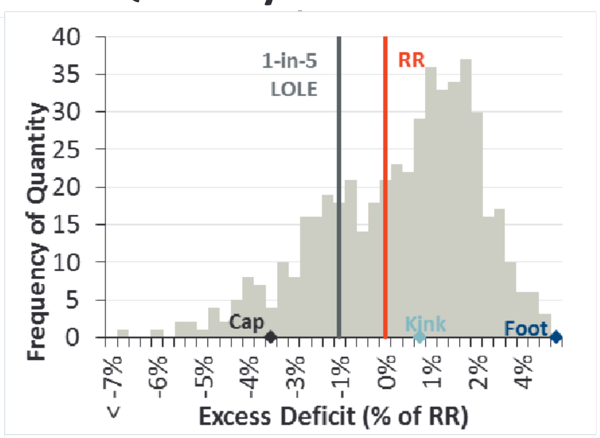
Current VRR Curve



Simulated Distribution of Price Outcomes



Simulated Distribution of Quantity Outcomes



Sensitivity to Modeling Uncertainties

- Illustrate varying shocks sizes to test the robustness of base modeling assumption results
- Decreasing/eliminating shocks improves reliability and reduced price volatility
- Increasing shocks causes worse reliability outcomes and more price volatility

Sensitivity of Simulation Results to Model Uncertainties

	Price			Reliability					Procurement Costs		
	Average *($/MW-d)*	Standard Deviation *($/MW-d)*	Freq. at Cap *(%)*	Average LOLE *(Ev/Yr)*	Average Excess (Deficit) *(IRM + X%)*	Reserve Margin St. Dev. *(% ICAP)*	Freq. Below Rel. Req. *(%)*	Freq. Below 1-in-5 *(%)*	Average *($mil)*	Average of Bottom 20% *($mil)*	Average of Top 20% *($mil)*
Current VRR Curve											
Current VRR Curve	$331	$95	6%	0.121	0.4%	2.0%	35%	20%	$20,167	$12,672	$28,094
Zero Out Supply Shocks	$331	$50	0%	0.074	0.8%	1.0%	22%	4%	$20,283	$16,364	$24,824
Zero Out Demand Shocks	$331	$91	4%	0.115	0.5%	1.9%	35%	19%	$20,170	$12,831	$27,617
Zero Out Net CONE Shocks	$331	$93	5%	0.120	0.5%	2.0%	35%	20%	$20,170	$12,603	$27,749
All Shocks 33% Higher	$331	$115	12%	0.186	0.2%	2.7%	39%	26%	$20,087	$10,923	$29,638
All Shocks 33% Lower	$331	$70	1%	0.089	0.7%	1.4%	29%	11%	$20,227	$14,826	$26,227

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Appendix

Locational Sensitivity Analysis

- Price volatility increases and reliability decreases with higher shocks; the reverse with lower shocks
- For 33% lower shocks, current VRR curve achieves reliability objectives in all LDAs
- For 33% higher shocks, only two of nine LDAs meet the reliability target
- Assuming no CETL shocks largely improves reliability in the most import-dependent zones but has minimal impacts in the larger and less import-dependent LDAs
- These cases assume local Net CONE is always 5% Higher than parent, with no systematic estimation error

