The Effect of Capacity Payments on Peaking Generator Availability in PJM

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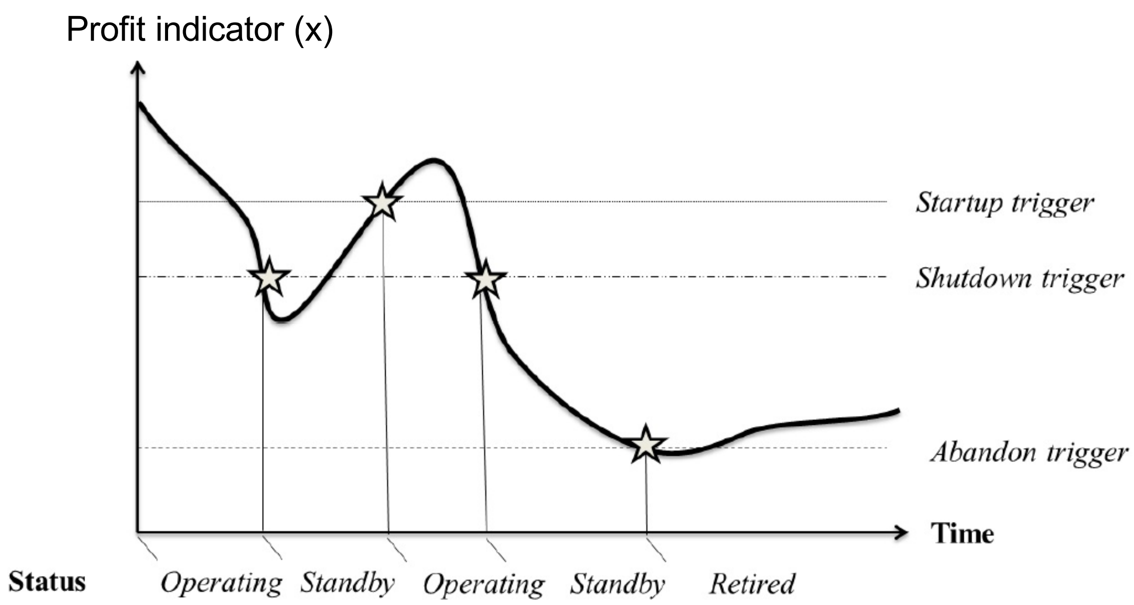
Motivation

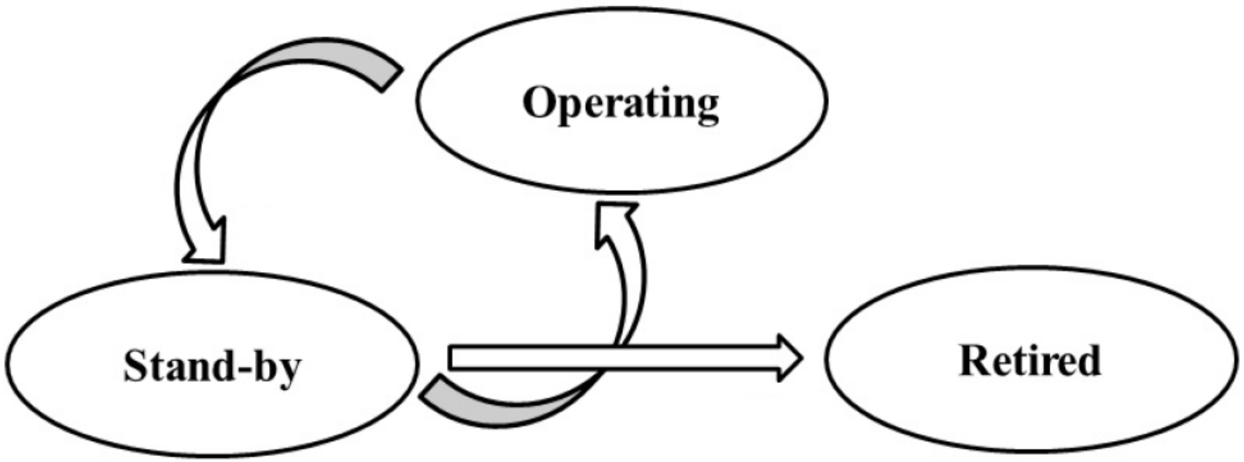
- Peaking power plants = cornerstones
- Missing money problem -> capacity remuneration (Joskow 2008)
- Unknown: cost of starting up a plant from mothball state, mothballing and retirement cost
  - Hard to determine in practice
- Estimate irreversible switching costs associated with economic state changes
  - Asset valuation

