The Impact of Environmental Policy Instruments and Fuel Price Uncertainty on the Shifting Electricity Generation Portfolio in the U.S.

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1 Introduction

Over the last five years natural gas fired generation has increased as a portion of total electricity consumption in response to unexpected and unprecedented reductions in natural gas prices. The increase in natural gas fired generation has occurred at two margins. At the intensive margin, existing gas plants are being dispatched more intensely at the expense of coal and oil fired plants. There is a significant economics literature evaluating this short term response to the radical change in fuel prices, including its impacts on electricity prices, pollution emissions and existing energy or environmental policy. At the extensive margin, the stock of generating capacity is changing. Coal and oil plants are being retired and new natural gas facilities are coming online. Additionally, existing coal and oil fired facilities are being converted to natural gas to take advantage of existing connections to the electric grid and avoid NIMBY pressures that greenfield facilities would face.

Unlike intensive margin decisions, changes at the extensive margin require significant sunk costs (e.g., decommissioning existing facilities, technology purchases). These sunk costs influence extensive margin responses when changes in fuel prices are unexpected (Dixit and Pindyck, 1994). Systematic volatility in natural gas prices makes generation facility operators more hesitant to commit to natural gas as a fuel source.[1] In addition, parts of the country are awash in consistently cheap natural gas, while other parts see significant price volatility. Recent regional spikes in natural gas prices have given pause to generators considering converting to gas. Natural gas transmission constraints and demand for natural gas for heating have led to extremely high natural gas prices, particularly in the Northeastern and Midwestern United States. During the winter of 2014 spot prices in New York were more than four times higher than the price at Henry Hub in Louisiana. In Chicago the price of spot natural gas peaked at over ten times the Henry Hub price.

Coal generators typically maintain two to three months of fuel inventories on site, but natural gas fired facilities are able to keep little or no gas on-site. Generators typically purchase coal through relatively long term contracts while natural gas must be purchased through short term contracts or on the spot market. This leaves natural gas generators exposed to unexpected changes in fuel prices while contracts and inventories protect coal fired power plants. The combination of volatile regional prices and exposure to spot markets increase the riskiness of extensive margin decisions - retiring or converting existing facilities to natural gas only to see natural gas prices unexpectedly rise.

With the Clean Power Plan finalized in October of 2015, existing power plants will work to cut carbon pollution using the Environmental Protection Agency's (EPA) three building blocks that define the best system of emissions reduction (BSER). BSER consists of the following: 1. Reducing the carbon intensity of electricity generation by improving the heat rate of existing coal-fired power plants 2. Substituting increased electricity generation from lower-emitting existing natural gas plants for reduced generation from higher-emitting coal-fired power plants and 3. Substituting increased electricity generation from new zero-emitting renewable energy sources (like wind and solar) for reduced generation from existing coal-fired power plants (U.S. Environmental Protection Agency, 2015). The Clean Power Plan will only intensify the rate at which coal and oil fired facilities are being converted to natural gas. This new regulation will create an additional

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[1] Figure 1 displays the volatility in natural gas prices and the lack thereof for coal prices in the U.S. from January 2008 to September 2015 on a monthly basis.

cost to electricity generating units (EGUs) in the form of state based standards that create either a rate-based state goal measured in pounds per megawatt hour, a mass-based state goal measured in total short tons of carbon dioxide, or a mass-based state goal with a new source complement measured in total short tons of carbon dioxide.

An electricity generating unit that utilizes real options theory to make optimal investment decisions in the timing to convert from a coal-fired unit to a natural gas unit (or the timing to retire the coal-fired unit altogether) owns an option value, which is the value of waiting to convert or retire the unit given uncertain natural gas prices. The option value could be terminated if a state chooses to use a rate-based policy that requires the electricity generating unit to convert or retire before it would do so when using real options theory. The loss of the option value would itself measure the cost of regulation. Further, if a state chooses to use a mass-based plan, regulatory costs take a different form. The mass-based plans will look very similar to cap-and-trade programs. The price at which EGUs trade emissions allowances will be stochastic and add another uncertain cost component than just fuel-type volatility to the decision maker's objective function.

