Dynamic Analysis of Demand Curves for PJM Reliability Pricing Model January 6, 2005

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Review of Previous Results

- Installed capacity additions are a dynamic process.
  - For each ICAP auction, generators make investment decisions and offer capacity based on capacity and energy prices from the recent auctions.
  - The amount of new CT construction increases to the extent that assumed margins exceed the cost of construction (including return on capital).
  - If recent margins and ICAP prices have been highly variable, the amount of CT construction is less due to risk aversion, resulting in over/undershoot response.
- Use of demand curve changes the market dynamics.
  - Johns Hopkins University modeled the dynamics of capacity additions under ICAP demand curve variations.

Calculating Maximum New Capacity Additions (*NCA_y*) on-line in year y (Auction held in year *y*-4):

Actual & Anticipated CT profits *y*-7, *y*-6, …, *y*
(depend on ICAP Price, Total Energy/AS Profit)

↓ ← *Forecast Weights*, *Risk Attitudes*

Risk-Adjusted Forecast Profit (*RAFP*)

↓ ← *Entry Response Function*

NCA_y is a function of *RAFP*
(if *RAFP* = 0, *NCA_y* is enough to meet average load growth)

↓ ← *Bid Price.*, *Demand Curve*

$P_{ICAP,y}$ based on *NCA_y* + Existing Capacity

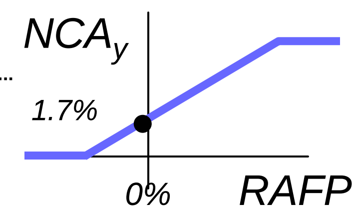
Blue = Known at Auction in Year y-4; Brown = Estimated

Year y-7:	Year y-6:	Year y-5:	Year y-4:	Year y-3:	Year y-2:	Year y-1:	Year y:
Profit = P_{ICAP} + E/AS Profit – Fixed Cost	P_{ICAP} + E/AS Pro – FC	P_{ICAP} + E/AS Pro – FC	P_{ICAP} + E/AS Pro – FC	P_{ICAP} + E/AS Pro – FC	P_{ICAP} + E/AS Pro – FC	P_{ICAP} + E/AS Pro – FC	P_{ICAP} + E/AS Pro – FC

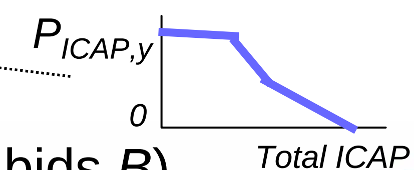
Weights for Profits in y-7, …, y

Risk averse utility function penalizing variable profits

Risk-Adjusted Forecast Profit (***RAFP****$_y$*)
(Increases if profits higher, decreases if profits more variable)



Maximum New Capacity Additions NCA_y



ICAP Price from Demand Curve
(Assume existing capacity bids 0, and NCA_y bids B)

System Simulated

- Used the PJM Mid Atlantic system representation to assess the “relative” impact of demand curves on:
  - capacity additions and prices
  - LOLP
  - scarcity revenues
- Other features of RPM (locational constraints, operating characteristics, “backstop”) are not modeled.
- The model is primarily assessing the profitability of combustion turbines that are needed to meet the reliability requirement. Other types of generation and their profitability are not modeled.
- Assumed fixed cost of new entry as $57/kW-yr and normal Energy & Ancillary Services (E&AS) revenue as $20/kW-yr based on history.

Reliability:

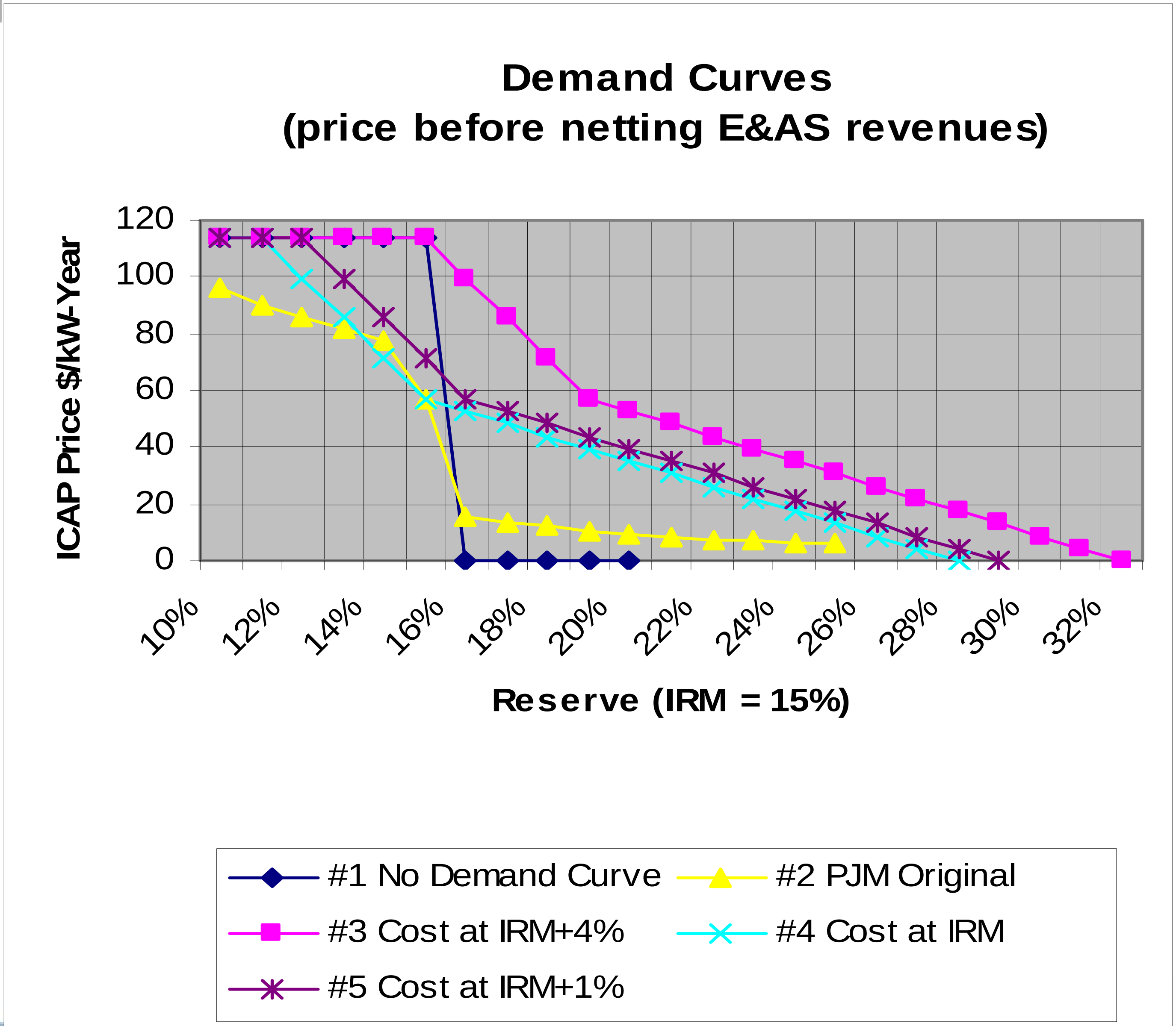
- Percentage of years forecast reserve margin exceeds the requirement for reliability (IRM).
- Avg. excess of forecast reserve over the IRM.

Revenues:

- Scarcity revenue.
- E&AS revenue.
- ICAP revenue.

Generation profit for new entry is the sum of scarcity, E&AS, and ICAP revenues, minus the annualized capital cost.

A portion of the consumer payment is the sum of scarcity and ICAP payments expressed on a peak load basis.