Background: real options

- Profitability in $/unit capacity
- Usual to assume MR or GBM; we use a nonparametric approach



- How does profitability indicators, environmental regulation and strategic interaction affect thermal peak generators decisions to switch between operating-ready and stand-by states
- Brennan and Schwartz (1985)
- Status changes
    - Shutdown
    - Startup
    - Abandonment



Structural estimation problem

- Maximize log likelihood
  - Likelihood of observing plant status given state variables: profitability in $/kW and plant status last year
- Subject to
  - Decision makers behave according to our real options switching specification
  - Forming expectations according to how the profitability indicator have been ”transitioning” in the past (k-means clustering)
- Output
  - Value functions: value for different profitability levels given OP or SB state
  - Switching and maintenance cost parameters

Current year profit function

$$g(X,s;u)=\begin{cases} P-M_{OP} & \text{if } s=\text{operating and } u=\text{operating,}\\ P/2-M_{OP}/2-M_{SB}/2-K_{SD}(\,) & \text{if } s=\text{operating and } u=\text{standby,}\\ P/2-M_{OP}/2-M_{SB}/2-K_{SU}(\,) & \text{if } s=\text{standby and } u=\text{operating,}\\ -M_{SB} & \text{if } s=\text{standby and } u=\text{standby,}\\ -M_{SB}/2-K_{RE}(\,) & \text{if } s=\text{standby and } u=\text{retired,}\\ & \text{else.} \end{cases}$$

- Parameters to be estimated:

M_{OP} = maint. cost in OP state
M_{SB} = maint. cost in OP state
K_{SD} = shutdown cost = $\gamma_0 + \gamma^T X$
K_{SU} = start up cost = $\lambda_0 + \lambda^T X$
K_{RE} = abandonment cost = $\eta_0 + \eta^T X$

Application: Peak power plants

- Main data source: EIA Form 860
  - Required annual filing
  - Information on every generator in US
  - Includes existing and planned

- EIA = Energy Information Administration

www.eia.gov

- Sample period 2001-2016
  - EIA 860 (data source) format changes in 2001
- Focus on peaking plants (CTs)
  - Natural gas and #2 oil
- Final sample:
  - 1,000+ unique generators

Photo: calpine.com

Spark spread (*$/MWh*) and profit indicator P_i ($/kW), year *i*

$$SPRD_{pjn} = PE_n - HR_p\, PF_{jn} - VOM_p$$

- PE_n = day *n* elec price
- HR_i = heat rate for plant *p*
- $PF_{j,n}$ = day *n* fuel price for fuel *j*
- VOM_p = variable O&M costs for plant *p*

➢ **Profit indicator P_i is pre-calculated as**

$$P_i = \sum_{n=1}^{T_i} \max\left(SPRD_n, 0\right) * \left(\frac{16}{1000\, kW/MW}\right)$$