This paper utilizes real options theory, computational economic techniques, and a suite of novel datasets to investigate extensive margin adjustments to the electricity generation stock in response to systematic risk and unexpected price spikes that arise due to pipeline congestion and new regulatory costs. In this proposal we describe a theoretical model based on Dixit (1989)'s model of market entry and exit under uncertainty. We then describe the data we have acquired to estimate this model and provide descriptive evidence of fuel switching. In principle any policy change that affects fuel prices could be evaluated using this approach. Our approach also allows us the rare opportunity to determine if generators decisions in response to price uncertainty align with real options theory (Kellogg, 2014). The last section detail deliverables.

2 Model

An electricity generating unit produces electricity at a specific rate.[2] The price of this electricity is treated as exogenous. The marginal cost of electricity generation depends on the fuel used for generation, whether that is coal or natural gas. The future profits from this unit are unknown due to uncertainty in the cost of fuel and regulatory costs. Consider a generating unit currently using coal. Based on expectations of future profits, the unit can switch to natural gas when the relative price of coal exceeds a critical threshold. This instantly switches unit profit. In addition to the fuel costs incurred to generate electricity, a one-time sunk cost is required to switch between fuels. This sunk cost represents the costs of changing boiler technology, adjusting pipeline connections, changing fuel contracts and any downtime required to make the switch. Alternatively, the unit may be retired, instead of being converted to natural gas, at a different sunk cost when coal prices rise to a level that is lower than the critical threshold.

The decision problem is cast in terms of a risk-neutral unit manager whose objective is to determine if and when to switch between fuels or retire the unit to maximize the expected present value of generation profits net of fixed costs of switching or retirement. The unit retirement problem is a problem of optimally timing the termination of a negative profit flow. The fuel switching problem is one of optimally switching between a regime where the unit uses coal and a regime where the unit uses natural gas. Based on traditional discounted cash flow analysis, fuel switching would be implemented when the expected present value of the difference in profits equals or exceeds the cost of switching. However, when fuel switching incurs sunk costs, there is an incentive (an option value) to delay these decisions longer than suggested by discounted cash flow analysis.[3] The delay allows the unit managers to gain economically valuable information on relative fuel costs.

The unit manager must evaluate, at each instant in time, whether or not fuels should be switched or the unit retired given all future fuel management decisions are made optimally. The evaluation at each instant in time maximizes expected profits from that point forward by making a simple choice to continue using coal (whose payoff is defined as W_c in Figure 2) or to switch to natural gas at a sunk cost (whose payoff is defined as W_g in Figure 2).

[2] A generating unit contains all the equipment needed to produce electricity and typically operate independently. Electric power plants can include multiple fuel generating units which can use different fuels. For that reason we conduct our analysis at the unit level.

[3] Figure 2 depicts the difference between the benefit-cost threshold and the one using real options theory.

3 Data

Calibrating the model requires detailed data on electric power plants, their fuel choices, and current and future fuel prices. We also need to observe entry and exit of power plants by fuel type. Most importantly we need to observe units that change fuel types and have detailed data on their characteristics. We have assembled this data from a variety of sources including publicly available EPA, U.S. Energy Information Administration (EIA), and Federal Energy Regulatory Commission (FERC) filings as well as proprietary data from Bloomberg, ICE and FERC on fuel prices. Our ability to link fuel price volatility and empirical evidence of fuel switches and unit retirements, allows us to assess the degree to which the behavior of electricity generators can be explained by real options theory (Kellogg, 2014).

Using EPAs Emissions & Generation Resource Integrated Database (eGRID) and EIA form 860 data we have compiled an extensive description of every electric generating unit at every power plant in the United States. The data includes detailed location information, turbine type, fuel type and quantity, generation and emissions output and the year the unit came online. We use the primary and secondary fuel types reported in EIA-860 data as an initial check for fuel switching generating units. Figure 3 below displays the frequency of fuel switching to natural gas in the eGrid data. The frequency of fuel switching has increased as the low natural gas price environment has continued. A non-trivial amount of coal capacity has switched over the time horizon.

We combine the electric generating unit characteristic data with detailed fuel price data from a variety of sources. We have compiled Bloomberg and ICE market price data to create series of spot and future prices at hubs across the country. There is some variation in the level of prices across natural gas trading hubs, but there are large differences in the variation in natural gas prices across hubs. Hubs in the Northeast and Midwest tend to experience very high winter prices while hubs in the southeast and Texas see little seasonal change in price. These regional price differences could be smoothed by increased pipeline capacity. Our analysis will be at the EGU level, allowing us the ability to account for these differences in regional prices.

