JAMES MADISON UNIVERSITY

Policy Uncertainty and Real Options in Switching of Peak Generators

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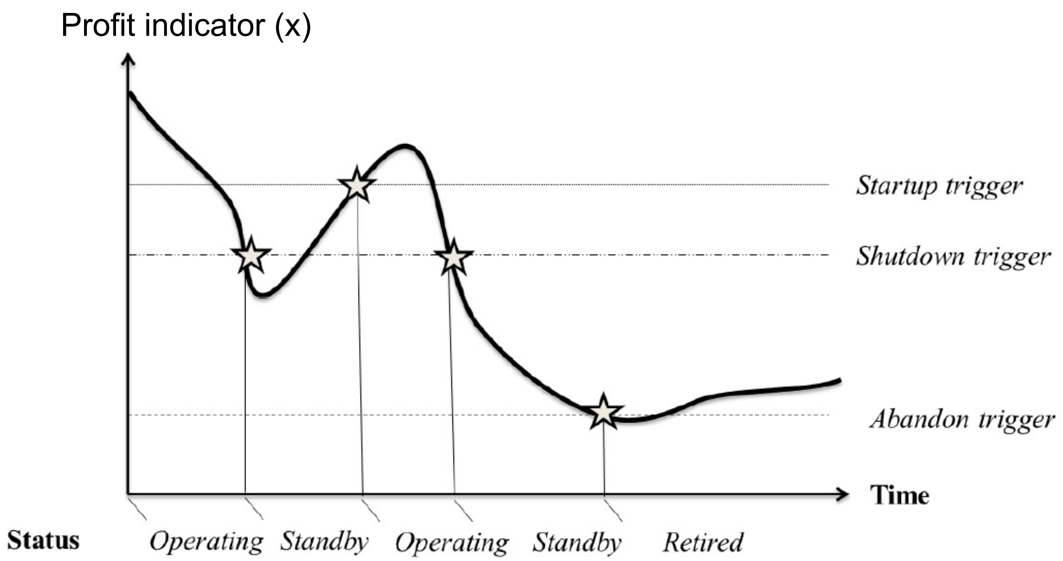
Background: real options

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



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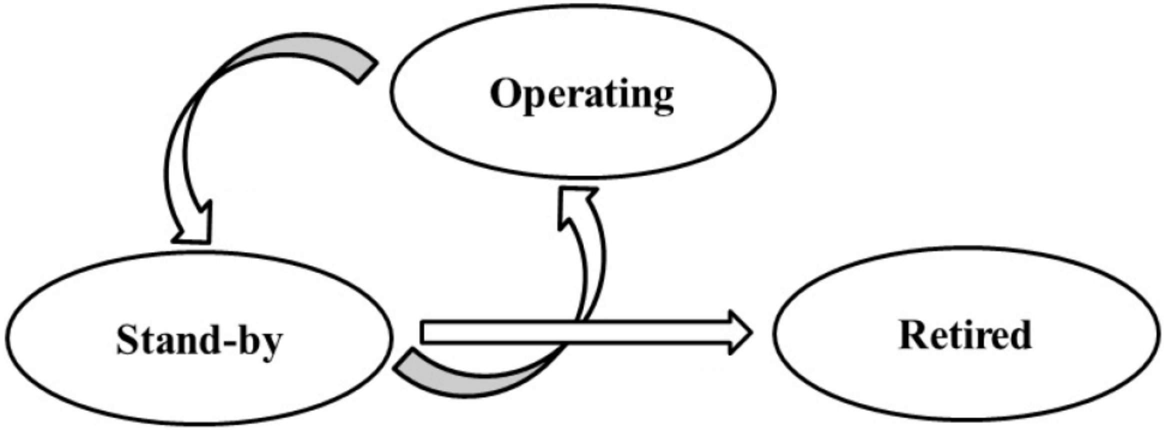
Structural estimation of real options

- Estimate irreversible switching costs associated with economic state changes
- Data need
  - Observed state changes over many facilities and over time
  - A time series of a profitability indicator
    - Nonparametric dynamics
- Builds on Che-Lin Su and Kenneth Judd (2012)
  - Constrained optimization approaches to estimation of structural models

- How does profitability indicators, policy uncertainty 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



On empirical verification

Why might these estimates of firms' responses to changes in expected volatility accord so well with theory? Given the small size of the majority of these firms, it seems unlikely that they are formally solving Bellman equations. However, they may have developed decision heuristics that roughly mimic an optimal decision-making process. Moreover, the firms have a strong financial incentive to get their decision-making at least approximately right(Kellogg, 2010, p. 30).