Demand Curves
(price before netting E&AS revenues)
ICAP Price $/kW-Year
120
100
80
60
40
20
0
10%
12%
14%
16%
18%
20%
22%
24%
26%
28%
30%
32%
Reserve (IRM = 15%)
#1 No Demand Curve
#2 PJM Original
#3 Cost at IRM+4%
#4 Cost at IRM
#5 Cost at IRM+1%

Reserve %	Curve 1 No Demand Curve	Curve 2 PJM Original	Curve 3 Cost at IRM + 4%	Curve 4 Cost at IRM	Curve 5 Cost at IRM+1%
10%	114	96	114	114	114
11%	114	90	114	114	114
12%	114	85	114	100	114
13%	114	81	114	86	100
14%	114	78	114	71	86
15%	**114**	**57**	**114**	**57**	71
16%	0	16	100	53	**57**
17%	0	14	86	48	53
18%	0	12	71	44	48
19%	0	11	**57**	39	44
20%	0	9	53	35	39
22%	0	8	44	26	31
24%	0	6	35	18	22
26%	0		26	9	13
28%	0		18	0	4
29%	0		13		0
32%	0		0		

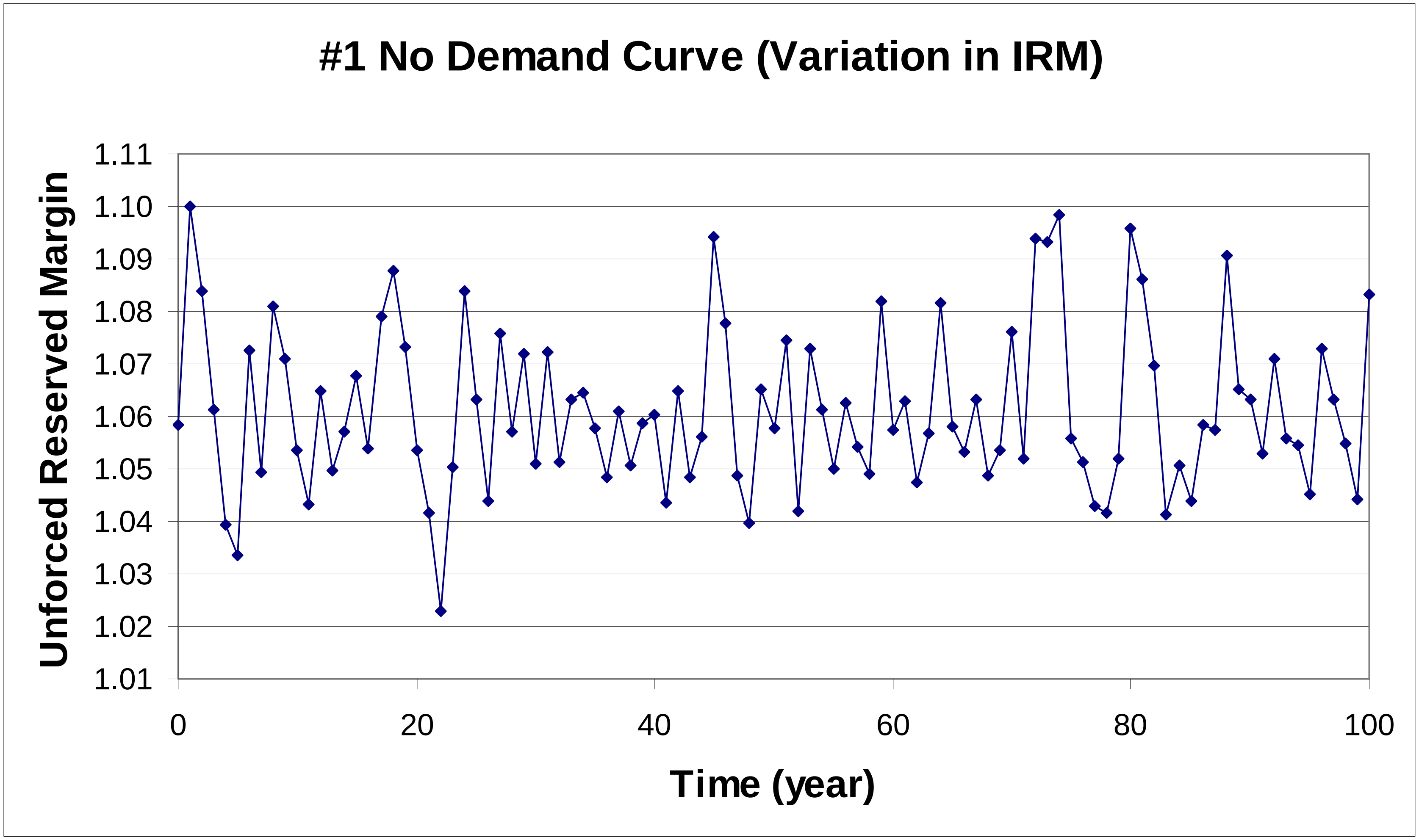
Key Results (Average over 25x100 Year Simulations)

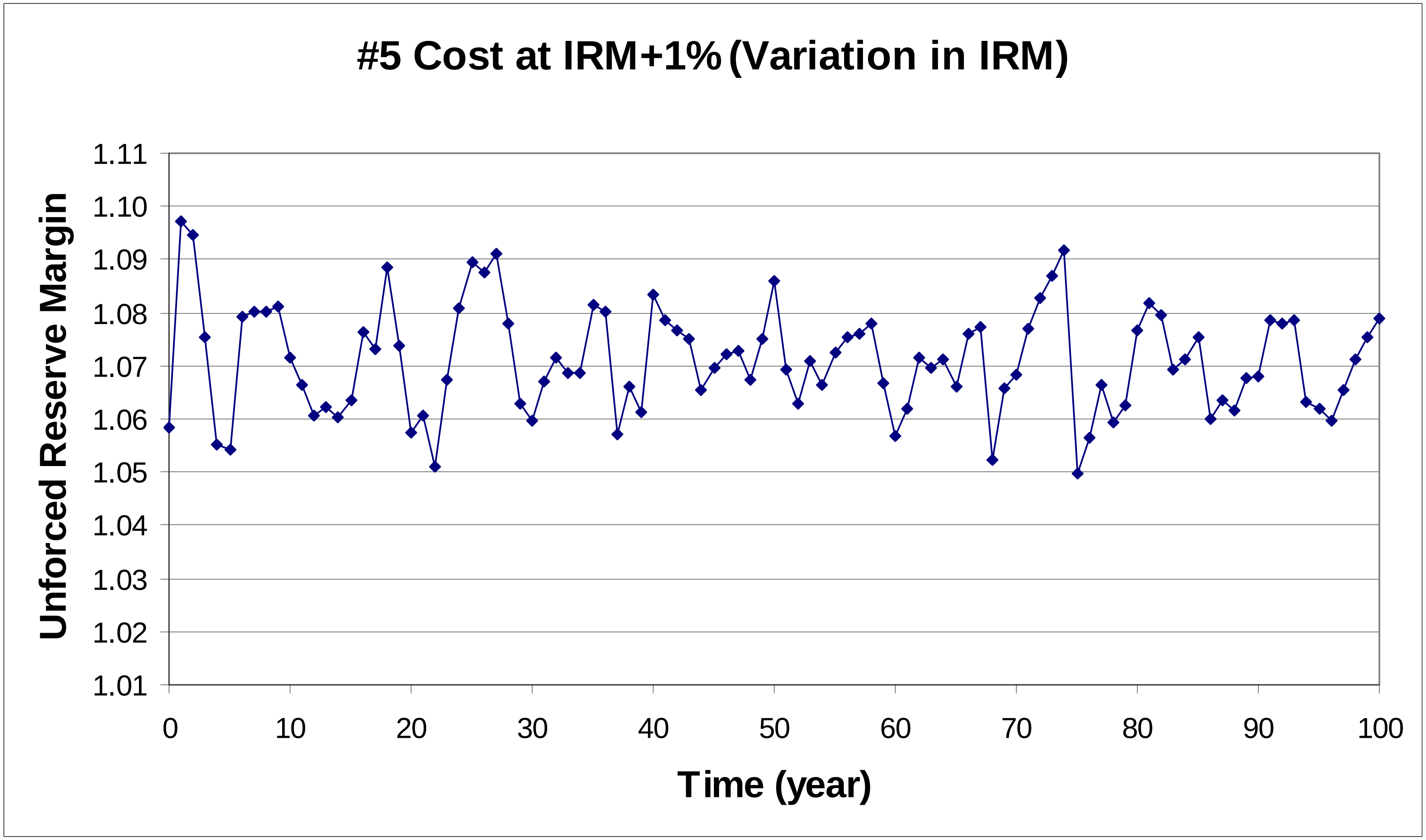
Case	% Years meet or Exceed IRM	Average % Reserve over IRM	Generation Profit Avg. $/kW-yr	Scarcity Revenue $/kW-yr	E&AS Revenue $/kW-yr	ICAP Payment $/kW-yr ($/MW-Day)	Scarcity + ICAP Payment by Consumers (Peak Ld Basis)
1. No Demand Curve	49	0.1	46	41	20	42 (114)	94
2. Original PJM Curve, Based on VOLL	58	0.2	25	39	20	23 (63)	69
3. Alternate Curve with New Entry Net Cost at IRM + 4%	100	3.5	10	15	20	33 (89)	55
4. Alternate Curve with New Entry Net Cost at IRM	70	0.5	22	35	20	24 (66)	67
5. Alternate Curve with New Entry Net Cost at IRM + 1%	92	1.2	18	29	20	26 (71)	63

