Energy Transitions in Regulated Markets

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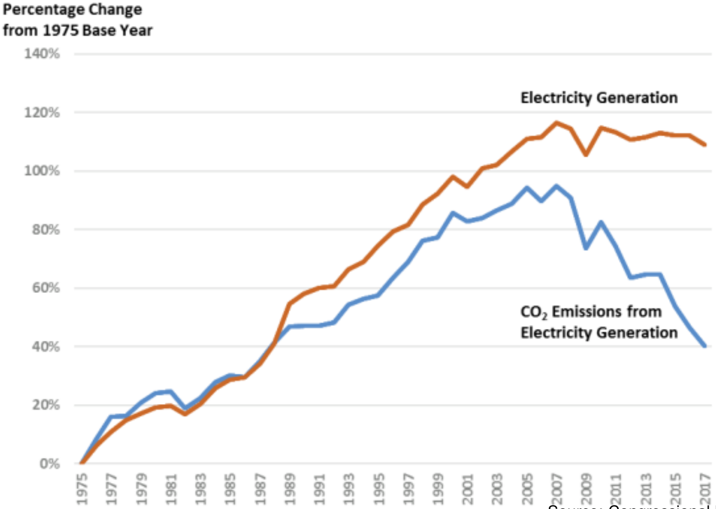
U.S. Electricity Generation Has Gotten Cleaner



Source: Congressional Research Service, 2019

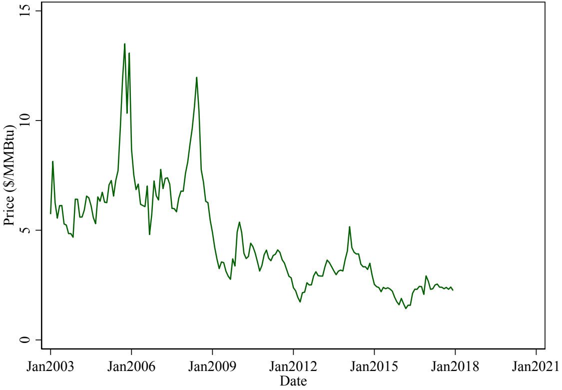
Why Has Generation Gotten Cleaner?

1) Improved Natural Gas Technologies

- Heat rates (fuel per MWh):
  - Natural gas turbine (NGT): 8,000-10,000 Btu/kWh
  - Combined-cycle natural gas (CCNG): 6,200-8,000 Btu/kWh

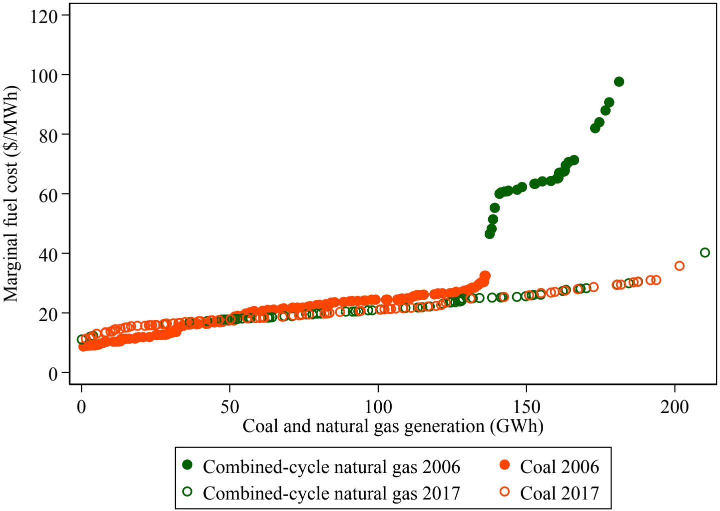
Source: Energy KnowledgeBase

2) Declining Natural Gas Fuel Prices



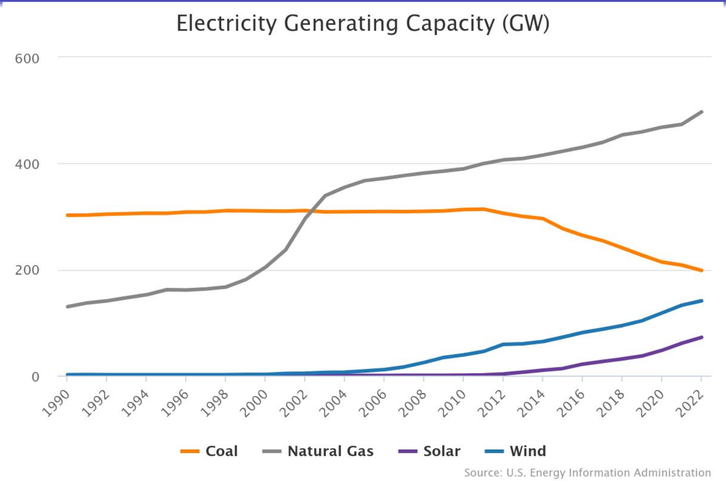
Source: Authors' calculations from analysis data