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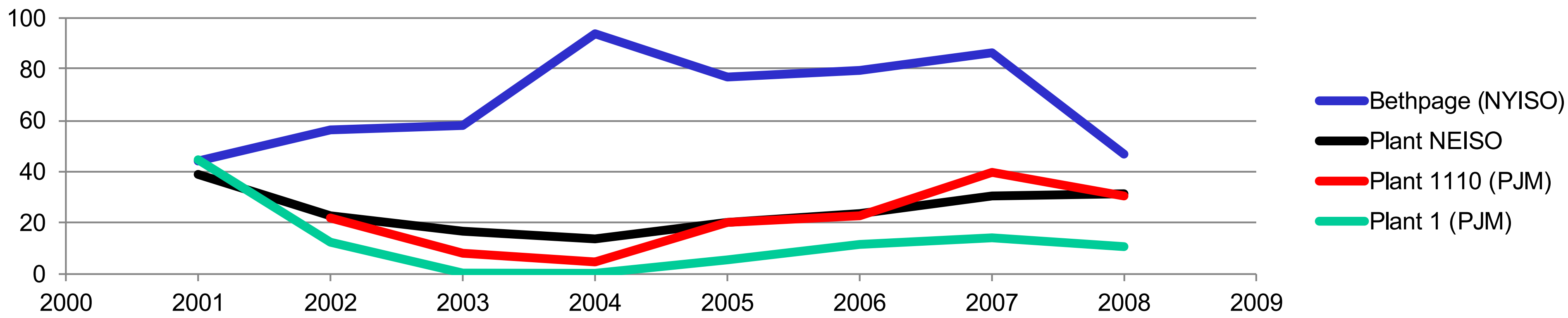
Data summary

- An observation is a triple (X_i, s_i, u_i)

i. the operating state of the power plant s_i in the current year,

ii. the exogenous state X_i (base case = P_i) during the year, and,

iii. the decision of the manager regarding the operating state u_i of the power plant in the upcoming year.



Assumptions

- Discount factor $\beta = 0.91$.
- Coefficients constrained nonnegative except K_RE.
- St.dev of estimates in parantheses. Found by nonparametric bootstrapping.

Finally: estimated coefficients

M_{OP}	$E(M_{SB})$	σ_{M_OP}	K_{SD}	$E(K_{SU})$	σ_{K_SU}	K_{RE}
8.5	2.45	0.16	0.0	0.79	0.46	-31.3
(1.22)	(1.03)	(0.18)	(0.0)	(1.32)	(0.77)	(11.0)

Interpretation: Assuming plant managers behave according to our decision model, these are the implied costs.

M_{OP} = maint. cost in OP state
M_{SB} = maint. cost in OP state
K_{SD} = shutdown cost
K_{SU} = start up cost
K_{RE} = abandonment cost (salvage value)

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Discounting at 5%

β=0.95

M_{OP}	$E(M_{SB})$	σ_{M_OP}	K_{SD}	$E(K_{SU})$	σ_{K_SU}	K_{RE}
9.32	3.23	0.05	0.0	0.56	0.32	-49.0
(1.28)	(1.06)	(0.10)	(0.0)	(1.36)	(0.79)	(22.5)

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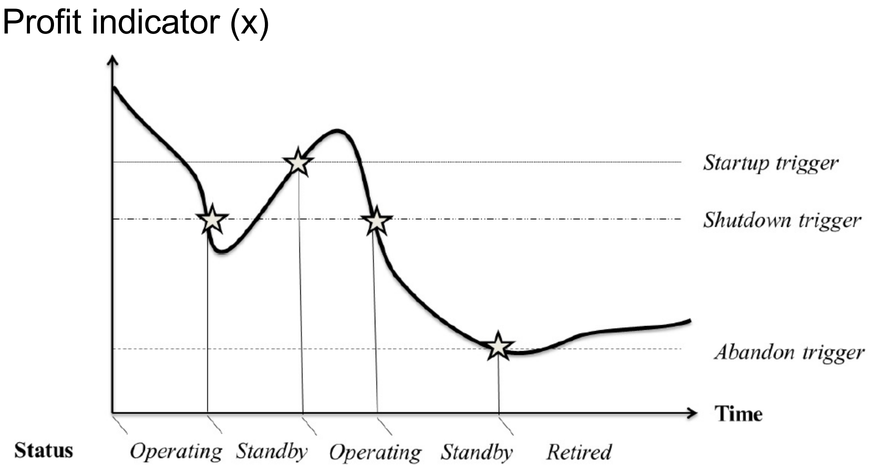


Statnett (Norwegian ISO) announcement April 2015

- 170 Mill NOK used over 5.5 years for 300 MW peak plants, 150 MW to be sold.
- 170 mill NOK/(5.5 yr * 300 MW) = 103 NOK/(yr*kW) = **13.4** USD/(yr/kW) (at 7.7 NOK/USD).
- Our 95% range: M_{OP} is [-1, 15] USD/(yr/kW) ☺