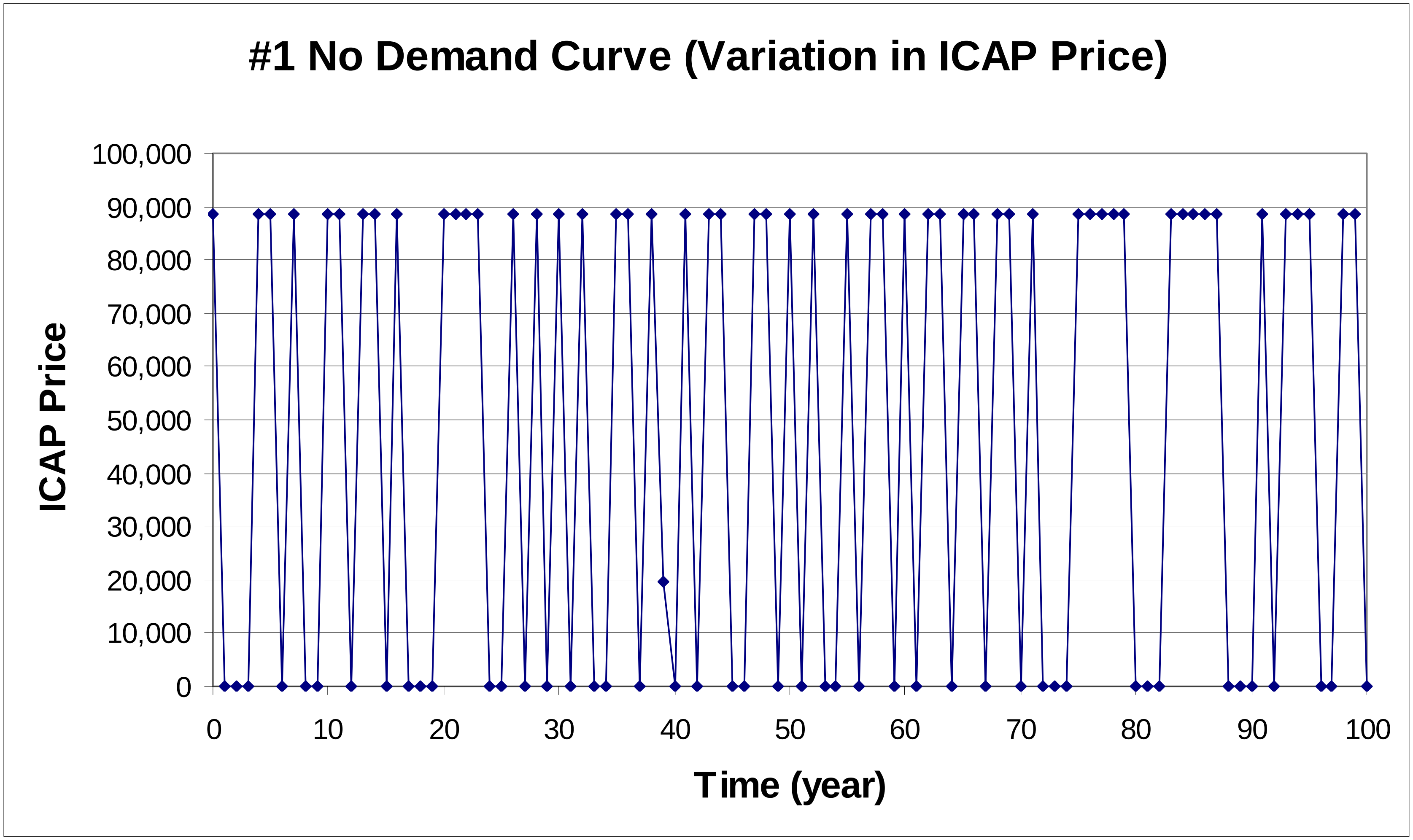
Note: There are some changes since Dec. 9 because of program updates

Key Results: Average (Standard Deviation)

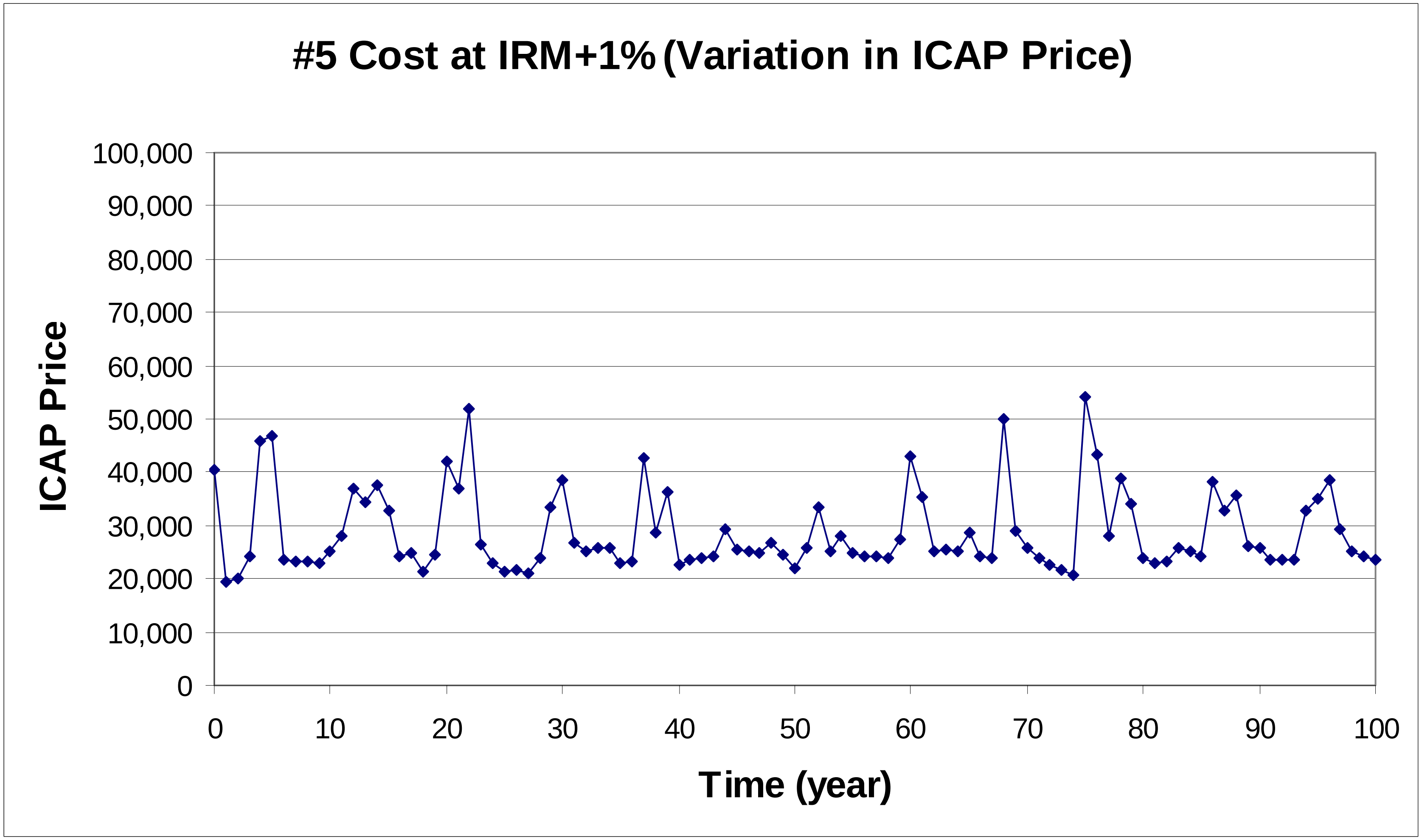
Case	% Years meet or Exceed IRM	Average % Reserve over IRM	Generation Profit $/kW-yr	Scarcity Revenue $/kW-yr	E&AS Revenue $/kW-yr	ICAP Payment $/kW-yr	Scarcity + ICAP Payment by Consumers (Peak Ld Basis)
1. No Demand Curve	49	0.1 (1.5)	46 (93)	41 (78)	20	42 (40)	94 (102)
2. Original PJM Curve, Based on VOLL	58	0.2 (0.8)	25 (74)	39 (73)	20	23 (7)	69 (81)
3. Alternate Curve with New Entry Net Cost at IRM + 4%	100	3.5 (0.9)	10 (37)	15 (34)	20	33 (8)	55 (39)
4. Alternate Curve with New Entry Net Cost at IRM	70	0.5 (1.0)	22 (70)	35 (69)	20	24 (5)	67 (76)
5. Alternate Curve with New Entry Net Cost at IRM + 1%	92	1.2 (0.9)	18 (62)	29 (60)	20	26 (6)	63 (67)