For a more detailed view on fuel prices we have collected EIA form 423/923 data on delivered fuel prices to electric power plants. For plants in regulated power markets this data is publicly available from EIAs website, but for plants in de-regulated wholesale power markets the data is proprietary. We entered into a confidential data agreement with EIA and have access to this data giving us fuel price data for plants nationwide. The reason for so few empirical investigations of real options in the literature is due to a lack of data. Focusing on the question asked in this proposal, there has been no data on observed switches of fuel-type for electricity generating units. We are able to address this issue employing the fuel source identification technique developed in Holladay and Soloway (2015).

Data on the sunk costs of conversion are sparse; however, such data does exist. A study completed in 1986 by the Massachusetts Institute of Technology looks at several conversions and comes up with price estimates to convert per megawatt of capacity (Fay, 1986). More recently, Babcock & Wilcox Power Generation Group estimate the costs of converting existing coal-fired boilers to natural gas (Binkiewicz, Kleisley, McMahon, Monacelli, Roth, and Wong, 2010). They break down the costs based on the technology used in the conversion. For example, there are different costs between fuel switching with modifications to the existing boiler and a fuel switch for an existing boiler with the addition of a gas turbine.

4 Deliverables

The real options theory, computational techniques, and novel datasets used for the proposed paper will generate not only the research outlined in this proposal, but lend themselves to future applications. One such application would be to investigate the optimal fuel switching decision of electric generating units from oil to natural gas. The proprietary data from EIA and publicly available eGrid data point to a larger number of fuel switches from oil to natural gas than coal from 2001 to 2012. Adding in optimal portfolio theory, we can study each state's decision on policy choice (rate-based or mass-based) to reduce carbon dioxide emissions set by the Clean Power Plan. Our connection to the Howard H. Baker Jr. Center for Public Policy at the University of Tennessee provides a set of unique relationships with stakeholders in the utility industry, environmental interest groups, and state agencies. A webcast series or workshop at the Baker Center that explains the results of this research paper to utility companies like the Tennessee Valley Authority is readily available.

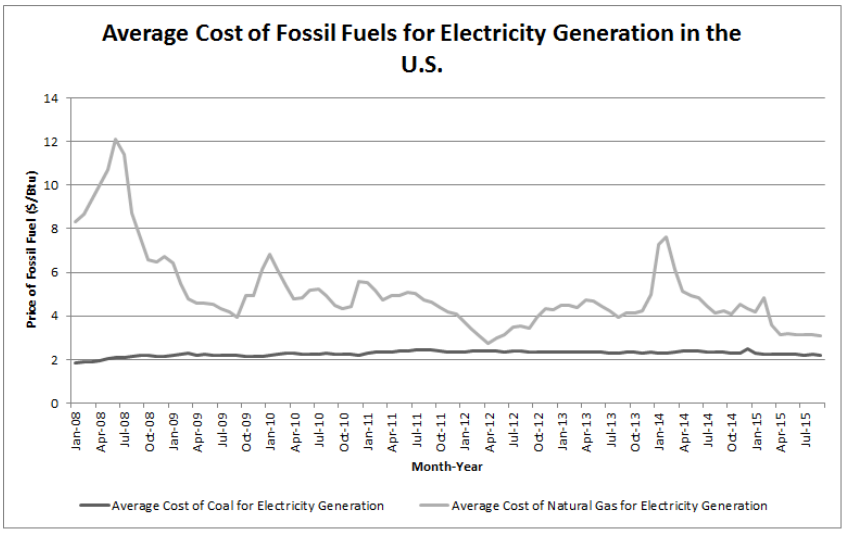


Figure 1: Average cost of fossil fuels for electricity generation (per Btu) for coal and natural gas on a monthly basis from January 2008 to September 2015. Source: U.S. Energy Information Administration. The data used in the proposed analysis and paper will be proprietary data from Bloomberg, ICE, and FERC. Further we will use fuel price data for plants nationwide through a confidential data agreement with EIA.