	Price				Reliability								Procurement Costs		
	Average ($/MW-d)	St. Dev ($/MW-d)	Freq. at Cap (%)	Freq. of Price Separation (%)	Conditional Average LOLE (Ev/Yr)	Conditional Average LOLE (Additive) (Ev/Yr)	Average Excess (Deficit) Above Rel. Req. (MW)	St. Dev. (MW)	Average Quantity as % of Rel. Req. (%)	St. Dev. as % of Rel. Req. (%)	Freq. Below Rel. Req. (%)	Freq. Below 1-in-15 (%)	Average ($mil)	Average of Bottom 20% ($mil)	Average of Top 20% ($mil)
Base Shocks															
MAAC	$277	$89	12%	33%	0.053	0.160	1389	2356	102%	3%	27%	17%	$7,218	$4,199	$10,669
EMAAC	$291	$98	8%	25%	0.033	0.193	1349	1706	103%	4%	22%	15%	$4,058	$2,274	$6,049
SWMAAC	$291	$96	6%	17%	0.042	0.202	1215	1163	107%	7%	14%	8%	$1,689	$969	$2,504
ATSI	$277	$87	11%	18%	0.035	0.143	1,152	1,121	107%	7%	14%	11%	$1,476	$904	$2,120
PSEG	$305	$105	5%	15%	0.022	0.215	1036	886	108%	7%	13%	9%	$1,351	$730	$2,003
PEPCO	$305	$104	25%	14%	0.064	0.266	1099	923	112%	10%	11%	10%	$856	$471	$1,292
PS-N	$321	$116	31%	15%	0.023	0.238	503	442	108%	7%	12%	8%	$687	$361	$1,047
ATSI-C	$291	$95	10%	12%	0.059	0.202	906	694	115%	11%	9%	8%	$533	$316	$796
DPL-S	$305	$105	13%	15%	0.027	0.220	309	259	110%	8%	12%	7%	$308	$167	$464
Zero CETL Shocks															
MAAC	$277	$90	9%	35%	0.051	0.160	1163	2202	102%	3%	29%	19%	$7,206	$4,065	$10,917
EMAAC	$291	$101	11%	40%	0.044	0.204	650	1374	102%	3%	32%	20%	$4,061	$2,244	$6,205
SWMAAC	$291	$99	10%	36%	0.048	0.207	334	623	102%	4%	28%	17%	$1,706	$945	$2,602
ATSI	$277	$92	10%	29%	0.036	0.145	430	620	103%	4%	24%	17%	$1,490	$847	$2,227
PSEG	$305	$107	7%	31%	0.034	0.238	226	388	102%	3%	27%	14%	$1,361	$734	$2,077
PEPCO	$305	$105	8%	28%	0.035	0.243	270	378	103%	4%	24%	15%	$881	$469	$1,371
PS-N	$320	$115	9%	31%	0.036	0.274	144	255	102%	4%	29%	13%	$698	$357	$1,080
ATSI-C	$291	$99	6%	25%	0.030	0.175	171	217	103%	4%	22%	15%	$552	$298	$875
DPL-S	$306	$107	7%	27%	0.032	0.236	87	119	103%	4%	21%	12%	$313	$165	$486
33% Higher Shocks															
MAAC	$277	$106	13%	32%	0.115	0.267	1612	3139	102%	4%	29%	21%	$7,207	$3,620	$11,179
EMAAC	$291	$115	11%	24%	0.047	0.314	1743	2269	104%	6%	22%	17%	$4,048	$1,971	$6,364
SWMAAC	$291	$113	7%	16%	0.082	0.349	1648	1539	110%	9%	13%	10%	$1,686	$842	$2,623
ATSI	$277	$103	9%	17%	0.068	0.220	1,524	1,491	109%	9%	15%	12%	$1,473	$791	$2,234
PSEG	$306	$122	7%	14%	0.032	0.346	1402	1178	111%	9%	13%	10%	$1,347	$628	$2,099
PEPCO	$305	$120	8%	13%	0.162	0.511	1509	1223	117%	14%	11%	9%	$851	$405	$1,344
PS-N	$320	$133	7%	13%	0.029	0.376	686	584	111%	9%	11%	8%	$683	$304	$1,086
ATSI-C	$291	$110	6%	11%	0.172	0.392	1233	925	120%	15%	9%	8%	$531	$275	$826
DPL-S	$305	$122	6%	14%	0.049	0.364	413	343	113%	11%	11%	8%	$307	$142	$483
33% Lower Shocks															
MAAC	$277	$67	3%	39%	0.033	0.116	1100	1600	102%	2%	25%	11%	$7,267	$4,922	$10,018
EMAAC	$291	$77	4%	27%	0.027	0.143	952	1158	102%	3%	21%	11%	$4,091	$2,681	$5,682
SWMAAC	$291	$75	4%	20%	0.025	0.140	793	784	105%	5%	15%	7%	$1,704	$1,137	$2,360
ATSI	$277	$67	4%	20%	0.023	0.107	782	756	105%	5%	15%	9%	$1,483	$1,039	$1,988
PSEG	$306	$83	3%	16%	0.018	0.161	686	596	105%	5%	14%	7%	$1,363	$868	$1,891
PEPCO	$306	$84	6%	16%	0.028	0.169	722	624	108%	7%	12%	9%	$866	$556	$1,225
PS-N	$321	$92	4%	18%	0.020	0.181	329	302	105%	5%	13%	6%	$694	$425	$985
ATSI-C	$291	$76	5%	14%	0.026	0.133	585	466	110%	8%	11%	8%	$539	$360	$755
DPL-S	$306	$84	4%	17%	0.019	0.161	205	175	107%	6%	12%	7%	$311	$197	$438