#1 No Demand Curve (Variation in IRM)
Unforced Reserved Margin
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
0
20
40
60
80
100
Time (year)

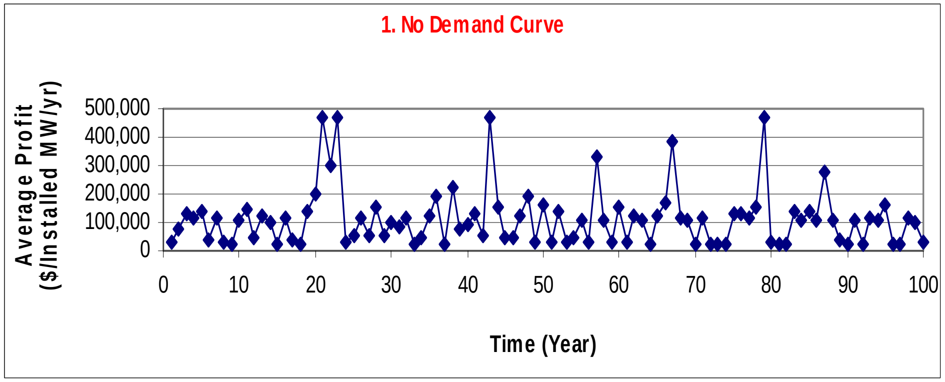

#5 Cost at IRM+1% (Variation in IRM)
Unforced Reserve Margin
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
0
10
20
30
40
50
60
70
80
90
100
Time (year)

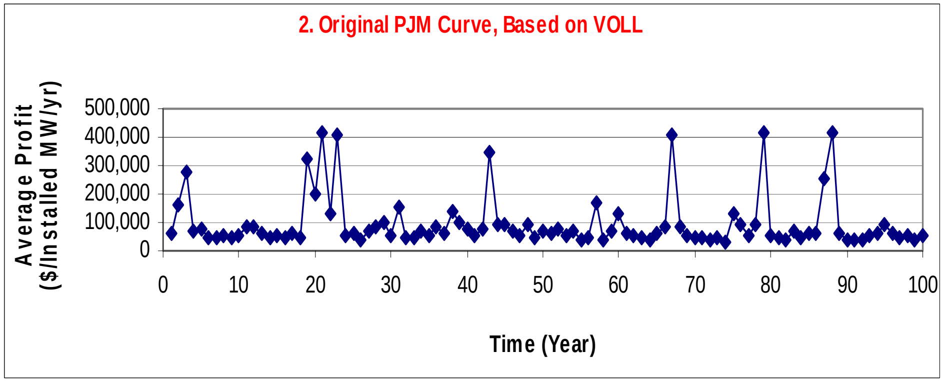


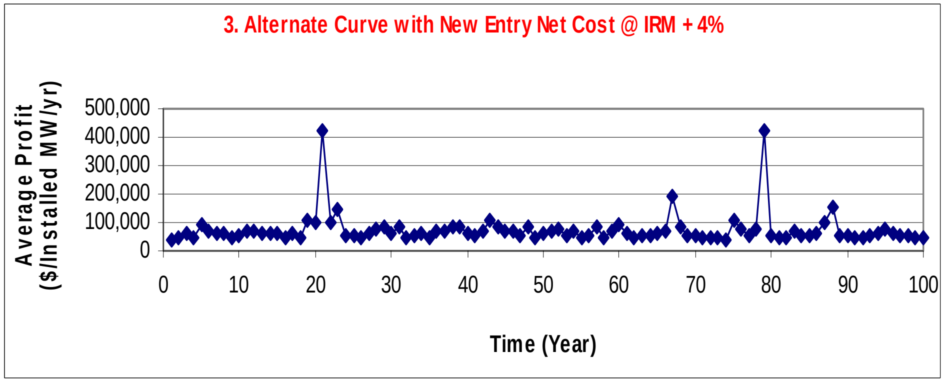
#1 No Demand Curve (Variation in ICAP Price)
ICAP Price
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
10
20
30
40
50
60
70
80
90
100
Time (year)

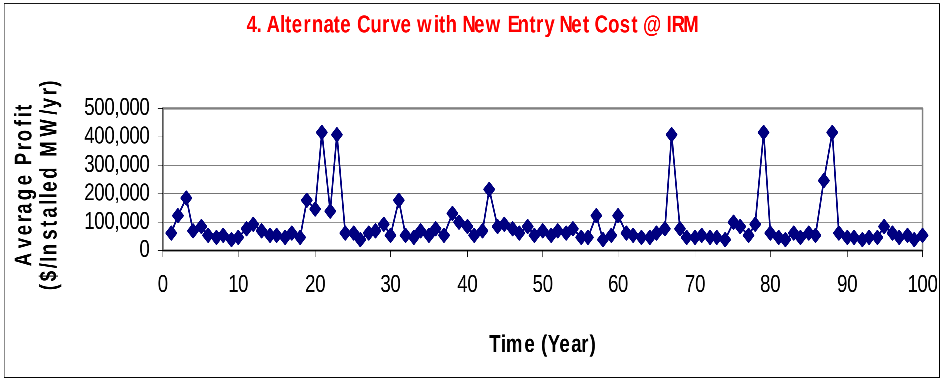

#5 Cost at IRM+1% (Variation in ICAP Price)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
ICAP Price
0
10
20
30
40
50
60
70
80
90
100
Time (year)

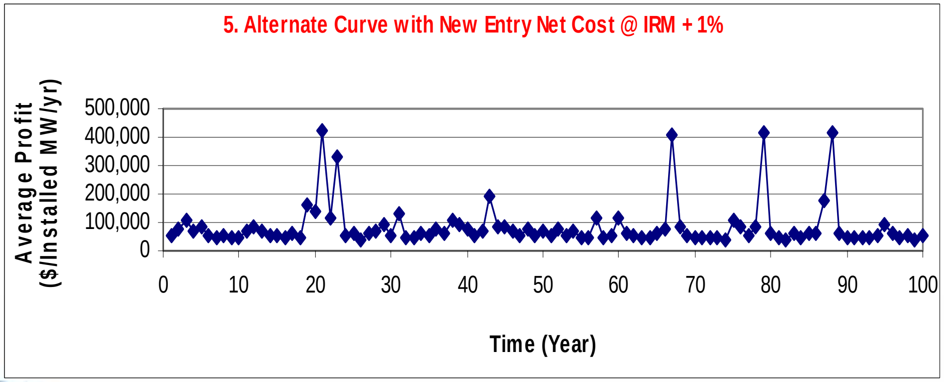
Sample Time Series of Profits for Cases 1-5