Natural Gas Fuel Costs Became Cheaper than Coal



Source: Authors' calculations from analysis data.

These Innovations Led to a Transition From Coal to Gas Capacity



- And the next energy transition to renewables has begun!

Electricity is Often Regulated

- Electricity is historically viewed as a “natural monopoly.”
  - High fixed costs and low marginal costs imply that having one firm is efficient.
  - But, an unregulated monopoly would charge monopoly prices.
- Generally, *rate-of-return regulation* is used to limit the exercise of monopoly power:
  - Regulator grants the utility a monopoly to provide the service.
  - Sets a maximum price to cover costs and allow a fair rate of return on capital.
- In the electricity context, regulation has two main goals (Joskow, 1974):
  - *Reliability:* Regulator requires that the utility meet load (demand).
  - *Affordability:* It encourages low-cost generation and limits capital.
- Many states restructured electricity *generation* starting in the mid-1990s.
  - Created wholesale markets and forced utilities to sell off generation capacity.
  - 2001 CA electricity crisis stopped restructuring, leaving some states regulated.

Retirement of Coal Capacity by Regulatory Status

- Coal exited more quickly in restructured states than in regulated ones.

Source: Authors' calculations from EIA data.

The Current Regulatory Structure

- Regulator can observe costs, but not the costs of alternative choices.
  - Leads to broad asymmetric information issues.
  - Regulator creates an incentive structure against which the utility optimizes.
- Structure specifies:
  - Maximum rate of return on allowed capital (the “rate base”).
  - Approval process for how capital investments contribute to the rate base.
- Regulator’s task has become more complicated over the past 25 years:
  - The energy transitions have involved new technologies, changing fuel prices, and increased environmental concerns.
  - Accentuates the problem of the regulator not knowing costs of alternatives.
- This structure leads to known inefficiencies (e.g., Averch and Johnson, 1962):
  - Incentive to overinvest since utilities earn a rate of return on capital.

Regulatory Responses to Overinvestment

- To mitigate overinvestment, regulators require investments to be "prudent."
- Utilities may thus run old technologies to prove that they are "used and useful" (Gilbert and Newbery, 1994).

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Coal Is No Longer a Baseload Resource, So Why Run Plants All Year?

JOSEPH DANIEL, SENIOR ENERGY ANALYST | JANUARY 15, 2020, 12:12 PM EDT

This Paper

- How does the current regulatory structure affect energy transitions relative to a cost minimizer or a social planner?
- We develop and estimate a dynamic structural model of electric utility regulation.
  - Considers operations decisions and capacity investment and retirement.
  - Extends the literature on RoR regulation including allowing for long-run responses to energy transitions.
- With our estimated model, we simulate the impact of alternatives to RoR regulation:
  - Could competition facilitate the energy transition while maintaining reliability?
  - Can changing regulatory parameters improve outcomes?
  - How would carbon taxes interact with RoR regulation?

Overview of Model and Estimation

- We model the regulator as using two instruments to create appropriate incentives:
  1. Offered maximum rate of return declines in utility's total variable costs, *TVC*.
  2. Coal's contribution to the rate base depends on its usage.
- Utility optimizes against the regulatory structure:
  - Long run: chooses coal retirement and combined-cycle natural gas investment.
  - Each hour: chooses generation mix and imports to meet load.

The Energy Transition Helps the Model Reflect the Data

- Consider a utility in 2006 with mostly coal capacity, but facing low-cost CCNG.
- Utility faces conflicting incentives:
    - If it invests in and uses CCNG, total variable costs fall and hence profits rise.
    - However, this reduces the usage rate of coal capacity.
    - Makes it harder to justify coal maintenance or upgrade expenditures as prudent.
- This tension will potentially lead the utility to keep and over-use legacy coal capacity.
- Contrast this with a utility with higher CCNG capacity before the energy transition.
    - Relative investment in and usage of CCNG identifies regulatory parameters.