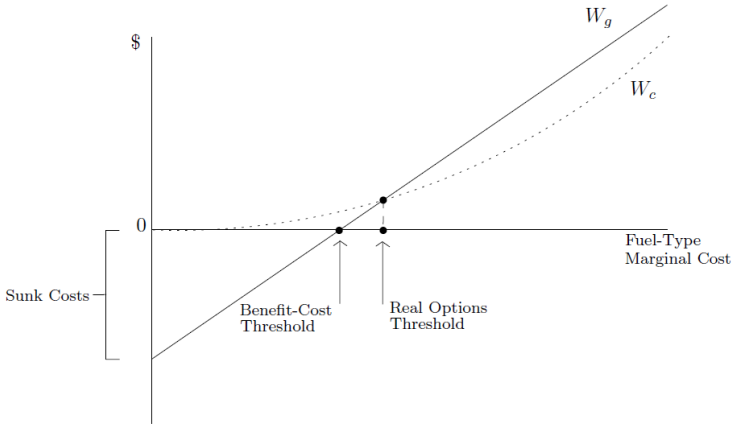


Figure 2: The payoff from using coal is W_c and is represented by a solid black line. The payoff from using natural gas is W_g and is represented with a dotted black line. Where W_c intersects the horizontal axis determines the benefit-cost threshold, defined by the marginal cost of coal. Here, the expected profits from using coal to generate electricity just becomes non-negative. The point in which W_c and W_g intersect, traced down to the horizontal axis, determines the critical threshold defined by real options theory and is in terms of the marginal cost of natural gas. Here, the expected payoff from using coal to generate electricity is just equal to the expected payoff from using natural gas.

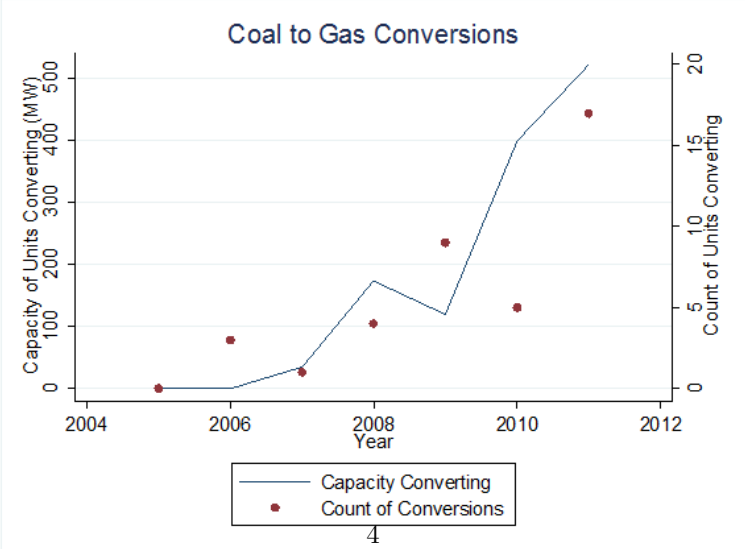


Figure 3: Generating capacity (left vertical axis) and count of generating units (right vertical axis) converting from coal to natural gas from 2005-2011. Conversions have increased significantly in the era of inexpensive natural gas. Additional data is available to update this figure through 2013.

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Research Interests

Energy Economics, Environmental Economics, Public Economics

Focus: Management of natural resources, risk and uncertainty, optimal control theory, real options, applied econometrics

Education

2017-2018 (Anticipated) *Ph.D., Economics*, The University of Tennessee

Dec. 2013 *M.A., Economics*, The University of Tennessee

Dec. 2011 *B.S., Economics*, West Virginia Wesleyan College

Academic & Teaching Experience

2013-Present *Graduate Research Assistant* - Howard H. Baker Jr. Center for Public Policy, Matthew Murray & Charles Sims, University of Tennessee

Primary Instructor (Sole Responsibility for Course)

Econ 313 "Intermediate Macroeconomics," Sum. 2015, University of Tennessee

Graduate Teaching Assistant

Econ 511 "Microeconomic Theory," Fall 2013, University of Tennessee

Econ 201 "Introductory Economics" (Micro/Macro), Fall 2012 & Spr. 2013, University of Tennessee

Publications

2015 "Economic Potential of South Knoxville's Urban Wilderness" with Charles Sims and Bongkyun Kim. *Howard H. Baker Jr. Center for Public Policy White Paper 2:15.*

2015 "Coal Mining and Tourism: Engines of Economic Development for Campbell County and Claiborne County, Tennessee" with Matthew N. Murray, Charles Sims, and Bongkyun Kim. *Howard H. Baker Jr. Center for Public Policy Project Report 4:14.*

2014 "Economic Impacts on Tennessee Arising from Construction of the Uranium Processing Facility" with Matthew N. Murray. *Howard H. Baker Jr. Center for Public Policy Project Report 3:14.*

2014 "Energy Data Collection and Performance Calculation Project" with Jean H. Peretz, Catherine Wilt, and Matthew N. Murray. *Howard H. Baker Jr. Center for Public Policy Project Report 1:14.*

Papers

Working Papers

– "To Frack or Not to Frack: Option Value Analysis of the U.S. Natural Gas Market" with Charles Sims.