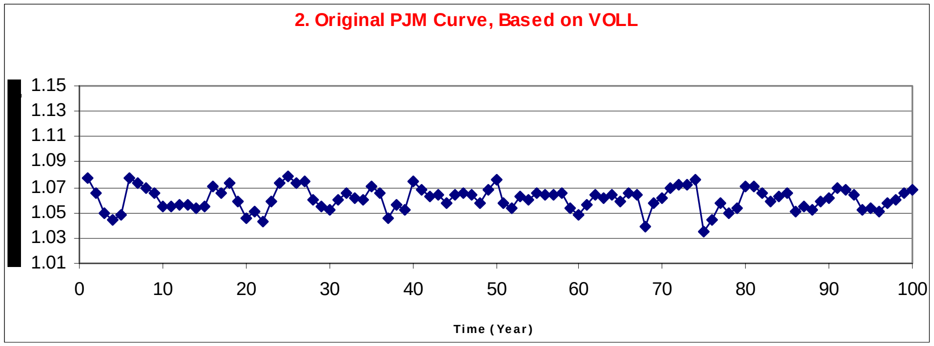


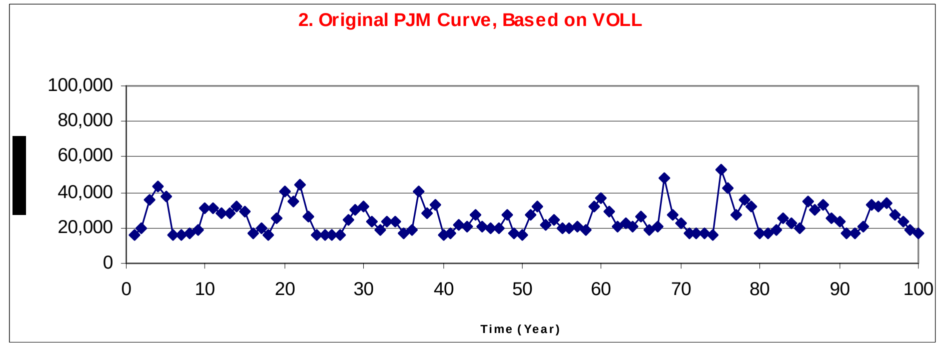


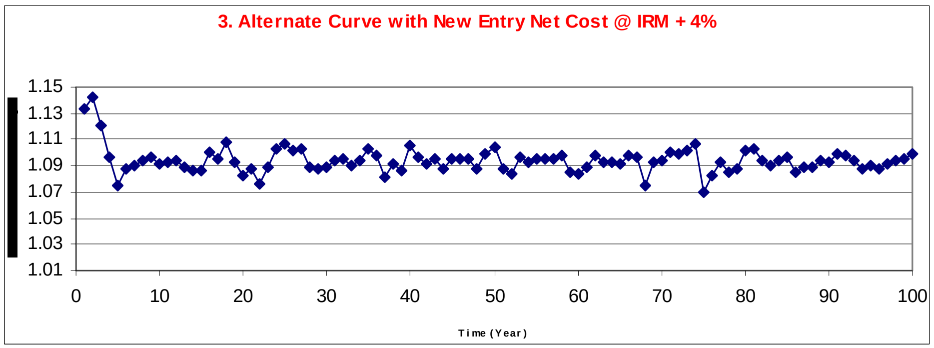


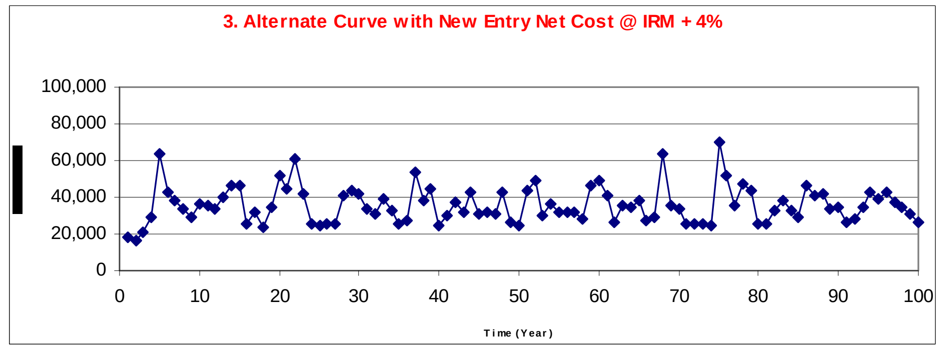


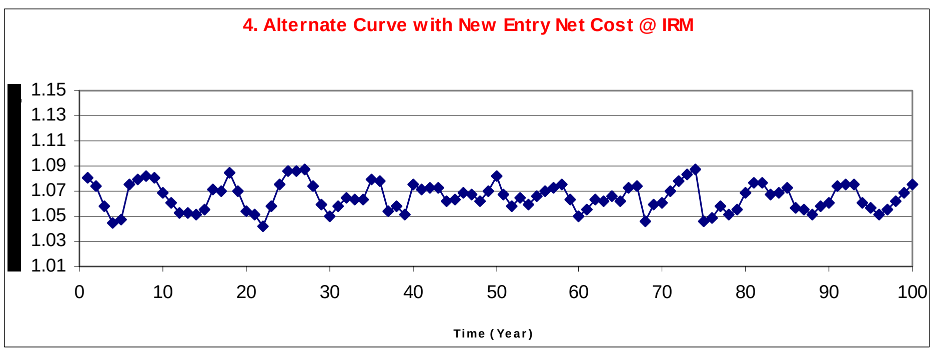
Reserve Margins/ICAP Prices for Cases 2,3, & 4