Background on Regulated Electricity Industry

- Regulator acquires information from multiple sources:
  - *Integrated resource plans:* utilities describe long-run resource needs.
  - *Rate hearings:* utilities provide observed usage and cost information.
- Regulator uses information to adjust rate base and allowable rate of return:
  - Rate base determined by capital stock and prudent investments.
  - Consumer prices set to give allowable rate of return on rate base.
- We assume the regulator observes costs and usage but not costs of alternatives.
  - It therefore does not dictate choices to the utility.
  - Instead it sets a fixed regulatory framework to meet objectives.
  - Broad uncertainty like Averch & Johnson (1962) not Laffont & Tirole (1986).

Conceptual Model of Regulatory Incentives

1. Regulator uses prudence standards to limit incentive for over-investment.
   - For coal, utility demonstrates prudence by using it to meet load.
   - This limits capital but doesn't fully correct the AJ incentive.
2. Utility still doesn't have the incentive to generate with the lowest cost technologies.
   - Regulator therefore sets a maximum rate of return that is decreasing with *TVC*.
   - Incentivize utility (but imperfectly) to use lowest cost technology.
3. If a new technology suddenly becomes available:
   - AJ incentive implies that utility keeps too much of the legacy technology.
   - Prudence incentive leads to over-use of the legacy technology.
   - This may slow an energy transition.

Model of the Maximum Rate of Return

- In each year, y, regulator allows a maximum rate of return, $\bar{s}$, on the rate base, B, of:

$$\bar{s}_y = \left(\frac{TVC_y}{CostBasis(K_y)} \right)^{-\gamma}$$

  - Incentivizes low costs since, for $\gamma > 0$, rate of return decreases in TVC, the total variable generation and import costs.
  - Cost benchmark: minimum fuel and import costs given capital, $CostBasis(K_y)$.

Model of the Rate Base

- The utility earns this rate of return on its rate base, B_y, which is the dollar value of "effective capital" K_y^e (measured in MW).
- Effective capital is the weighted sum over three fuel-technology types: coal, combined-cycle natural gas, and natural gas turbines.
  - We model coal's contribution to effective capital as depending upon its usage.
  - Don't model this for CCNG since they run more than originally anticipated.
  - NGT serve a different purpose (peakers).
- Regulator sets consumer rates such that $Revenues_y = TVC_y + \bar{s}_y \times B_y$.

Long-Run Retirement and Investment Decisions

- A utility facing this regulatory framework makes investment and retirement decisions every 3-year period, t, over 30 years, with 95% annual discount factor.
  - Utility keeps generators after this, but state doesn't evolve.
- Each period, utilities make capacity investment and retirement choices in turn:
  1. Choose coal capacity to retire.
  2. Choose CCNG investment capacity.
- Investment/retirement costs are quadratic with utilities receiving a shock to the marginal investment cost each year.
- Specification allows us to match data where utilities invest very different amounts.

Hourly Operations Decisions

- Every hour, h, of year, y, the utility meets load with generation or imports, $\vec{q}_y$ to maximize profits subject to meeting load and capacity constraints:

$$\max_{\vec{q}_y} \overbrace{\left(\frac{TVC(p^{NG}, \vec{q}_y)}{CostBasis(K_y)} \right)^{-\gamma}}^{\text{Rate of return}} \overbrace{B(\vec{q}_y, K_y)}^{\text{Rate base}}$$

- Total variable costs, TVC_y, include import, fuel, startup/ramping, and O&M costs.
- Hours are connected via ramping costs, rate of return, and annual coal usage.
  - We solve for the optimum with a full-information finite horizon Bellman equation.

Structural Estimation

1. Estimate import supply curves following Bushnell, Mansur, and Saravia (2008).
2. Estimate most structural parameters from utilities' hourly operations decisions:
   - Use indirect inference: GMM nested fixed-point approach
   - Finds parameters to match data correlations similar to reduced form evidence.
3. Estimate investment and retirement costs from dynamic decisions.
   - Also GMM full solution nested fixed-point approach.
   - Annual operating profits at each state are inputs to Bellman equation.
   - Moments capture differences between model and data investment/retirement.
   - Apply Gowrisankaran and Schmidt-Dengler (2024) algorithm:
     - Idea: find ε^f cutoffs for chosen investment levels while eliminating others.