Photo: Shell

Photo: nrk.no

PJM study

- PJM only

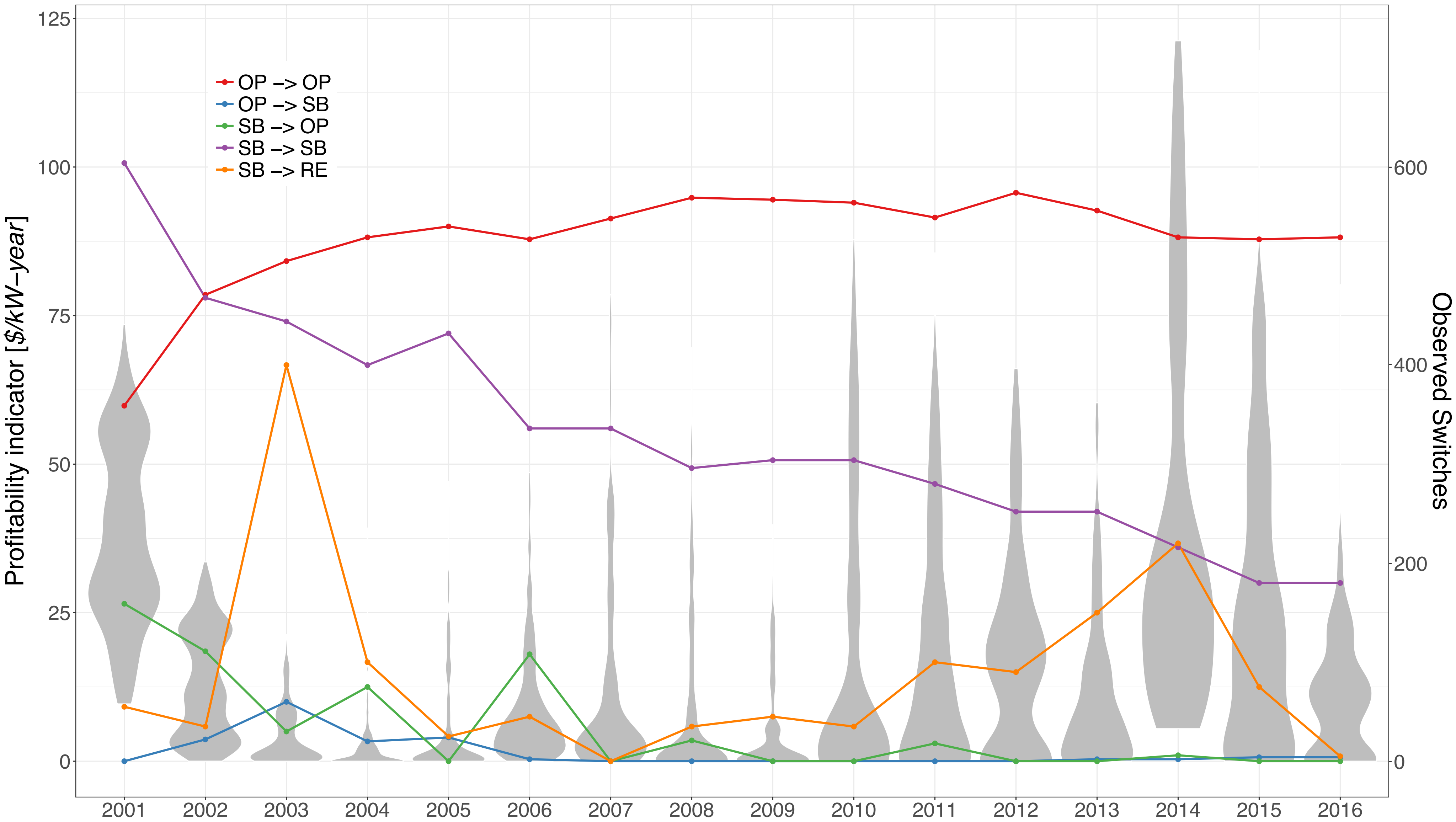
	Current state	*OP*		*SB*		
	Switching to	*OP*	*SB*	*OP*	*SB*	*RE*
	Number of observations	3479	64	161	755	76
2001-2007	Share	98.2 %	1.8 %	16.2 %	76.1 %	7.7 %
	Average profitability	12.28	5.85	14.25	13.00	5.58
	Number of observations	4435	4	15	521	32
	Share	99.9 %	0.1 %	2.6 %	91.7 %	5.6 %
2008-2016	Energy-only profitability	18.50	11.64	15.67	7.88	9.25
	Capacity payments	40.22	58.59	29.17	45.10	50.91
	Average profitability	58.72	70.23	44.84	52.98	60.15