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The real options problem

- Time index, k = 1, 2, … years
- X_k profit indicator
- s_k, u_k in {OP, SB, RE} operating states and action space
- g(x, s, u) current year profit including maint + switching costs

$$V(x,s) := \max_{s_k \lhd \sigma(X_k)} \mathbb{E}\left(\sum_{k=0}^{\infty} \beta^k g(X_k, s_k; s_{k+1}) \middle| X_0 = x \right)$$

$$V(x,s) = \max_{u \in S} g(x,s;u) + \beta \cdot \mathbb{E}(V(X_{k+1},u) | X_k = x)$$

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The real options problem

- Heterogeneity: $g(x, s, u) + \varepsilon_u$
- There is a random shock, observed by the decision maker, but not by the analyst

- The value funtion becomes

$$V_\varepsilon(x,s) = \max_{u \in S} g(x,s;\, u) + \varepsilon(u) + \beta \cdot \mathbb{E}\left(\int V_\varepsilon(X_1,u)\,\mathscr{E}(\mathrm{d}\varepsilon|X_1) \middle| X_0 = x \right)$$

- Define

$$v(x,s) := \mathbb{E}\left(\int V_\varepsilon(X_1,s)\,\mathscr{E}(\mathrm{d}\varepsilon) \middle| X_0 = x \right)$$

- Then,

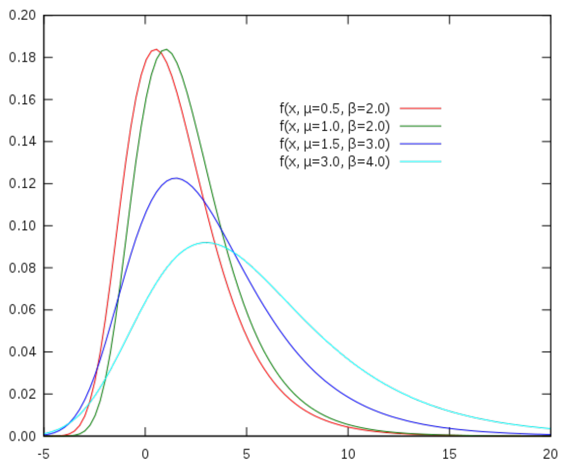
$$v(x,s) = \mathbb{E}\left(\int \max_{u \in S} g(X_1,s;\, u) + \varepsilon(u) + \beta \cdot v(X_1,u)\,\mathscr{E}(\mathrm{d}\varepsilon) | X_0 = x \right)$$

- Conforming with the structural estimation literature, this shock is Gumbel distributed, independent of the profit indicator, and is additively separable

of
y

The Gumbel variable

- If we have independent and identically distributed random variables ε_i, what can we say about
- $M_n := \max_{i=1..n} \varepsilon_i$?
- It will be extreme value distributed!
  - Assuming M_n exponential tail -> Gumbel



$$P(\varepsilon \leq z) = \exp\left(-e^{-\frac{z-\mu}{b}-\gamma}\right)$$

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Choice probability

- Analyst' model of decision makers choices (later to be compared to data; maximum likelihood)
- If ε_i ~ Gumbel(μ_i,b), and with $\mu := b \cdot \log\left(\sum_{i=1}^{n} \exp\left(\frac{\mu_i + c_i}{b}\right)\right)$ then

$$P\left(\max_{i=1,\ldots n} \varepsilon_i + c_i \leq z\right) = \exp\left(-e^{-\frac{z-\mu}{b} - \gamma}\right) \sim Gumbel\left(\mu, b\right)$$

- It follows that the choice probability is

$$P\left(\varepsilon_1 + c_1 = \max_{i \in \{1,2,\ldots n\}} \varepsilon_i + c_i\right) = \frac{\exp\left(\frac{c_1 + \mu_1}{b}\right)}{\exp\left(\frac{c_1 + \mu_1}{b}\right) + \cdots + \exp\left(\frac{c_n + \mu_n}{b}\right)}$$

