# Drivers of Coal Generator Retirements and their Impact on the Shifting Electricity Generation Portfolio in the U.S.

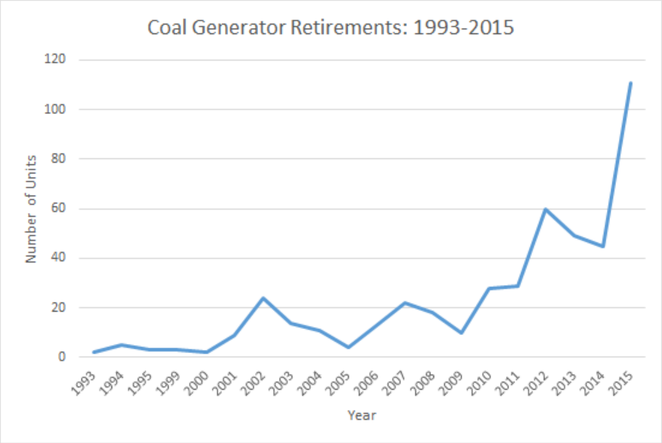
Rebecca J. Davis, Charles Sims, and J. Scott Holladay

Camp Resources XXIV

August 7, 2017

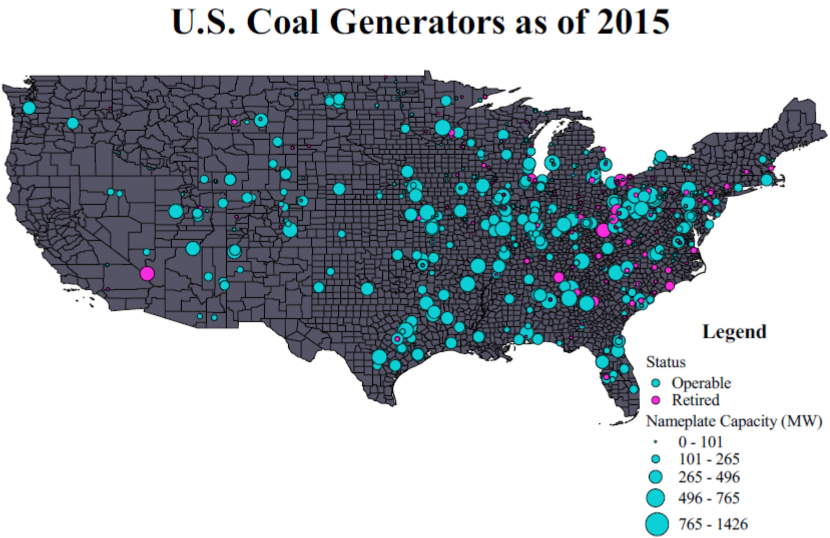
THE UNIVERSITY OF TENNESSEE KNOXVILLE

# Background




Data: EIA 860 Form

# Background


U.S. Coal Generators as of 2015
Legend
Status
Operable
Retired
Nameplate Capacity (MW)
0 - 101
101 - 265
265 - 496
496 - 765
765 - 1426

# Motivation/Literature

- Coal's share of electricity generation in the U.S. dropped from 48% in 2008 to 33% in 2015 (U.S. Energy Information Administration).
- Coal-fired generator retirements have consequences on the economy and the environment.
    - Cullen & Mansur, 2017; Knittel, Metaxoglou, & Trindale, 2017; Holladay & Soloway, 2016; Kaffine, McBee; Black, McKinnish, & Sanders, 2005; Hoag and Wheeler, 1996

# Motivation/Literature

- Yet there is little known about the costs of decommissioning generators due to their proprietary nature.
  - Collard-Wexler, 2013; Roberts & Tybout, 1997; Baldwin, 1989; Pakes, 1986; Bain, 1954

- These retirement costs play a critical role in the decision to put down a generator.

# Research Questions

- What are the implied retirement costs for coal generators that have already retired in the U.S.?
- What factors influence these costs?
- What is the economic lifetime of a coal-fired electricity generator?
- What factors shorten this life?

# Method

Utilize real options theory in a **stochastic dynamic programming** setting.

- Real Options Theory: Uncertainty + Sunk Costs = Option Value
- Delivered coal prices and wholesale electricity prices are stochastic.
- Sunk costs associated with retiring a coal generator depend on the level of decommissioning chosen.

# The Model

A firm operating a coal-fired generator receives a flow payoff:

$$\pi(P_E, P_C) = \left( P_E(t)q_E(t) - P_C(t)q_C(t) - VC(q_E(t)) - FC \right) \tag{1}$$

subject to $dP_E/dt$ and $dP_C/dt$.