Notes: All cases assume LDA Net CONEs are 5% higher than each successive parent area; no systematic Net CONE estimation error

Supply Shocks

- Supply shocks based on range of actual total supply offers observed in historical BRAs
- Shocks used in simulation model are based on formula using historic deviations in supply offer from time trend, and LDA size

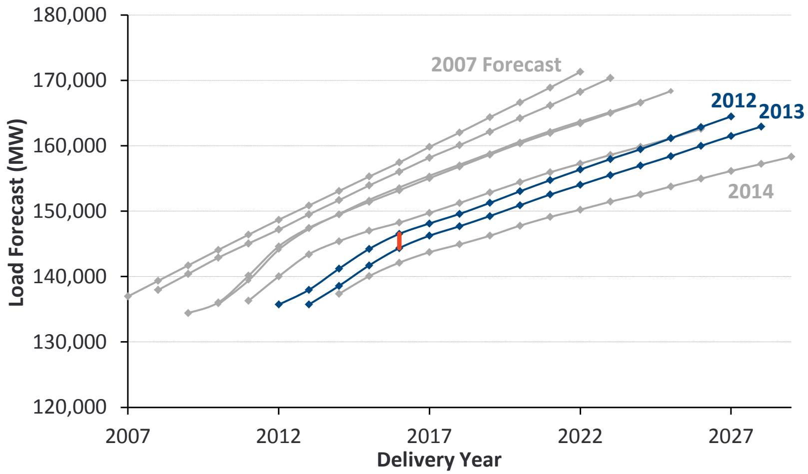
		Total Supply Offered by Delivery Year								Standard Deviation of Historical "Shocks"						
		2009	2010	2011	2012	2013	2014	2015	2016	Total Offers	Annual Change in Offer	Diff. from Trend	Total Offers	Annual Change in Offer	Diff. from Trend	Simulation Shock St. Dev
		(MW)	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(%)*	*(%)*	*(%)*	*(MW)*
										[1]	[2]	[3]	[4]	[5]	[6]	[7]
RTO Including Subzones																
Total Offered (No Adjustments)		133,551	133,093	137,720	145,373	160,898	160,486	178,588	184,380	20,040	7,229	4,816	13%	5%	3%	4,129
Adjust for Expansions Only	[A]	133,551	133,093	137,057	144,333	146,479	146,646	163,802	165,729	12,594	6,105	3,983	9%	4%	3%	
Adjust for FRR Only	[B]	133,551	133,093	137,720	145,373	160,898	160,486	163,231	169,023	14,604	5,518	3,878	10%	4%	3%	
Adjust for Expansions and FRR	[C]	133,551	133,093	137,057	144,333	146,479	146,646	158,769	160,696	10,537	4,452	2,697	7%	3%	2%	
Parent LDAs Including Sub-LDAs																
MAAC		63,443	63,919	65,582	68,283	68,338	70,885	74,261	71,608	3,842	2,069	1,229	6%	3%	2%	2,818
EMAAC		31,684	31,218	32,034	32,983	33,007	34,520	37,226	34,140	1,939	1,829	1,102	6%	5%	3%	1,620
SWMAAC		10,312	10,928	11,651	12,396	11,768	12,458	12,722	12,386	843	562	409	7%	5%	3%	655
ATSI		n/a	n/a	n/a	n/a	13,335	12,679	11,777	12,791	646	1,043	557	5%	8%	4%	676
PSEG		6,957	7,220	7,403	7,431	8,033	8,184	8,964	6,784	725	987	657	10%	13%	9%	369
Average LDA Shock										**1,599**	**1,298**	**791**	**7%**	**7%**	**4%**	
Smallest LDAs																
PEPCO		5,064	5,498	5,670	5,382	5,289	5,875	6,235	6,126	412	325	234	7%	6%	4%	334
PS-North		3,767	3,871	4,010	3,420	4,173	4,170	4,931	4,182	436	586	338	11%	14%	8%	231
ATSI-Cleveland		n/a	n/a	n/a	n/a	2,232	2,341	1,657	2,874	499	956	473	22%	42%	21%	160
DPL-South		1,587	1,546	1,486	1,499	1,612	1,600	1,768	1,764	108	84	70	7%	5%	4%	98
Average LDA Shock										**364**	**488**	**279**	**12%**	**17%**	**9%**	