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Value function

- Recall value function before ε(u) was assumed Gumbel

$$v(x,s) = \mathbb{E}\left(\int \max_{u \in S} g(X_1, s; u) + \varepsilon(u) + \beta \cdot v(X_1, u) \mathscr{E}(\mathrm{d}\varepsilon) \middle| X_0 = x \right)$$

- With Gumbel assumption

$$v(x,s) = \mathbb{E}\left(b \cdot \log\left(\sum_{u \in S} \exp\left(\frac{g(X_1, s; u) + \beta \cdot v(X_1, u)}{b} \right) \right) \middle| X_0 = x \right)$$

Structural estimation recap

- An individual solves an optimization problem
- Analyst observes states and decisions
- Want to estimate unobserved parameters that are consistent with optimality conditions

Structural estimation problem

$$\begin{array}{ll} \text{maximize} & \frac{1}{N}\sum_{i=1}^{N} \log P_{v_g}(u_i | X_i, s_i) \\ \text{subject to} & v_g = t_g(v_g), \\ & g \in \mathscr{G}, \end{array}$$

where (the probability of choice!)

$$P_v(u|x,s) = \frac{\exp\left(\frac{g(x,s;u)+\beta v(x,u)}{b}\right)}{\sum_{u' \in S} \exp\left(\frac{g(x,s;u')+\beta v(x,u')}{b}\right)}$$

with the contraction

$$(t_g v)(x,s) = \mathbb{E}\left(b \cdot \log\left(\sum_{u \in S} \exp\left(\frac{g(X_1, s; u) + \beta \cdot v(X_1, u)}{b} \right)\right) \middle| X_0 = x \right)$$

Structural estimation problem

- Maximize log likelihood
  - Likelihood of observing plant status given state variables (profitability in $/kW, spark spread standard deviation, reserve margin, inverse competitiveness, regulatory uncertainty) and plant status last year
- Subject to
  - Decision makers behave according to our real options switching specification (next slide)
  - 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 = $\eta_0 + \eta^T X$

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Structural estimation problem

- The constraints are not yet computable
- We contribute by using a Nadaraya–Watson estimator for the transition probabilities

$$\mathbb{E}\left(b \cdot \log\left(\sum_{u \in S} \exp\left(\frac{g\left(X_1, s;\, u\right) + \beta \cdot v\left(X_1, u\right)}{b} \right) \right) \middle| X_0 = x \right) \sim$$

$$\sim \sum_{i=1}^{N-1} \frac{K\left(\frac{x - X_i}{h}\right)}{\sum_{i'=1}^{n} K\left(\frac{x - X_{i'}}{h}\right)} \cdot b \cdot \log \sum_{u \in S} \exp \frac{g\left(X_{i+1}, s;\, u\right) + \beta \cdot v\left(X_{i+1}, u\right)}{b}$$

- This is discretized along the x-axis and for operating modes OP and SB

Summary

- We have setup a nonlinear program which solves the structural estimation problem
- Next: Our case study

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Application: Peak power plants

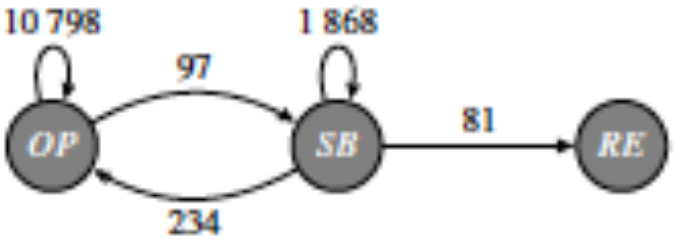
- Motivation: Regulators are concerned with mothballing and closures of conventional flexible power plants
  - Driven by penetration of renewables
  - Peak power plants are cornerstones of power systems since they provide necessary reserve flexible capacity
  - New capacity markets/incentives are being designed for conventional plant to not mothball/shut down
- Furthermore, these parameters are necessary for asset valuation
- We arrive at estimates for switching costs and maintenance costs

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



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- Sample period 2001-2011
  - EIA 860 (data source) format changes in 2001
- Focus on peaking plants (CTs)
  - Natural gas and #2 oil
- Final sample:
  - 1,388 unique generators
  - 13,078 generator-year observations

Photo: tu.no

➢ Status code of generator

- From EIA 860
  - OP – operating
  - SB – on standby (mothballed/shutdown)
  - RE – retired