Primary Data Sources

Our main sample includes utilities in the Eastern Interconnection from 2006–17.

- Generator-level information:
  - Utility ownership, generator regulatory status, efficiency, and capacity (EIA).
  - Hourly production by generator (EPA).
- Utility-level information:
  - Load-serving entities (Federal Energy Regulatory Commission, FERC).
  - Hourly load for each load-serving entity (FERC).
  - Nearest nodal price (various ISOs).
  - Annual revenue (EIA).
- State-level information:
  - Coal and gas contract fuel prices (EIA).

Empirical Support for Our Regulatory Model

We investigate correlations in the data that underlie our model:

1. Relationship between observed rates of return and total variable costs.
2. Propensity for coal generators in regulated markets to run "out of dispatch order" relative to restructured markets.

Rate of Return on Variable Cost Measures

	Dependent Variable: Variable Profits per MW of Capacity					
Variable Costs per Capacity (Thou.$/MW)	−246.3 (63.2)	−420.8 (39.3)				
Variable Costs per High Load (Mil.$/MWh)			−0.115 (0.090)	−0.581 (0.046)		
Variable Costs (Mil.$)					−0.016 (0.004)	−0.044 (0.006)
Utility FE	N	Y	N	Y	N	Y

Note: Each column presents regression results from a separate regression on our analysis data. Variable costs include fuel and import costs but not O&M and ramping costs. Variable profits are revenues net of these costs. High load is the 95th percentile of hourly load for the utility-year.

- Within utility, proxy for rate of return decreases with variable cost measures.

Out-of-Dispatch-Order Generation by Regulatory Status

	$\mathbb{1}\{$Fuel-Technology Operating$\}$	
	Combined Cycle Natural Gas	Coal
$\mathbb{1}\{$Fuel Cost $>$ Price$\}$	-0.201	-0.031
	(0.031)	(0.031)
$\mathbb{1}\{$Fuel Cost $>$ Price$\}\times$ Restructured	0.005	-0.122
	(0.029)	(0.050)
R^2	0.132	0.089
N	20,723,467	19,782,473

Note: Regressions are linear probability models that include state and year fixed effects. Data are for regulated and restructured utilities at the utility-hour level for the Eastern Interconnection. We cluster standard errors (in parentheses) at the state and year level.

- Regulated coal (but not CCNG) runs “out of dispatch order” more frequently.

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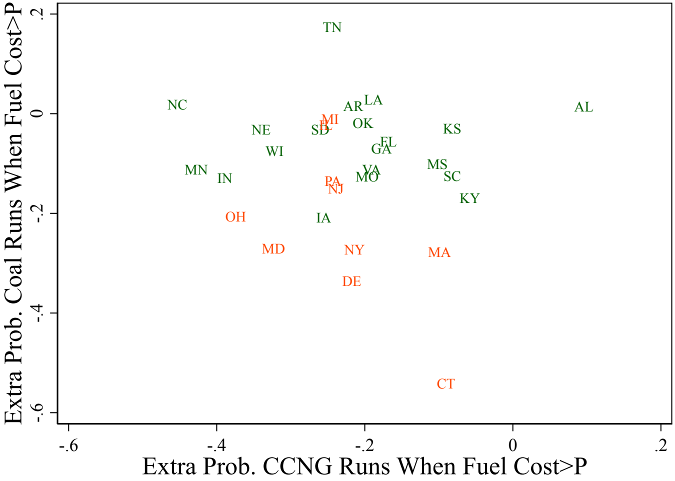
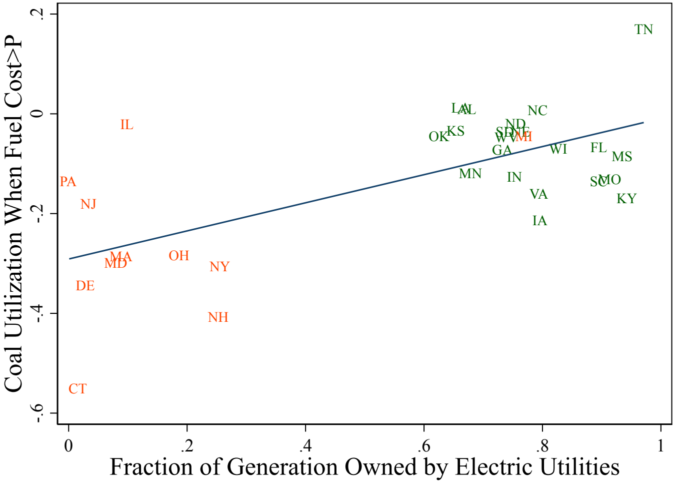
Out-of-Dispatch Order Generation Varies Across States



- Most restructured states behave differently than regulated with coal but not CCNG.