Appendix: Detail on Shocks

RTO Load Forecast Error (LFE) Shock

- Calculate historical "shocks" to RTO load forecast as delta between four- and three-year ahead forecast for the same delivery year, since that's the change market participants see just before each auction
- Observe 0.8% standard deviation for RTO
- LDA-level load forecast shocks consider correlations with RTO and parent LDAs:
  - Generate shocks for smallest LDAs as RTO shock plus another independent shock that depends on LDA size
  - Bigger LDAs aggregate small LDA shocks and an appropriately sized "rest of" LDA shock

RTO Load Forecast

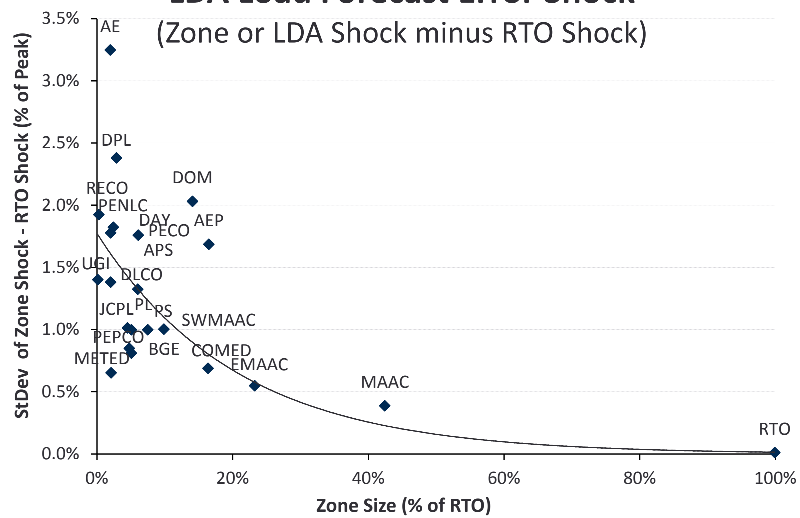


Aggregate RTO and LDA Shocks

Location	Base Assumptions 2016/17		Simulated Shock Standard Deviation			Historical
	Peak Load	Total Shocks	RTO-Correlated Shock	Shock on Top of RTO	Total Shock	Load Forecast Shocks
	(MW)	*(MW)*	*(%)*	*(%)*	*(%)*	*(%)*
RTO	152,383	1,237	0.8%	0.0%	0.8%	0.8%
MAAC	61,080	604	0.8%	0.6%	1.0%	1.0%
EMAAC	33,299	373	0.8%	0.8%	1.1%	1.3%
SWMAAC	14,088	187	0.8%	1.1%	1.3%	1.2%
ATSI	13,295	183	0.8%	1.1%	1.4%	1.3%
PSEG	10,600	158	0.8%	1.3%	1.5%	1.3%
PEPCO	6,800	114	0.8%	1.5%	1.7%	1.0%
PS-N	5,141	87	0.8%	1.5%	1.7%	n/a
ATSI-C	4,562	77	0.8%	1.5%	1.7%	n/a
DPL-S	2,439	46	0.8%	1.7%	1.9%	n/a