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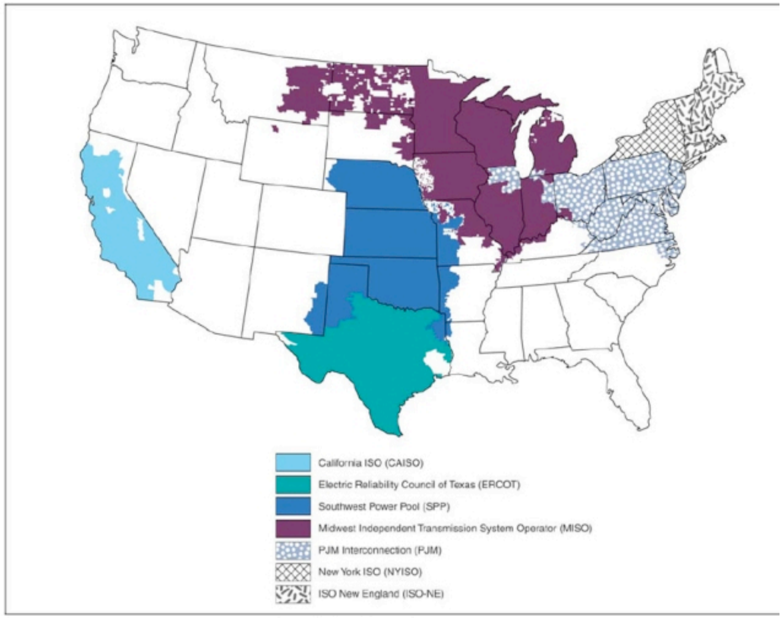
- From EIA860 “Layout” file

“Cold Standby (Reserve): deactivated (mothballed), in long-term storage and cannot be made available for service in a short period of time, usually requires three to six months to reactivate.”

➢ Electricity Prices (*$/MWh*)

- Wholesale prices for three markets
  1. New England (NEISO)
  2. Pennsylvania-NJ-Maryland (PJM)
  3. New York (NYISO)



Sources: FERC; Map Resources (map).

➢ Average daily peak price

- Hours Ending 07:00 - 22:00

- Fuel Prices (*$/MMBtu*)
  - Daily spot prices
    - NY Harbor No. 2 Oil
    - Henry Hub Natural Gas
  - Data taken from EIA website
    - http://www.eia.gov/petroleum/data.cfm
    - http://www.eia.gov/naturalgas/data.cfm

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**

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

- Reserve margin
- $RM_{kt} = (C_{kt} – D_{kt})/D_{kt}$
  - RM_{kt} – reserve margin
  - C_{kt} – capacity (year t, region k)
  - D_{kt} – demand

- Proxy for future profitability
  - Low RM – high electricity prices – high future profitability
  - High RM – low electricity prices – low future profitability

- Spark spread volatility

$SPRDSD_{it} = Stdev\ (SPRD_{in})$

- *Stdev* taken over days of previous year
  $n=1,T$

➢ Plants = options

- Power plants are (a series of) call options on the spark spread

- An increase in volatility increases the option value of the plant.
  - Fewer shutdowns & abandonments.
  - More startups.

- Strength of competition
- How inefficient is this generator compared to nearby generators from competing firms
- HR = heat rate = inverse of efficiency
- A = set of generators in the state of plant *p* (HR_A is avg)

$$C_{t,p} = \begin{cases} \dfrac{HR_{t,p}}{HR_A} & \text{if } |A| > 0 \\ 0 & \text{else} \end{cases}$$