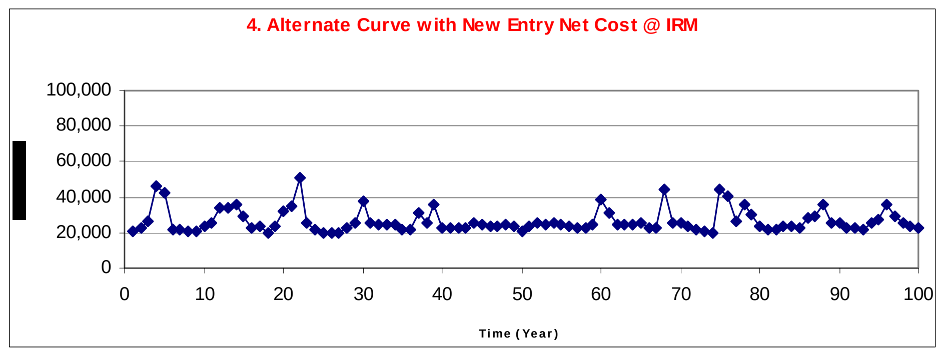










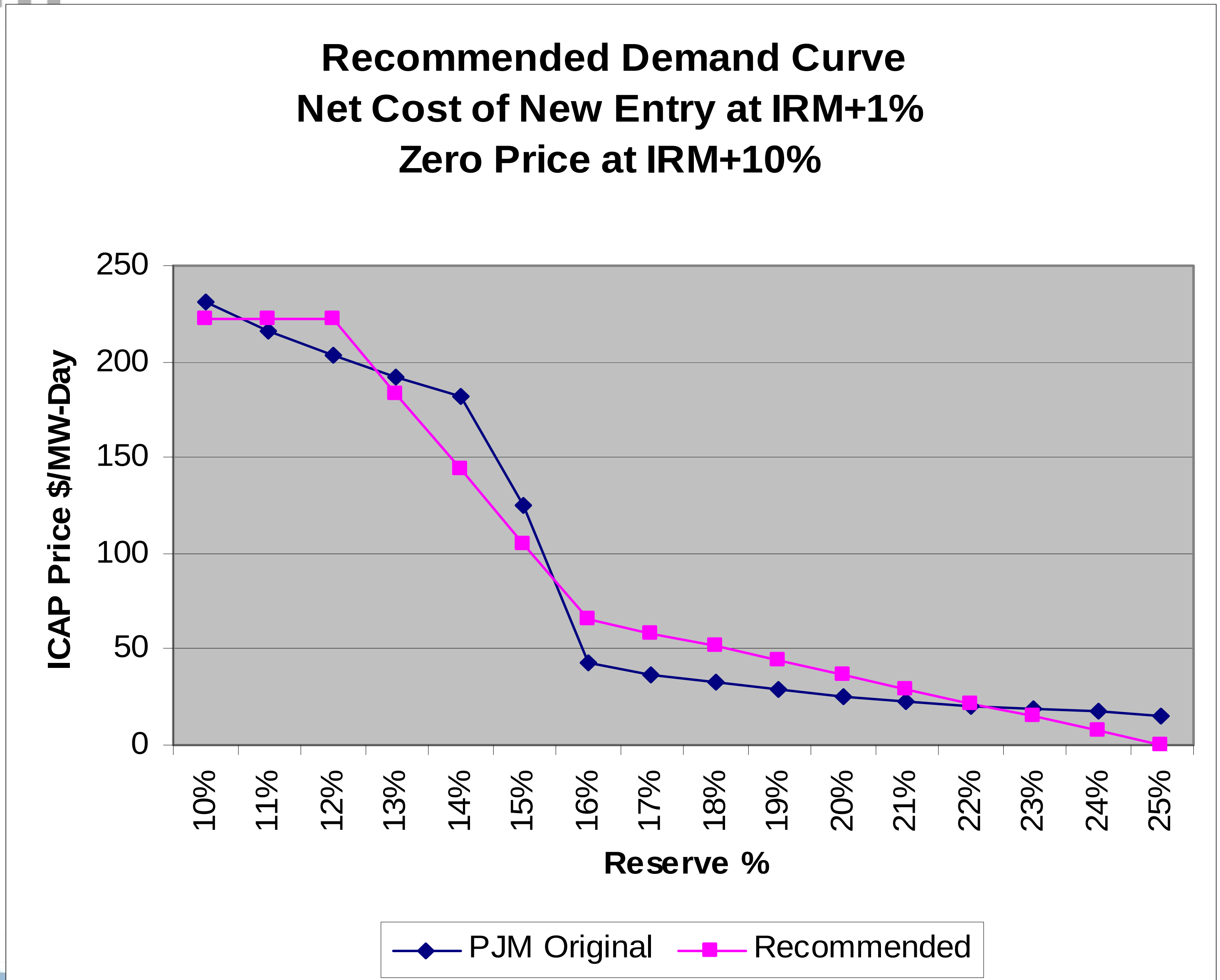


- Shifting the demand curve left or right affects all measures more than changing other parameters.
  - Shifting right increases the average forecast reserves.

- No Demand Curve (Case 1) (today's construct) meets IRM only 49% of time.
  - The scarcity and E&AS payments add to the ICAP price, increasing the consumer payment.

- The PJM Curve based on VOLL (Case 2) does not improve the performance much
  - But the consumer payment is lower relative to Case 1.

- The Alternate Curve with new entry net cost @ IRM+4% (Case 3) meets IRM all years
  - 3.5% excess reserve on the average.
- The Alternate Curve with new entry net cost at IRM (Case 4) meets IRM 70% of time.
- The Alternate Curve with new entry net cost @ IRM+1% meets IRM 92% of time.
  - This curve appears to balance the performance in terms of meeting the IRM without building too much excess reserve and consumer payments.
- The performance of the demand curves appear reasonably robust for changes in investment assumptions.



Recommended Demand Curve
Net Cost of New Entry at IRM+1%
Zero Price at IRM+10%
ICAP Price $/MW-Day
250
200
150
100
50
0
10%
11%
12%
13%
14%
15%
16%
17%
18%
19%
20%
21%
22%
23%
24%
25%
Reserve %
PJM Original
Recommended

Sensitivity Analysis

Demand Curve Assumptions:

- Price drops to zero at IRM+10% and at IRM+5%.
- Max. price: net cost multiplied by 1.5 and 1.2 (base: 2.0).

Investment Assumptions:

- Percent CT added when profit is equal to cost (base: 7%)
  - lower: 5%
  - higher: 9%
- Degree of risk aversion (base 0.7):
  - neutral = 0.5
  - very risk averse = 0.9, heavily penalizing low profit years
- Relative weight placed on prior year profits (base: 0.8):
  - low: 0.6
  - high: 0.9

Sensitivity Analysis of Case 1: No Demand Curve

Sensitivity	% Years meet or Exceed IRM	Average % Reserve over IRM	Generation Profit $/kW-yr	Scarcity Revenue $/kW-yr	E&AS Revenue $/kW-yr	ICAP Payment $/kW-yr	Scarcity + ICAP Payment (Peak Ld Basis)
Base	49	0.08	46	41	20	42	94
Zero price at IRM+10%	49	0.07	46	42	20	42	94
Zero price at IRM+5%	48	0.07	46	41	20	42	94
Max price 1.5 * net cost	42	-0.21	38	44	20	30	84
Max price 1.2 * net cost	32	-0.53	35	48	20	24	81
Lower % CT added	46	-0.06	49	42	20	44	97
Higher % CT added	51	0.26	44	41	20	40	91
Lower risk aversion	75	1.54	13	30	20	20	57
Higher risk aversion	25	-2.41	114	91	20	60	168
Lower wt to prior yr profits	57	0.50	35	37	20	35	81
Higher wt to prior yr profits	47	-0.09	50	44	20	43	98

Sensitivity Analysis of Case 2: Original PJM Curve

Sensitivity	% Years meet or Exceed IRM	Average % Reserve over IRM	Generation Profit $/kW-yr	Scarcity Revenue $/kW-yr	E&AS Revenue $/kW-yr	ICAP Payment $/kW-yr	Scarcity + ICAP Payment (Peak Ld Basis)
Base	58	0.16	25	39	20	23	69
Zero price at IRM+10%	58	0.16	25	39	20	23	69
Zero price at IRM+5%	58	0.16	25	39	20	23	69
Max price 1.5 * net cost	53	0.05	26	40	20	23	70
Max price 1.2 * net cost	49	-0.08	27	42	20	22	71
Lower % CT added	56	0.12	26	39	20	24	71
Higher % CT added	59	0.18	24	38	20	23	69
Lower risk aversion	66	1.35	16	32	20	21	59
Higher risk aversion	44	-0.22	34	44	20	27	80
Lower wt to prior yr profits	66	0.13	24	38	20	23	69
Higher wt to prior yr profits	56	0.23	28	40	20	25	73

Sensitivity Analysis of Case 3: New Entry Cost at IRM + 4%

Sensitivity	% Years meet or Exceed IRM	Average % Reserve over IRM	Generation Profit $/kW-yr	Scarcity Revenue $/kW-yr	E&AS Revenue $/kW-yr	ICAP Payment $/kW-yr	Scarcity + ICAP Payment (Peak Ld Basis)
Base	100	3.51	10	15	20	33	55
Zero price at IRM+10%	100	3.51	10	15	20	33	55
Zero price at IRM+5%	100	3.42	11	15	20	33	56
Max price 1.5 * net cost	100	2.99	12	17	20	31	56
Max price 1.2 * net cost	97	2.15	14	22	20	29	59
Lower % CT added	100	3.44	12	15	20	34	57
Higher % CT added	100	3.56	10	14	20	32	55
Lower risk aversion	100	4.23	7	13	20	31	51
Higher risk aversion	100	3.25	15	16	20	36	61
Lower wt to prior yr profits	100	3.42	10	15	20	33	56
Higher wt to prior yr profits	99	3.63	13	15	20	34	58

Sensitivity Analysis of Case 4: New Entry Cost at IRM

Sensitivity	% Years meet or Exceed IRM	Average % Reserve over IRM	Generation Profit $/kW-yr	Scarcity Revenue $/kW-yr	E&AS Revenue $/kW-yr	ICAP Payment $/kW-yr	Scarcity + ICAP Payment (Peak Ld Basis)
Base	70	0.54	22	35	20	24	67
Zero price at IRM+10%	70	0.54	22	35	20	24	67
Zero price at IRM+5%	57	0.13	26	39	20	24	71
Max price 1.5 * net cost	65	0.44	23	36	20	24	67
Max price 1.2 * net cost	61	0.32	24	37	20	23	68
Lower % CT added	67	0.50	23	35	20	25	68
Higher % CT added	73	0.57	21	35	20	24	66
Lower risk aversion	74	1.62	14	29	20	22	58
Higher risk aversion	65	0.21	28	38	20	26	73
Lower wt to prior yr profits	86	0.39	21	36	20	23	66
Higher wt to prior yr profits	66	0.72	24	35	20	26	69