LDA Load Forecast Error Shock

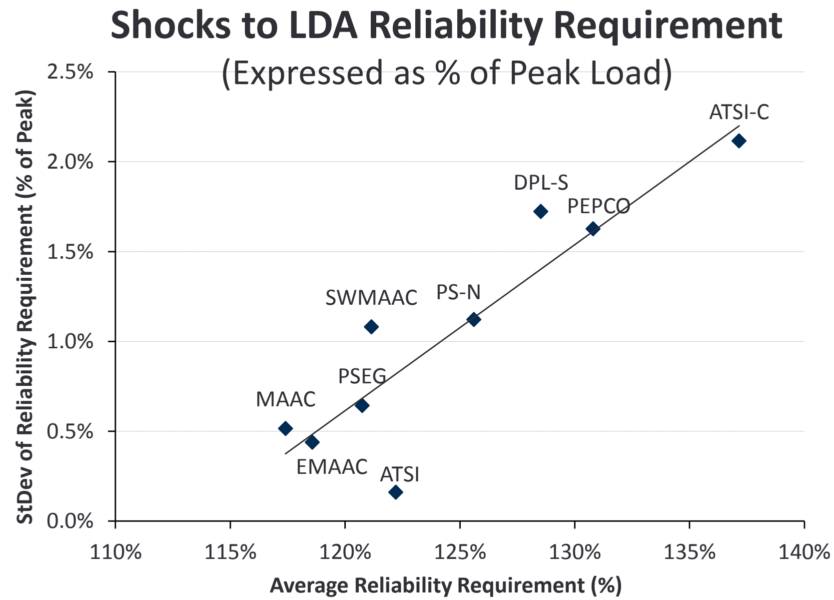
(Zone or LDA Shock minus RTO Shock)



Appendix: Detail on Shocks

Shocks to Reliability Requirements

- Total Reliability Requirement shock is load forecast shock plus an independent shock to the Reliability Requirement itself (expressed as a % of Peak load)
- **RTO:** the RR% has a standard deviation of 0.4%, calculated based on variation among historical reliability requirements (this is in addition to the 0.8% load forecast error)
- **LDAs:** standard deviation of Reliability Requirements increases for LDAs where it is a greater % of peak load

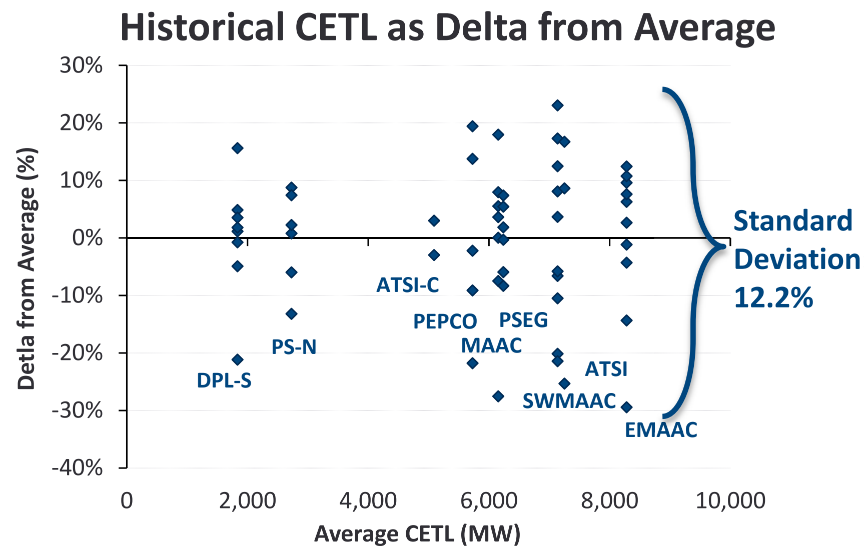


Shocks to Reliability Requirements

Location	2016/17 Reliability Requirement (MW)	2016/17 Reliability Requirement (% of Peak)	Simulation Shock Standard Deviations: Reliability Requirement (% of Peak)	Simulation Shock Standard Deviations: Load Forecast (MW)	Simulation Shock Standard Deviations: Total Load Forecast + RR (MW)	Historical Reliability Requirement StDev (% of Peak)
RTO	166,128	109%	0.4%	1,237	1,499	0.4%
MAAC	72,299	118%	0.4%	604	794	0.5%
EMAAC	39,694	119%	0.5%	373	492	0.4%
SWMAAC	17,316	123%	0.7%	187	279	1.1%
ATSI	16,255	122%	0.8%	183	259	0.2%
PS	12,870	121%	0.7%	158	215	0.6%
PEPCO	9,012	133%	1.6%	114	220	1.6%
PS NORTH	6,440	125%	1.1%	87	131	1.1%
ATSI-Cleveland	6,164	135%	2.2%	77	164	2.1%
DPL SOUTH	3,160	130%	1.4%	46	76	1.7%