- Low C means competitive, high C means low competitiveness

- State-Level retail competition index

1. No activity
2. Investigation underway
3. Competition recommended
4. Law passed
5. Competition implemented

Source: EIA; State Utility Commissions

➢ Regulatory uncertainty indicator

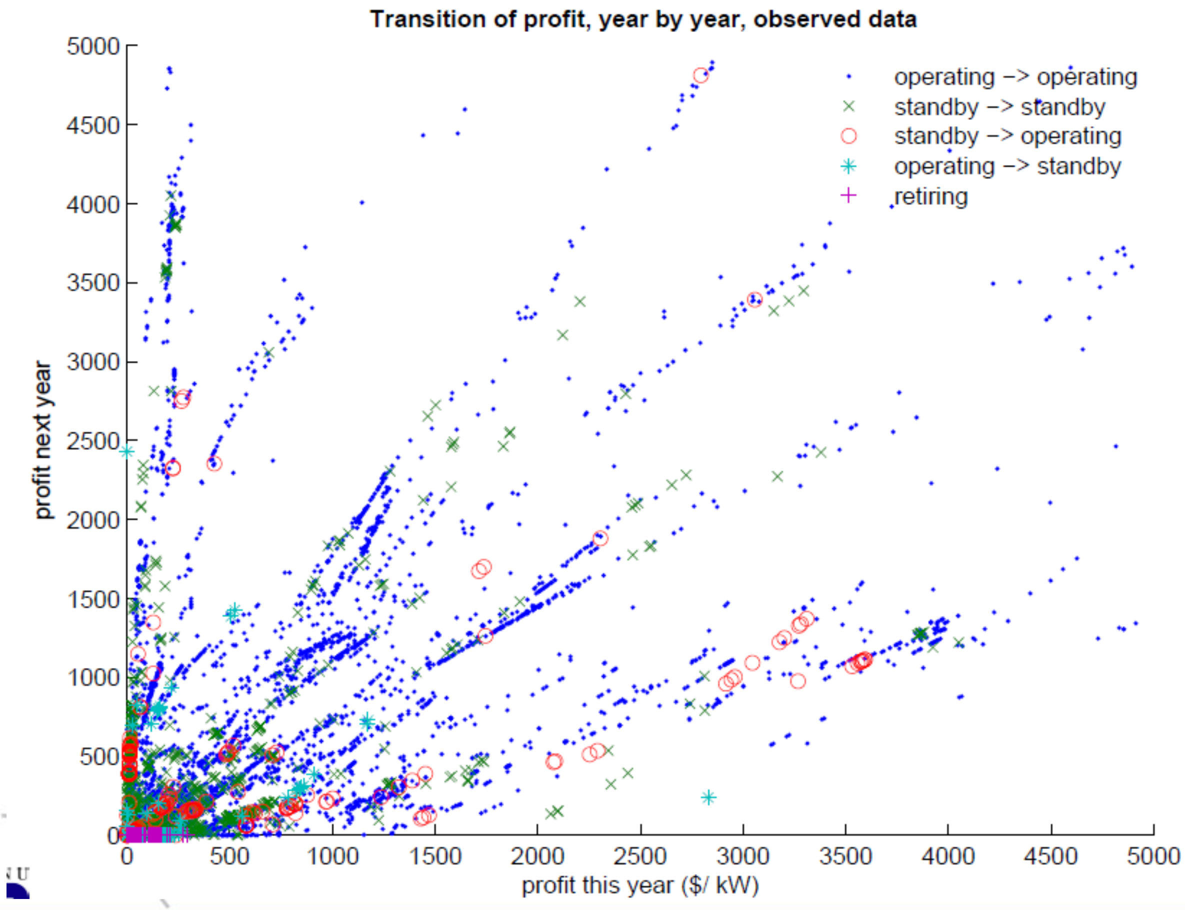
- *REGUNCERT* = 0
  - When competition index = 1, 4, 5
- *REGUNCERT* = 1
  - When competition index = 2, 3

- Regulatory uncertainty

  - Likely to reduce the probability of ***any*** status change.