Out-of-Dispatch-Order Generation vs. Utility Ownership Share

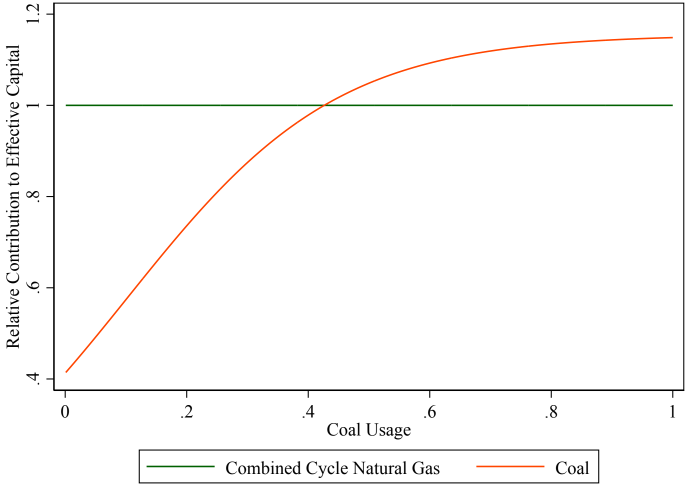


- All regulated states have high utility ownership.
- Coal's responsiveness to low wholesale prices correlates strongly with utility ownership share.

Overview of Results

- Operations model results:
  - Return to one MW of coal relative to CCNG.
  - Benefit of reducing TVC.
  - O&M and ramping costs.
- Investment/retirement model results:
  - Cost of coal retirement and CCNG investment.
- Counterfactual results:
  - How do operations outcomes differ under different regulatory regimes?
  - How do long-run investment and retirement decisions differ?

Estimation Results: Coal Contribution to Effective Capital



- One MW of coal capacity increases the rate base by about 40% as much as CCNG if unused.
- When fully used, it contributes 115% as much.

Estimation Results: *TVC* penalty and Ramping Costs

- Rate of return is a function of γ and α:
  - A 500 MW change in effective capital (the mean CCNG generator capacity in the data) increases variable profits by 6.7% on average.
  - A 10% increase in *TVC* decreases variable profits by 4%, while a 10% decrease increases variable profits by 4.6%.
- Ramping costs:
  - A 100MW coal ramp costs $5,780.
  - A 100MW CCNG ramp costs $2,190.
  - Below Borrero et al. (2023) but similar to Reguant (2014).
- O&M costs:
  - Coal: $16.35/MWh, similar to Linn and McCormack (2019).
  - CCNG: $2.59/MWh, very close to EIA estimates of $2.67 and $1.96.

Estimation Results: Retirement and Investment Cost Magnitudes

- Coal retirement:
  - 250 MW coal retirement yields $836 million in scrap value with mean cost shock.
  - Includes avoided regulatory costs (e.g. installing additional pollution abatement equipment, Gowrisankaran, Langer, and Zhang, 2023).
- CCNG investment:
  - 250 MW CCNG investment costs $1.6 billion with mean cost shock.
  - EIA estimates—which account for capital but not land, administrative, or regulatory costs—are 1/6 to 1/3 as large.

Counterfactual Approach

- First, examine counterfactual operations outcomes over utility-years in our data.
- Then evaluate the long-run impact of the energy transition:
  - Simulate investments/retirements and resulting operations over 30-year horizon.
  - Start with 2006 capacities but 2018-20 natural gas fuel price.
  - This captures utilities' reaction when hit with unexpected market shocks.
- We compare RoR regulation to different market and regulatory structures.
  - Cost minimizing competition.
  - Carbon taxes of $190/ton.
  - Changing regulatory parameters.