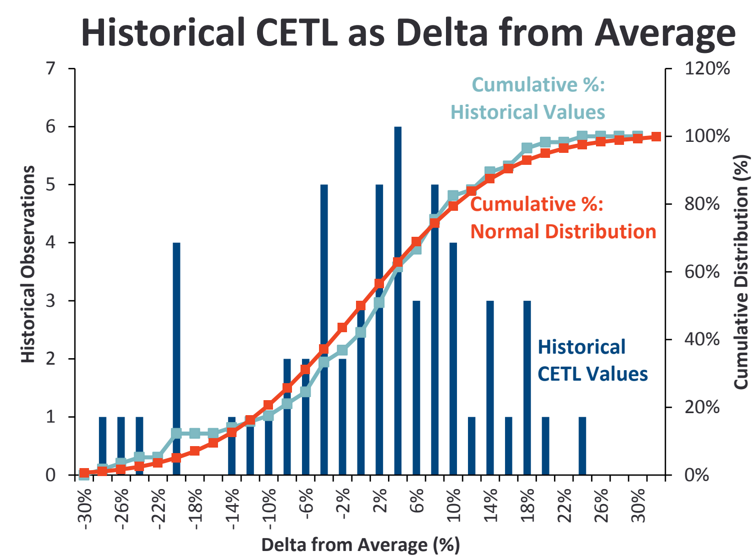
Appendix: Detail on Shocks
CETL Shocks

- We implement CETL shocks using a normal distribution with a standard deviation of 12.2% around the 2016/17 parameter value
- We find that shocks are proportional to absolute CETL size (but relatively constant as a % of CETL)