    - Fewer shutdowns
    - Fewer startups
    - Fewer abandonments

Scatterplot of transitions of profit indicator levels from year i to year i+1



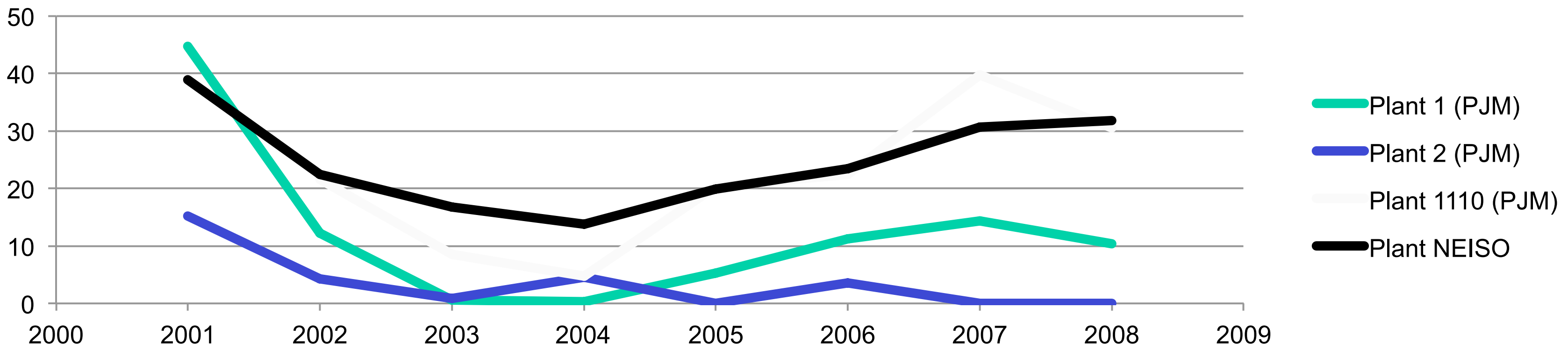
Data summary

- 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 (5D!) during the year, and,

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



Implementation

- Computer language: AMPL
- Solver: KNITRO 9.0
- 35 variables, 33 constraints
- Solve time 11s on MacBook Air 2GHz i7 w/8 GB memory running OS X 10.9.4

Unobserved heterogeneity

- In addition to the random shock ε_u
- Some groups of plants may have relatively high cost parameters, others lower
- Assume some of the coefficients are random with a given distribution (Train (2002))
  - Need to integrate over these r.v.
- Here random:
  - Maintenance cost in operating ready state
  - Startup costs
  - (Cost of retiring the plant, maint cost in standby, shutdown costs)

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

(for large firms, and γ, λ and η = 0)

$E(M_{OP})$	σ_{M_OP}	M_{SB}	K_{SD}	$E(K_{SU})$	σ_{K_SU}	K_{RE}
7.14	4.14	1.50	0.0	3.8	1.78	-8.00
(0.47)	(0.27)	(0.36)	(1.52)	(3.34)	(1.77)	(1.54)

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

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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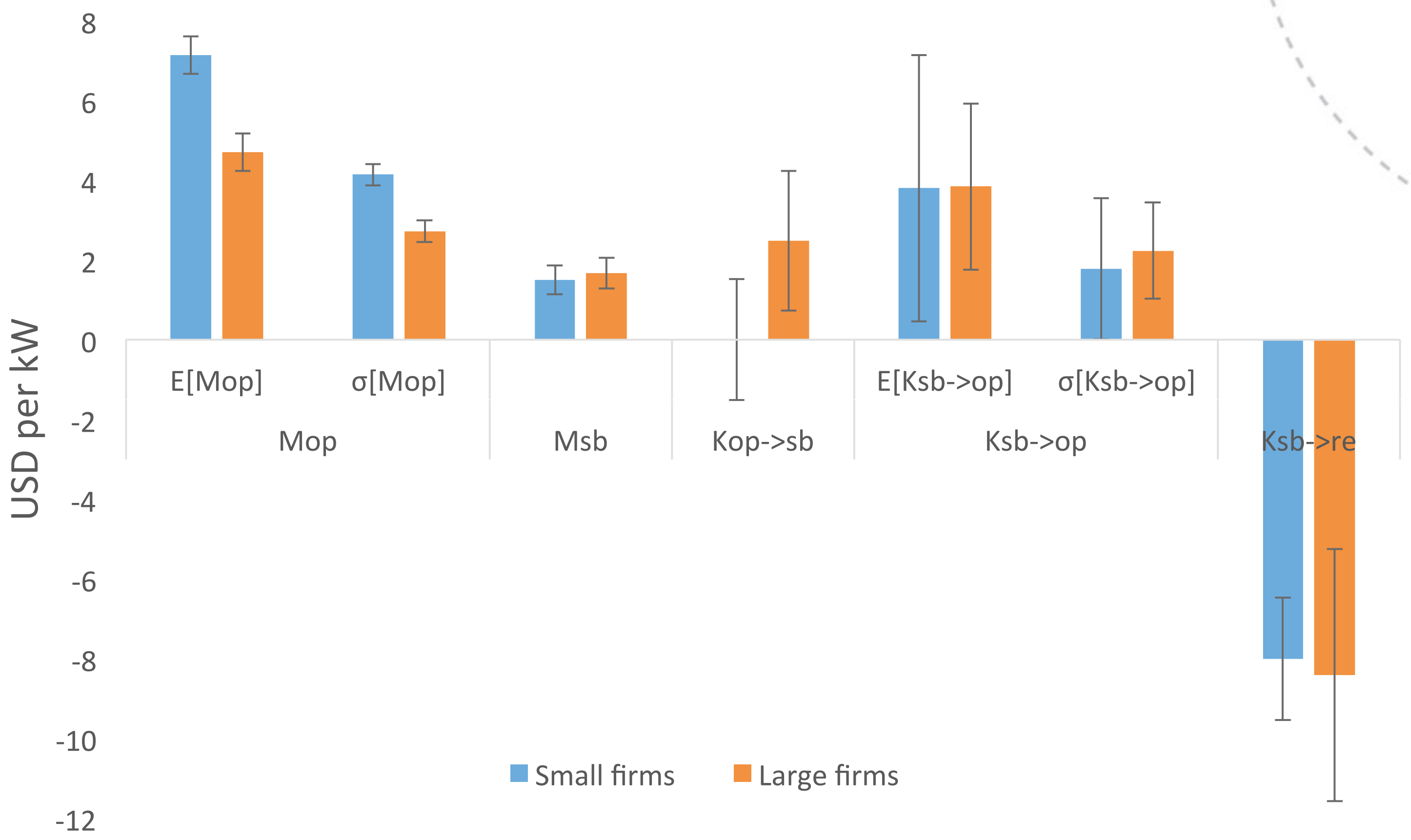
Results