Electricity and coal prices are modeled as Geometric Mean Reversion:

$$\mathrm{d}P_E = r_{P_E}(\bar{P}_E - P_E)P_E\mathrm{d}t + \sigma_{P_E}P_E\mathrm{d}z_{P_E} \tag{2}$$

$$\mathrm{d}P_C = r_{P_C}(\bar{P}_C - P_C)P_C\mathrm{d}t + \sigma_{P_C}P_C\mathrm{d}z_{P_C} \tag{3}$$

Stochastic Paths | Augmented Dickey Fuller Tests | Geometric Mean Reversion Estimation

# The Model

Decision Problem: risk-neutral firm determines if and when to retire $t_R$ an electricity generator to maximize the generator's expected discounted profits net of any sunk retirement costs. The optimal retirement decision satisfies:

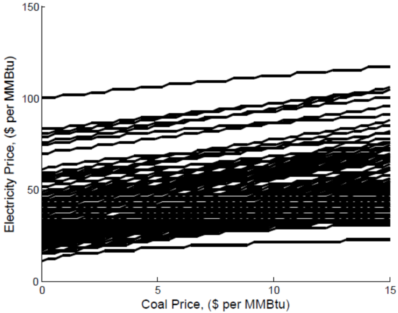
$$V(P_{E_0}, P_{C_0}) = \max_{t_R} \mathrm{E}_0 \left[ \int_0^{t_R} \pi\Big(P_E(t), P_C(t)\Big) e^{-\delta t} dt + \Big\{ V\Big(P_E(t_R), P_C(t_R)\Big) - K \Big\} e^{-\delta t_R} \right] \tag{4}$$

# Data

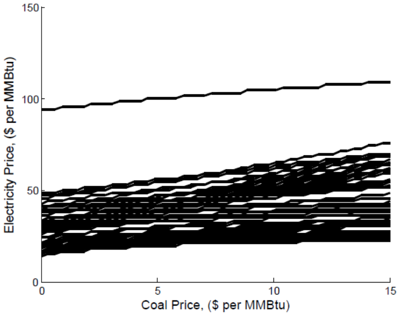
- Focus on coal generator retirements from 2009-2015.
- Identify retirements: EIA Form-860
- Delivered coal prices: EIA Form-923
- Wholesale electricity prices: PJM zonal wholesale electricity prices and FERC Form 714 hourly system lambda electricity prices
- Coal and electricity quantities: EPA CEMS data
- Variable and fixed costs: EIA Annual Energy Outlook estimates of O&M and levelized capital costs
- Retirement costs: EPRI report by Henson (2004) for benchmark analysis

Benchmark Parameters

# Results




Panel A: Regulated Coal Generator Retirement Thresholds



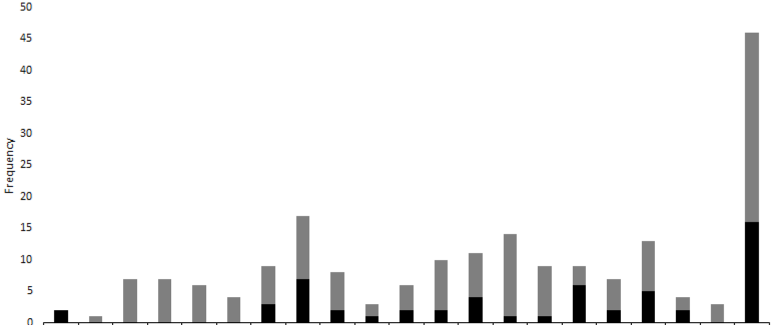

Panel B: Deregulated Coal Generator Retirement Thresholds

# Sensitivity Analysis

| Parameter | ↑ | | ↓ | |
|---|---|---|---|---|
| | RE | DR | RE | DR |
| $r_{P_C}$ | -3.34% | -1.28% | 3.90% | 1.26% |
| $\overline{P_C}$ | 5.02% | 1.71% | -4.68% | -1.76% |
| $\sigma_{P_C}$ | -1.16% | -0.56% | 1.25% | 0.42% |
| $r_{P_E}$ | 12.23% | 4.19% | -13.49% | -4.27% |
| $\overline{P_E}$ | -6.81% | -2.76% | 6.74% | 2.63% |
| $\sigma_{P_E}$ | -20.87% | -7.85% | 20.55% | 7.85% |
| $\rho$ | 0.00% | 0.00% | 0.00% | 0.00% |
| $\beta_{P_E}$ | -41.82% | -15.90% | 44.85% | 16.97% |
| $\beta_{q_E}$ | 31.94% | 11.09% | -31.34% | -11.13% |
| $\delta$ | -0.94% | 0.70% | 0.89% | 8.92% |

Electricity price volatility, fuel efficiency, and the elasticity of generator supply significantly influence the retirement decision - more so for generators in regulated electricity markets.