Results PJM 2001-2007

	M_{OP}	M_{SB}	$K_{SB \to OP}$	$K_{OP \to SB}$	$K_{SB \to RE}$
Estimate $[\$/kW - year]$	9.127	0.409	1.911	0.436	-56.066
Significance level	1%	-	-	-	1%

Recall previous slides 5%

M_{OP}	$E(M_{SB})$	K_{SD}	$E(K_{SU})$	K_{RE}
9.32	3.23	0.0	0.56	-49.0
(1.28)	(1.06)	(0.0)	(1.36)	(22.5)



OP –> OP
OP –> SB
SB –> OP
SB –> SB
SB –> RE
Profitability indicator [$/kW–year]
Observed Switches
125
100
75
50
25
0
600
400
200
0
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Descriptive statistics for PJM study state variables

Profitability indicator

$$P_{n,t}^{CM} = \sum_{d=1}^{T_t} max(S_{n,d,t}^{CM}, 0) * \left(\frac{16}{1000kWMW^{-1}}\right)$$

$$S_{n,d,t}^{CM} = P_{n,d}^{e} - H_{n,t} * P_{n,d}^{f} - V_{n,t} + P_{n,t}^{c}$$

Strength of competition

$$C_{t,n} = \frac{H_{t,n}}{\bar{H}_{t,n}}$$

Changes in gas prices

$$P_t^{NG} = \overline{P^{NG}}_t - \overline{P^{NG}}_{t-1}$$

Env. regulation

$$R_t = \begin{cases} 1 & \text{if } t \in [2002, 2003, 2010, 2011, 2012, 2013, 2014] \\ 0 & \text{else} \end{cases}$$

	P_t^{CM}	C_t	P_t^{NG}	R_t
Min	0	0.62	-4.92	0
Max	199.40	2.17	3.03	1
Average	37.42	1.00	-0.08	0.38

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How is switching behavior affected by state variables?

	Estimated value
M_{OP}	33.565 (***)
M_{SB}	0 (***)
$K_{SB \rightarrow OP}$	
Intercept	0
C_i	22.457
P_i^{NG}	2.074 (*)
R_i	-14.281 (***)
$K_{OP \rightarrow SB}$	
Intercept	1.233
C_i	-38.628 (**)
P_i^{NG}	-7.435 (***)
R_i	13.049 (***)
$K_{SB \rightarrow RE}$	
Intercept	-80.807 (***)
C_i	-69.147 (***)
P_i^{NG}	-1.465 (**)
R_i	10.155 (**)
Observations	10401
Note:	*p<0.1; **p<0.05; ***p<0.01

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PJM capacity market

- Generators get paid for available capacity
- ”Avoidable cost rates”

  $ACR = M_{OP} – K_{SD} – M_{SB} – K_{SU}$
- Our estimates imply ACRs in the range $14.1- 16.55/MW-day
- Default PJM range $17 - 30/MW-day
- Are consumers paying too much for reliability?

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Conclusions

- Real options theory is a useful lens for interpreting the power plant status data
- The degree of local competition, natural gas price changes and environmental regulation affects switchings
- Our method gives reasonable switching cost estimates
  - Useful for design of capacity markets

Discussion

- Peak power plants provide quick-start and load-following capacity
- Massive shutdowns could endanger system reliability
- Capacity payments/markets
  - Payment calculations should account for the cost incurred in shutdowns
- Policy makers should take into account e.g. restart cost for mothballed plants

Thank you for listening…

- Comments and questions ?
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