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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/(år/kW) ☺

Photo: Shell

Photo: nrk.no

Results

	Owner type Period	Large 2001-2008	Small 2001-2008	Large 2001-2011	Small 2001-2011
		Coefficient or parameter values			
M_{OP}	*constant*	3.000**	4.316***	2.386***	5.782**
M_{SB}	*constant*	2.088***	0.123	0.000	0.859
$K_{SB->OP}$	*constant*	0.000	0.917	0.001	0.047
	Regulatory uncertainty (U)	4.150	14.519	6.414	15.966**
	Projected reserve margin (R)	-6.480**	-44.926**	23.210**	-19.902
	Spark spread standard deviation (S)	137.708***	99.822***	104.451**	114.710***
	Competitieness measure (C)	0.600	2.530	-1.402	1.592
$K_{OP->SB}$	*constant*	0.000	0.205	0.001	0.176
	Regulatory uncertainty (U)	16.330***	17.907**	15.784**	14.651
	Projected reserve margin (R)	-10.221***	20.981	-9.210	13.831
	Spark spread standard deviation (S)	-5.839	-120.112***	-8.425	-139.506***
	Competitieness measure (C)	-1.480**	1.593	-2.896*	-1.696
$K_{SB->RE}$	*constant*	-10.732***	-19.221***	-30.235***	-21.648*
	Regulatory uncertainty (U)	14.758***	18.966***	18.487***	18.413*
	Projected reserve margin (R)	-12.447*	13.138	-7.093	13.003
	Spark spread standard deviation (S)	213.833**	-22.904	309.075***	-45.525*
	Competitieness measure (C)	-0.193	-0.102	-1.692	-0.810

Notes: Significance codes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Start-up

Shut down

Abandon

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Results

		Large	Small	Large	Small
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Notes: Significance codes: *** p < 0.01, ** p < 0.05, * p < 0.1

INSIGHTS

Regulatory uncertainty increases shut-down and abandonment costs
- A real options effect

Reserve margin
- Wrong sign for startup, ok for shut-down and abandonment

Capacity payments
- Mainly affects reserve margin impact for large firms

Spark spread standard deviation
- Many unexpected signs, counter to real options theory

Inverse competitiveness
- OK for shut-down costs of large firms, otherwise not significant

Small firms less affected by profitability factors
- 16% share of non-utilities

Conclusions

- Real options theory is a useful lens for interpreting the power plant status data
- Regulatory uncertainty affects switchings
- Our method gives reasonable switching cost estimates
- Capacity payments: some of the profitability indicators become less important
- Large firms more responsive to profitability indicators and strategic interaction

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Thank you for listening…

- Comments and questions ?
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