# Retirement Cost Distribution




| | $0-$8 | $8-$16 | $16-$24 | $24-$32 | $32-$40 | $40-$48 | $48-$56 | $56-$64 | $64-$72 | $72-$80 | $80-$88 | $88-$96 | $96-$104 | $104-$112 | $112-$120 | $120-$128 | $128-$136 | $136-$144 | $144-$152 | $152-$160 | >$160 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RE | 0 | 1 | 7 | 7 | 6 | 4 | 6 | 10 | 6 | 2 | 4 | 8 | 7 | 13 | 8 | 3 | 5 | 8 | 2 | 3 | 30 |
| DR | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 7 | 2 | 1 | 2 | 2 | 4 | 1 | 1 | 6 | 2 | 5 | 2 | 0 | 16 |

Retirement Cost (millions of dollars)

# Retirement Cost Analysis

Determine factors that are correlated with retirement costs by regressing estimated sunk costs against the following:

- generator-specific parameters,
- a dummy variable equal to 1 if the generator retired in a regulated market,
- a dummy variable equal to 1 if the generator has an ash impoundment at the plant,
- nameplate capacity in megawatts,
- and operational year.

$$K_i^* = \alpha_i + \beta_1 r_{P_{C_i}} + \beta_2 \bar{P}_{C_i} + \beta_3 \sigma_{P_{C_i}} + \beta_4 r_{P_{E_i}} + \beta_5 \bar{P}_{E_i} + \beta_6 \sigma_{P_{E_i}} + \beta_7 \rho_i + \beta_8 \beta_{q_{E_i}} + \beta_9 \beta_{P_{E_i}} + \vec{\gamma} \vec{X}_i + \epsilon_i$$

# OLS Results for Retirement Costs

| Coefficient on Covariate | All Generators | Regulated Generators | Deregulated Generators |
|---|---|---|---|
| | (1) | (3) | (4) |
| $r_{P_C}$ | -61.00*** | -66.92 | -48.96 |
| | (23.40) | (54.87) | (34.32) |
| $\bar{P}_C$ | -8.96*** | -8.98** | 18.28 |
| | (3.29) | (3.71) | (22.76) |
| $\sigma_{P_C}$ | 99.04* | 73.02 | 73.62 |
| | (57.92) | (88.97) | (97.70) |
| $r_{P_E}$ | 89.85** | 32.01 | 273.9** |
| | (38.45) | (53.45) | (111.0) |
| $\bar{P}_E$ | -1.21 | -2.08 | -1.20 |
| | (1.31) | (1.69) | (2.82) |
| $\sigma_{P_E}$ | 22.74 | 121.4 | -300.1** |
| | (87.83) | (121.0) | (141.8) |
| $\rho$ | -12.81 | -20.37** | 11.45 |
| | (9.23) | (8.65) | (15.17) |
| $\beta_{q_E}$ | -26.71** | -20.72** | -55.66** |
| | (11.93) | (9.38) | (25.29) |
| $\beta_{P_E}$ | 0.0000012 | 0.00020 | 0.00041 |
| | (0.00028) | (0.00037) | (0.00041) |
| Regulated | 3.75 | – | – |
| | (6.35) | – | – |
| Ash Impound | 13.31* | 16.24 | -12.23 |
| | (7.86) | (10.62) | (12.92) |
| Nameplate Capacity | 0.14*** | 0.14*** | 0.13* |
| | (0.032) | (0.047) | (0.074) |
| Operating Year | 1.76*** | 2.35*** | -1.51 |
| | (0.55) | (0.55) | (2.30) |
| Constant | -3,259*** | -4,448*** | 3,236 |
| | (1,089) | (1,085) | (4,479) |
| Observations | 196 | 140 | 56 |
| R-squared | 0.59 | 0.65 | 0.60 |

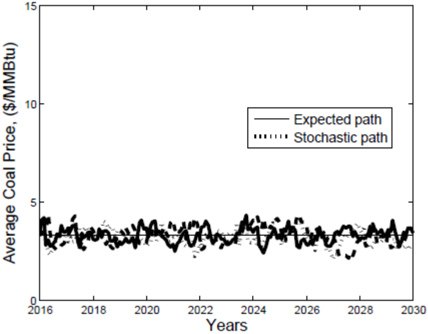
# Conclusion

- Higher and more volatile electricity prices make a coal generator less likely to be retired.
- Less fuel efficient coal generators tend to retire even when they face high electricity prices.
- Less responsive generator supply, the less likely that generator retires.
- Estimate retirement costs for 196 retired coal generators in the U.S. from 2009-2015.
- Coal price stochasticity matters more for generators in regulated electricity markets.
- Electricity price volatility matters fore for generators in deregulated markets.
- Fuel efficiency and nameplate capacity are highly correlated with retirement costs.