Sensitivity Analysis of Case 5: New Entry Cost at IRM + 1%

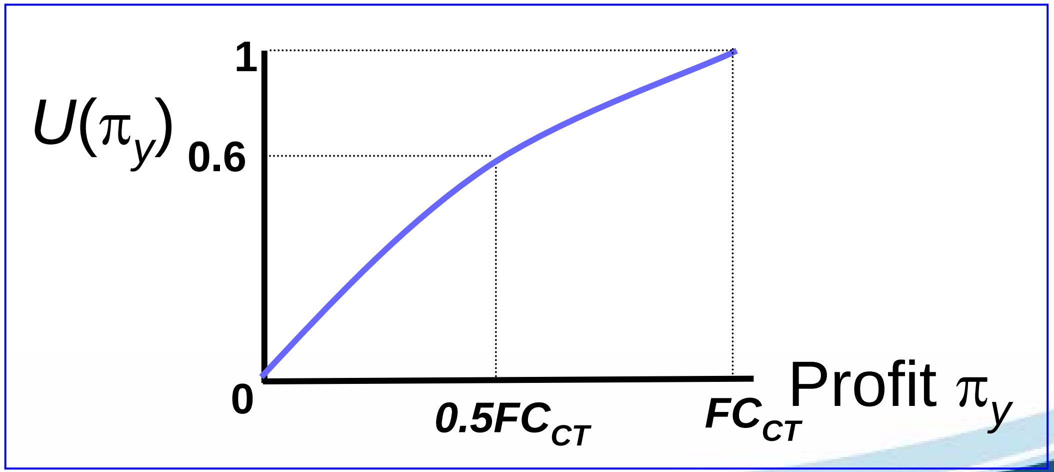
Sensitivity	% Years meet or Exceed IRM	Average % Reserve over IRM	Generation Profit $/kW-yr	Scarcity Revenue $/kW-yr	E&AS Revenue $/kW-yr	ICAP Payment $/kW-yr	Scarcity + ICAP Payment (Peak Ld Basis)
Base	92	1.15	18	29	20	26	63
Zero price at IRM+10%	92	1.15	18	29	20	26	63
Zero price at IRM+5%	91	0.92	20	31	20	26	65
Max price 1.5 * net cost	84	0.96	20	31	20	25	64
Max price 1.2 * net cost	74	0.72	21	33	20	24	66
Lower % CT added	88	1.12	19	30	20	27	64
Higher % CT added	94	1.16	18	29	20	26	62
Lower risk aversion	90	2.09	12	25	20	24	56
Higher risk aversion	85	0.85	23	32	20	28	68
Lower wt to prior yr profits	100	0.98	18	30	20	25	62
Higher wt to prior yr profits	81	1.33	20	29	20	28	65

Details of the Methodology

- Three types of loads:
  - *Forecast* Load (at time of ICAP auction):
    - Based on 1.7%/yr growth
  - *Weather Normalized* Load
    - 1.7%/yr average growth
    - 1%/yr variation in growth rate (standard deviation)
  - *Actual* Load
    - 4% error (standard deviation) relative to W/N load
- *Forecast* reserve margin as a measure of investment cycles
- *Actual* Reserve Margin used to estimate scarcity revenues (Energy/AS gross margins)

- Actual and anticipated CT profits π_y (in \$/installed kW/yr)
  - π_y = Total E/AS Profit + P_{ICAP} (adjusted for outages)
    = Normal E/AS Profit + Scarcity Revenue + P_{ICAP}
  - Actual profits assumed known for years up to and including the year *y-4* in which the auction takes place
  - Actual ICAP price assumed known for *y-3, y-2, y-1*, and E/AS gross margins are estimated
  - ICAP price and E/AS gross margin estimated for year *y*

- Utility function used to capture risk attitudes
  - Standard "negative exponential" form used by decision analysts
  - $U(\pi_y) = a - be^{-c\pi_y}$
- *a*, *b*, and *c* are parameters
  - *c* reflects degree of "risk aversion" (curvature)
- Calibrated so that:
  - $U(\pi_y = 0) = 0$
  - $U(\pi_y = FC_{CT}) = 1$
  - $U(\pi_y = 0.5FC_{CT}) = 0.6$ (indicating a somewhat but not extreme risk aversion)



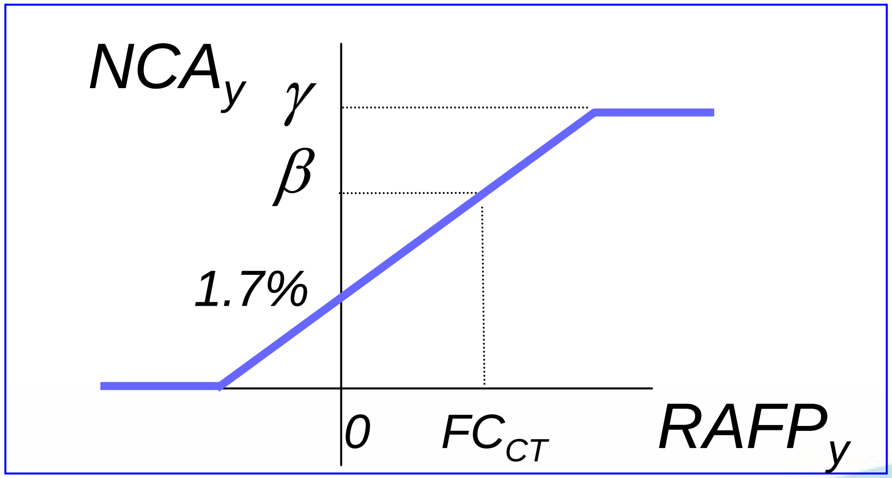
- Expected utility calculated by weighting utilities from each year:
  - $WU_Y = \Sigma_{y=Y, Y\text{-}1, .., Y\text{-}7} W_{Y-y} U(\pi_y)$

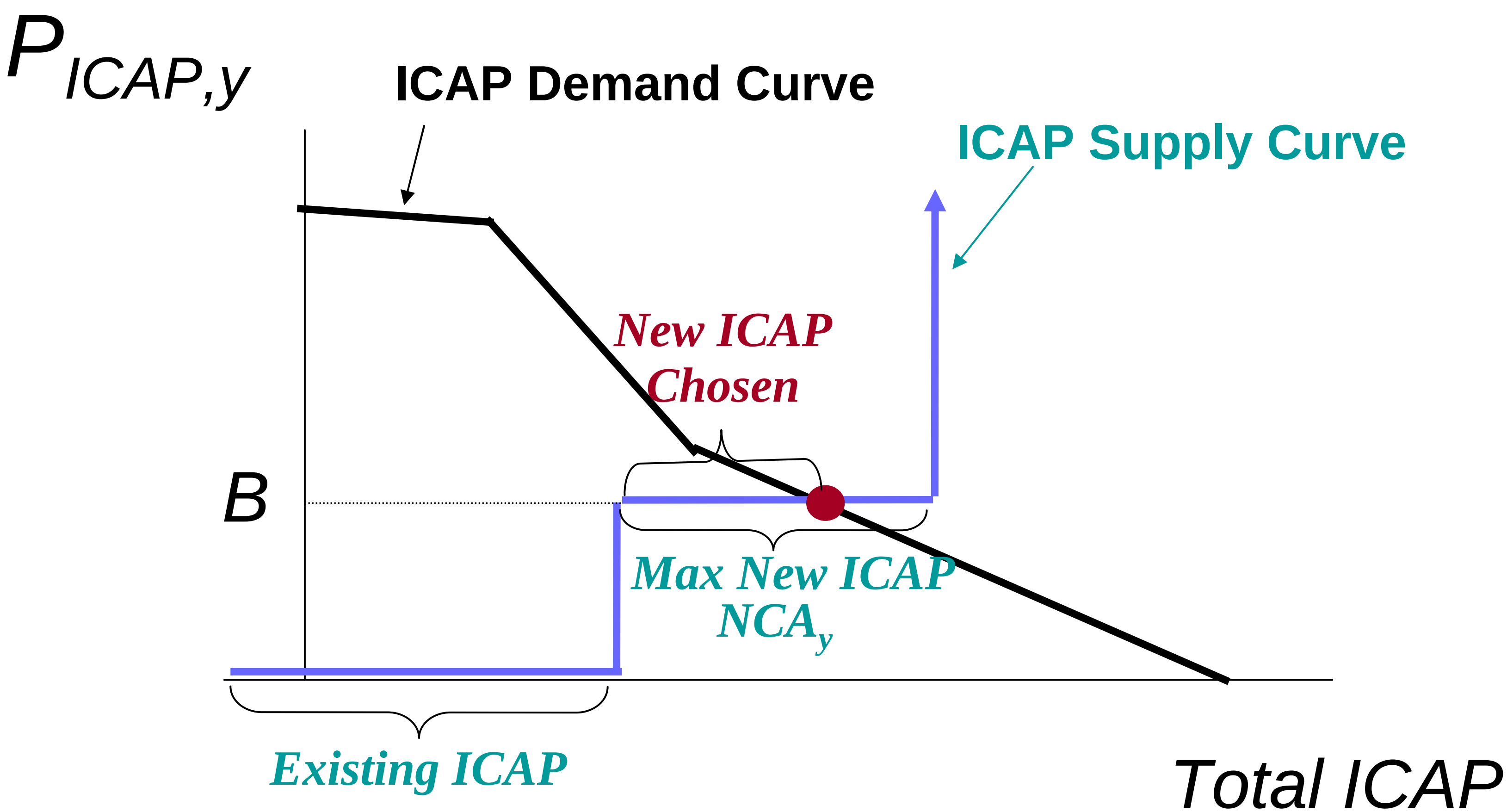
    $= .05U(\pi_{Y-7}) + .06U(\pi_{Y-6}) + .08U(\pi_{Y-5}) + .10U(\pi_{Y-4}) + .12U(\pi_{Y-3})$