Operations (Short-Run) Counterfactuals

	Coal Usage (%)	CCNG Usage (%)	Total Var. Production Costs (Mil. $)	Carbon Costs (Mil. $)	Electricity Revenues ($/MWh)	Variable Profits (Mil. $)
Baseline	61.80	21.66	1,338	5,057	92.62	1,582
Social Planner	2.98	48.94	4,482	3,004	151.30	651
Cost Min., $\mu_2 = 0$	29.32	36.79	1,183	4,050	73.94	1,155
$2\times$ Usage Incentive, μ_2	47.44	29.62	1,266	4,575	92.29	1,650
Half *TVC* Penalty, γ	71.98	16.98	1,382	5,381	95.42	1,597
$2\times$ *TVC* Penalty, γ	51.59	27.01	1,291	4,735	93.40	1,633
Carbon Tax w/ RoR	63.81	31.14	6,661	5,106	238.87	792

Planner and Cost Minimization Reduce Coal Use

	Coal Usage (%)	CCNG Usage (%)	Total Var. Production Costs (Mil. $)	Carbon Costs (Mil. $)	Electricity Revenues ($/MWh)	Variable Profits (Mil. $)
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But, Reliability May Suffer

	Coal Usage (%)	CCNG Usage (%)	Total Var. Production Costs (Mil. $)	Carbon Costs (Mil. $)	Electricity Revenues ($/MWh)	Variable Profits (Mil. $)
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Doubling Usage Incentive *Decreases* Coal Use 23%

	Coal Usage (%)	CCNG Usage (%)	Total Var. Production Costs (Mil. $)	Carbon Costs (Mil. $)	Electricity Revenues ($/MWh)	Variable Profits (Mil. $)
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Coal Use Inversely Related to Cost Penalty

	Coal Usage (%)	CCNG Usage (%)	Total Var. Production Costs (Mil. $)	Carbon Costs (Mil. $)	Electricity Revenues ($/MWh)	Variable Profits (Mil. $)
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Carbon Taxes are Largely Just Passed Through

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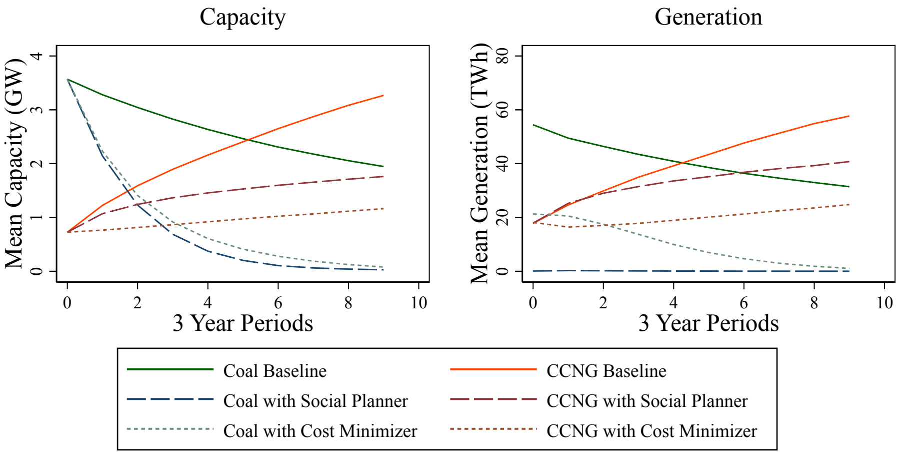
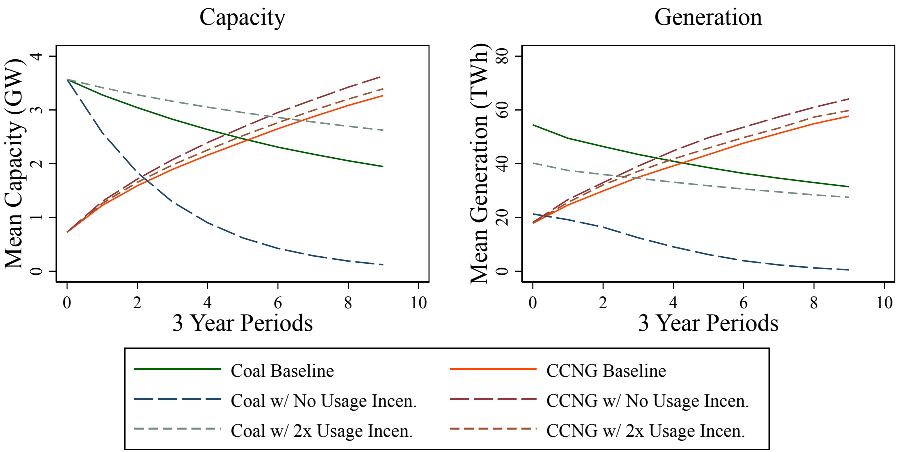
Capacity and Generation for Social Planner and Cost Minimizer