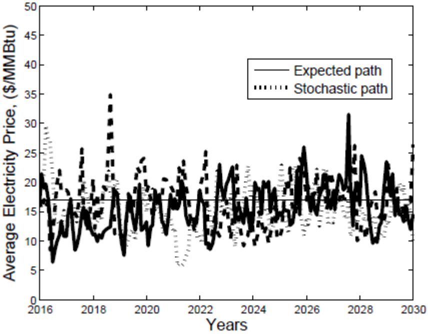
Thank you!

Becky Davis: becky.davis@utk.edu

# Uncertain Prices




Panel A: Simulated Coal Prices




Panel B: Simulated Electricity Prices

Back to main

# Augmented Dickey Fuller Tests

GBM assumes $P$ is log-normally distributed. The logged price level $p = \ln(P)$ is normally distributed and follows ABM $\mathrm{d}p = \mu dt + s\mathrm{dz}$.

Ito's Lemma ensures that $P$ is consistent with GBM if $p$ is consistent with ABM.

To test that $P_E$ and $P_C$ are consistent with GBM, we run a restricted regression:
$(p_t - p_{t-1}) = \beta_0 + \beta_1(p_{t-1} - p_{t-2}) + \epsilon_t$

and unrestricted regression:
$(p_t - p_{t-1}) = \beta_0 + \beta_1(p_{t-1} - p_{t-2}) + \beta_2 t + \beta_3 p_{t-1} + \epsilon_t$

Null hypothesis corresponds with $p$ being ABM is $\mathrm{H_O} : \beta_2 = \beta_3 = 0$. This is rejected at the 1% or 5% level for all coal generators in our analysis.

main

# Geometric Mean Reversion Estimation

Write GMR model as:

$$P_{t+1} = P_t + r_P(\bar{P} - P_t)P_t + \sigma_P P_t \epsilon_t \tag{5}$$

where $\epsilon_t$ is a standard normal random variable. Rewrite this as

$$\frac{P_{t+1} - P_t}{P_t} = r_P \bar{P} - r_P P_t + \sigma_P \epsilon_t \tag{6}$$

$r_P$ is the negative of the coefficient on $P_t$.
$\bar{P}_t$ is the ratio of the coefficient on $P_t$ and $\bar{P}_t$.
$\sigma_P$ is the standard error of the regression (Pachamanova & Fabozzi, 2011).
Use this method for electricity and coal prices.

main

# Average Coal-Fired Generator Parameters by Market Type: Benchmark Model

| Description | Parameter | Regulated | Deregulated |
|---|---|---|---|
| Coal Price Rate of Reversion | $r_{P_C}$ | 10.21% | 12.85% |
| | | (6.36) | (17.70) |
| Coal Price Long-Run Mean | $\bar{P}_C$ | \$3.33 per MMBtu | \$2.84 per MMBtu |
| | | (1.05) | (0.52) |
| Coal Price Volatility | $\sigma_{P_C}$ | 9.88% | 11.88% |
| | | (5.42) | (8.13) |
| Electricity Price Rate of Reversion | $r_{P_E}$ | 1.82% | 2.80% |
| | | (6.18) | (6.34) |
| Electricity Price Long-Run Mean | $\bar{P}_E$ | \$16.73 per MMBtu | \$16.97 per MMBtu |
| | | (4.34) | (3.59) |
| Electricity Price Volatility | $\sigma_{P_E}$ | 20.86% | 18.50% |
| | | (6.31) | (5.44) |
| Correlation Coefficient | $\rho$ | $-29\%$ | $-13\%$ |
| | | (33.23) | (33.71) |
| Quantity of Electricity | $q_E$ | $q_E = 11,174P_E$ | $q_E = 19,341P_E$ |
| | | $(11,087.65)$ | $(18,406.33)$ |
| Quantity of Coal | $q_C$ | $q_C = 3.07q_E$ | $q_C = 2.98q_E$ |
| | | (0.39) | (0.29) |
| Discount Rate | $\delta$ | 9.00% | 9.00% |
| Variable Costs | $VC(q_E)$ | $VC = 2.35q_E$ | $VC = 2.35q_E$ |
| Fixed Costs | $FC$ | $FC = 17.58\bar{q}_C$ | $FC = 17.58\bar{q}_C$ |
| Sunk Cost | $K$ | \$ 4 million | \$4 million |

main