    $+ .15U(\pi_{Y-2}) + .19U(\pi_{Y-1}) + .24U(\pi_{Y-7})$
  - Weights based on "distributed lag" model:

    $W_{y-1} = 0.8W_y$
- $RAFP_y$ is the single (equivalent) value of profit that gives the same utility: $U(RAFP_y) = WU_Y$
  - That is, $RAFP_y$ in all eight years gives same expected utility as the actual/forecasted profits π_y
  - $RAFP_y$ is less than average profit if profits are uncertain and generator is risk averse
  - Greater risk aversion (parameter c) results in greater difference between average profit and $RAFP_y$

- Maximum new capacity additions NCA_y are related to risk-adjusted forecast profit as follows:
  - if $RAFP_y$ is zero, NCA_y is 1.7% of existing capacity
    - So if all profits in every year are zero, then capacity growth would be just enough to meet the assumed average load growth
  - if $RAFP_y = FC_{CT}$, then $NCA_y = \beta$ percent of existing capacity
    - β > 1.7% of existing capacity
  - NCA_y at other values of RAFP follow a curve that is the same shape as the utility function, except that:
    - $NCA_y \geq 0\%$
    - $NCA_y \leq \gamma\%$



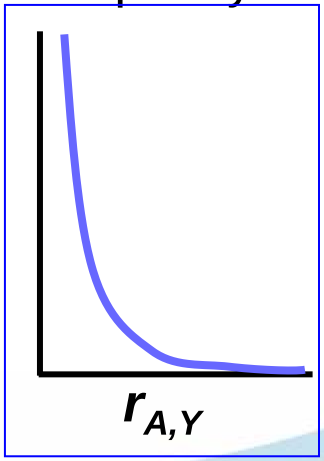

$P_{ICAP,y}$
ICAP Demand Curve
ICAP Supply Curve
New ICAP Chosen
B
Max New ICAP
NCA_y
Existing ICAP
Total ICAP

In a given year *y*:

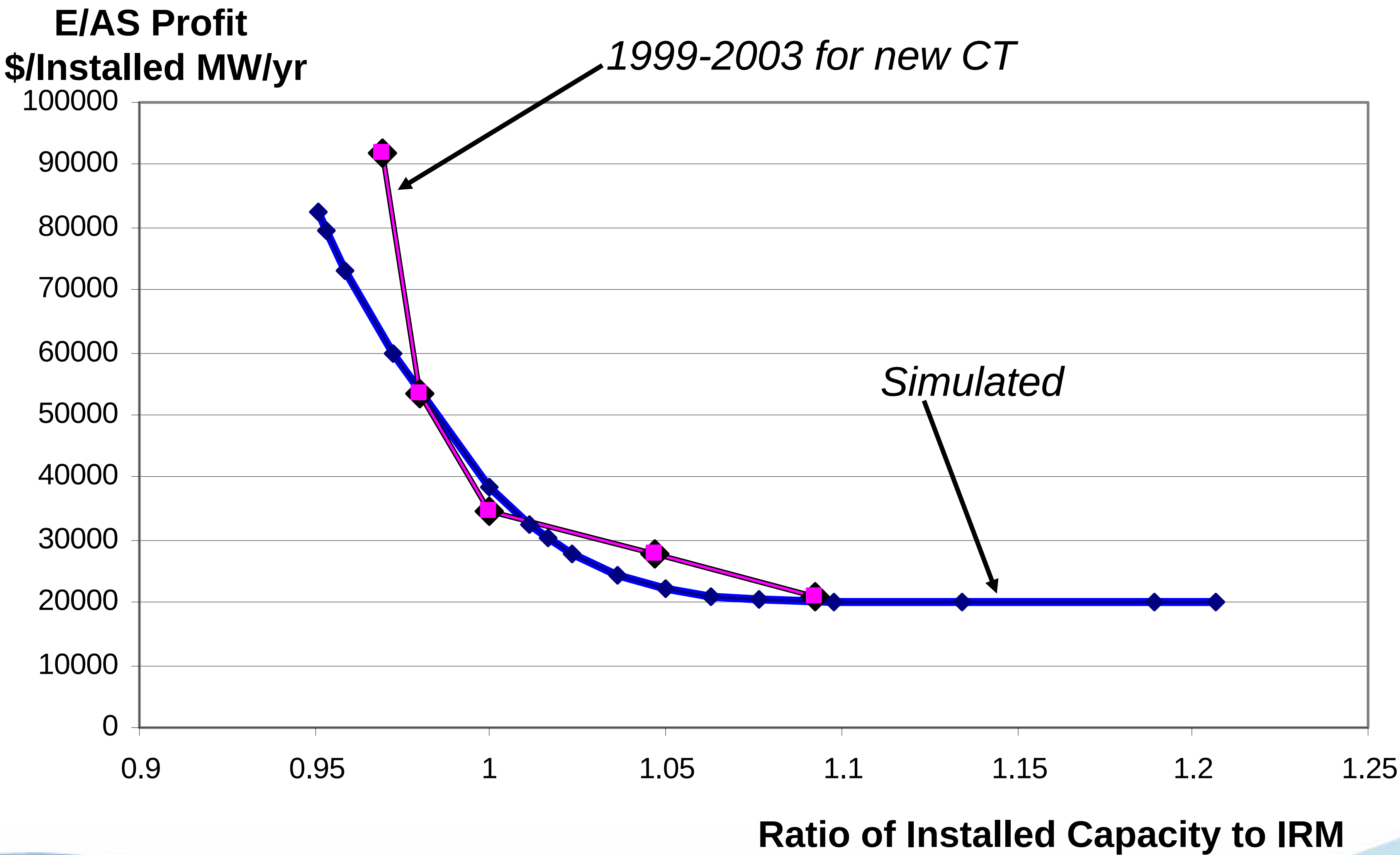
1. Calculate actual Energy/Ancillary Services profit in year *y*
   - Based on actual load
   - Calculate W/N load using random load growth, then add weather error
2. Forecast load in y+4 using 1.7%/yr growth rate
3. Construct demand curve for ICAP auction for capacity to be installed in year y+4
4. Calculate $RAFP_{y+4}$
   - Forecast P_{ICAP} for this auction based on nominal growth in capacity
   - Calculate actual and forecast profits
   - Calculate expected utility
5. Calculate Maximum New Capacity Additions NCA_{y+4}
6. Combine ICAP demand and supply curves to get P_{ICAP} and actual installed capacity in y+4
7. Go to next year: $y \leftarrow y+1$

Then repeat 100 times for each simulation

- Fixed cost of CT, including "normal" return to equity
  - $57/kW/yr
- Normal E&AS Profits
  - $20/kW/yr
  - Based on analysis of 1999-2003 profits earned by standard CT
- Scarcity Revenues:
  - Equals $exp(a_0 + a_1 r_{A,y} + a_2 r_{A,y}^2 + a_3 r_{A,y}^3)$, based on actual reserve margin $r_{A,y}$
  - Coefficients fit to output of production costing model, assuming that price goes to cap when load is within 8.4% of available capacity
  - Fits1999-2003 data reasonably well (next slide)
- LOLP:
  - Equals $\exp(b_0 + b_1 r_{A,y} + b_2 r_{A,y}^2 + b_3 r_{A,y}^3)$
  - Coefficients fit to output of production costing model



Total E/AS Profit as Function of Actual Reserve



Questions???