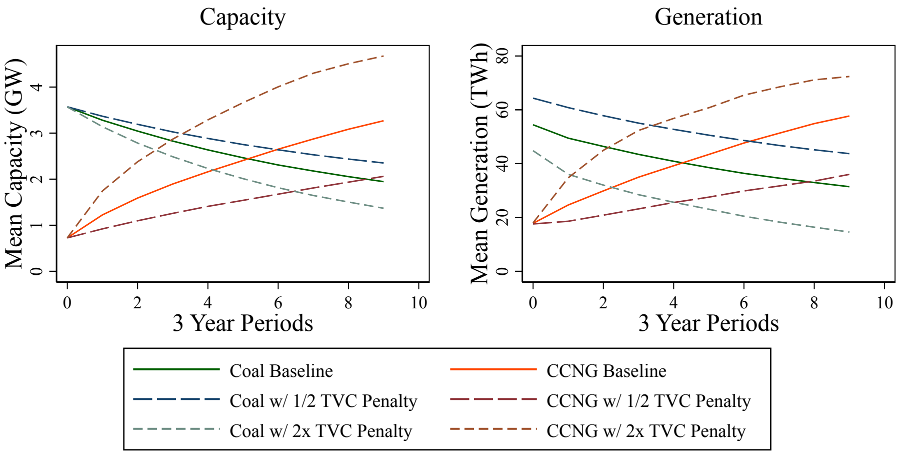
- Both social planner and cost minimizer retire virtually all coal capacity over horizon.
- Benefit of CO_2 tax compared to market incentives: less coal usage, not retirement.

Capacity and Generation for Different Coal Usage Incentives



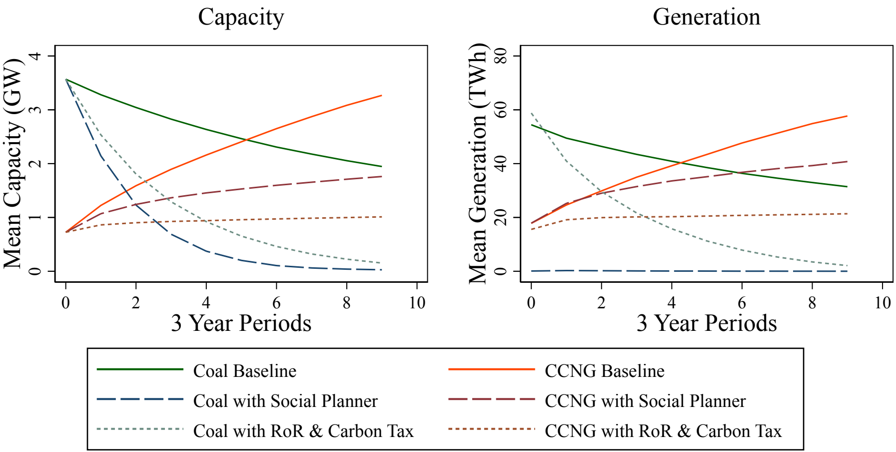
- Eliminating usage bonus causes coal exit by lowering coal's rate base contribution.
- Doubling coal usage bonus causes *less* usage because marginal incentive lower.

Capacity and Generation for Different TVC Penalties



- Doubling the penalty causes a huge increase in CCNG capacity and generation.
- Only a small drop in coal capacity, but big drop in coal generation.

Capacity and Generation for Carbon Tax with RoR Regulation



- RoR carbon tax has small (and positive) short-run effect on coal generation.
- But, in the long run, capacity and generation drop to almost 0, like planner.

Conclusion

- We develop and estimate a model of electricity regulation in energy transitions.
- Current regulatory structure creates unintended incentives to use more coal:
  - Cost minimizer virtually eliminates coal capacity in the 30 years after natural gas prices fall, while social planner essentially stops *using* coal immediately.
  - Current RoR regulation retires only 45% of coal capacity over this horizon.
  - Marginal adjustments to RoR regulation don't approach cost minimization.
  - RoR with CO_2 tax has 90% short-run pass through, but similar long-run effect.
- Broader takeaways for the transition to renewable energy:
  - Cost min, planner, and RoR with CO_2 tax may require transfers for reliability.
  - Consistent with subsidies in 2022 Inflation Reduction Act.
  - Over-investment in CCNG may be a difficult ongoing issue.