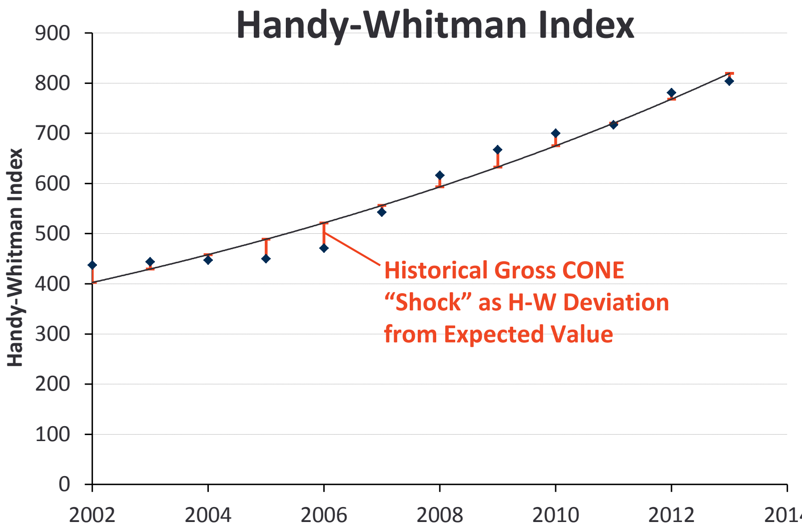
Historical and Simulation CETL Shocks

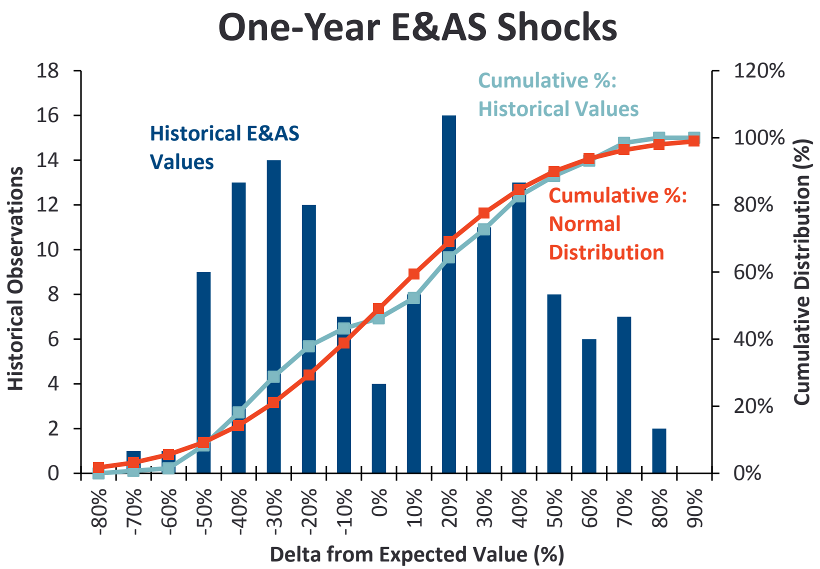
LDA	Historical CETL Values				Simulation CETL Values		
	Average *(MW)*	Standard Deviation *(MW)*	Standard Deviation *(%)*	Count	2016/17 Value *(MW)*	Standard Deviation *(MW)*	Standard Deviation *(%)*
EMAAC	8,286	1,091	13%	10	8,916	1,090	12%
SWMAAC	7,140	1,095	15%	10	8,786	1,074	12%
ATSI	7,256	1,619	22%	3	7,881	963	12%
PEPCO	5,733	964	17%	5	6,846	837	12%
PSEG	6,241	387	6%	6	6,581	804	12%
MAAC	6,155	886	14%	7	6,495	794	12%
ATSI-C	5,093	216	4%	2	5,245	641	12%
PS-North	2,733	191	10%	8	2,936	359	12%
DPL-South	1,836	228	8%	6	1,901	232	12%



Net CONE Shocks

- Net CONE shocks are developed as the sum of shocks to gross CONE and a 3-year average E&AS shock, but assuming no systematic bias
- Gross CONE shocks of 5.4% based on deviations in Handy-Whitman Index away from long-term trend
- E&AS Shocks:
  - One-year historical E&AS estimated with standard deviation of 38% around expected value, based on deviation of administrative estimates in each year from a fitted trend over 2003-13
  - Administrative E&AS shock of 22%, based on rolling 3-year average E&AS
- Results in standard deviation of 8% in administrative Net CONE for RTO (deviations from true Net CONE)





Net CONE Shocks

LDA	Base Assumptions from 2016/2017				Standard Deviation of Shock Components				Historical Shocks to Net CONE (%)
	Expected Gross CONE *($/MW-d)*	Expected E&AS *($/MW-d)*	Expected Net CONE *($/MW-d)*	Shocks to Net CONE *($/MW-d)*	Gross CONE *(%)*	One-Year E&AS *(%)*	Three-Year E&AS *(%)*	Net CONE *(%)*	
RTO	$405	$74	$331	$26	5.4%	38.4%	22.1%	8.0%	5.5%
ATSI	$405	$43	$363	$23	5.4%	38.4%	22.1%	6.4%	1.1%
ATSI-C	$405	$43	$363	$23	5.4%	38.4%	22.1%	6.4%	1.1%
MAAC	$413	$136	$277	$36	5.4%	38.4%	22.1%	13.1%	18.8%
EMAAC	$443	$113	$330	$33	5.4%	38.4%	22.1%	10.1%	9.8%
SWMAAC	$413	$136	$277	$36	5.4%	38.4%	22.1%	13.1%	12.8%
PSEG	$443	$113	$330	$33	5.4%	38.4%	22.1%	10.1%	3.0%
DPL-S	$443	$113	$330	$33	5.4%	38.4%	22.1%	10.1%	5.2%
PS-N	$443	$113	$330	$33	5.4%	38.4%	22.1%	10.1%	3.0%
PEPCO	$413	$136	$277	$36	5.4%	38.4%	22.1%	13.1%	4.6%

Notes:

Expected Gross CONE, E&AS, and Net CONE consistent with 2016/17 Planning Parameters.

Historical "Shocks" expressed as average of deviations from "trend" in Net CONE (i.e. point "b"), note that most LDAs have few data points.

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