Works in Progress

– "State Tax Base Elasticities: Analysis of Long-Run and Short-Run Dynamics Regarding Tax Rates" with Donald Bruce and William F. Fox.

– "The Effects of Confirmation Bias and Subgroup Bias in Hiring Decisions" with Jing Li, Matthew McMahon, and Nathan Murray.

Conference Presentations

Nov. 2014 "To Frack or Not to Frack: Option Value Analysis"
84th Annual Meeting of the Southern Economic Association, Atlanta, GA.

June 2014 "To Frack or Not to Frack: Option Value Analysis"
Western Agricultural Economics Association 2014 Annual Meeting, Colorado Springs, CO

Other Presentations

Oct. 2015 "Fracking: Economics and Policy Impact"
Howard H. Baker Jr. Center for Public Policy Baker Café, Knoxville, TN

Apr. 2014 "The Effects of Confirmation Bias and Subgroup Bias in Hiring Decisions"
University of Tennessee Brown Bag Workshop, Knoxville, TN

Honors and Awards

2014-2015 *Charles B. Garrison Award for Best Graduate Assistant*, University of Tennessee

2014-2015 *Charles B. Garrison Award for Excellence in Teaching*, University of Tennessee

Proficiencies

Matlab, Stata, z-Tree, LaTeX, Maple, MS Office

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To Whom It May Concern:

This letter is to recommend Rebecca Davis for the NBER Pre-Doctoral Fellowship Program on Energy Economics. Becky was in my Environmental and Natural Resource Economics class and I am also serving as Becky's graduate advisor. I have also worked closely with Becky on Department of Energy contracts through the Baker Center for Public Policy where I head the Energy and Environment program. In this capacity, I have had the ability to gauge Becky's scholastic ability as well as her capacity to conduct independent research.

I first met Becky in August 2013 when she was taking my PhD-level environmental and natural resource economics course. The first third of this course covers non-renewable resource extraction models. We quickly move from deterministic to stochastic models which present a formidable challenge to most students who have not been previously exposed to dynamic programming. Unlike other students who simply try to survive stochastic dynamic programming, Becky quickly recognized the limits of deterministic models and requested additional readings. I gave her Avinash Dixit and Robert Pindyck's *Investment Under Uncertainty*. A few weeks later she was in my office telling me about the fuel switching model she found in the book. This model showed that the sunk costs involved with switching electricity generation technologies from one fuel source to another could cause generators to delay this action; especially if fuel prices are very volatile. She quickly recognized that the model could be used to answer a number of questions. When will electricity generators switch from coal to natural gas given recent developments in domestic and international natural gas and coal markets? How will environmental policy (emissions targets, carbon taxes, etc.) affect the rate of transition from coal to natural gas in the electricity generation sector? Perhaps more impressively, she quickly realized how this information could be used inform persistent debates about the potential costs and benefits of the recent Clean Power Plan.

After reviewing the literature on the subject, she found that there had been few empirical investigations of the fuel switching decision of electricity generators. Surprisingly, virtually none of these applications had used a real options methodology despite it being mentioned as a potential application of the model in Dixit and Pindyck's book. Motivated by this finding, she began to develop a more representative model and search for the necessary data. At this point

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she realized why few studies had applied these real options techniques to the fuel choice decision. First, it is impossible to arrive at analytic solutions for all but the most simple real options models. Sophisticated computational techniques would be needed to solve the model that she planned to develop. Second, in order to verify that electricity generators do indeed make investments according to real options theory, one needs data on when generators switch from one fuel source to another. This data seemed nonexistent.

Becky has set out an ambitious research agenda for her dissertation. But I argue that she is a low risk-high reward investment for three reasons. First, she has already taught herself much of the stochastic calculus and computational techniques she will need to be successful. Another chapter in her dissertation which is currently nearing completion is devoted to modeling the market entry/exit decisions of firms engaged in fracking. This chapter also relies on computational techniques to solve real options models and the experience she gained in developing this chapter will be exceedingly helpful for completing the work outlined in her proposal.

Second, she has also already located the data she will need to be successful. Through collaboration with another faculty member in the economics department, Scott Holladay, Becky has been able to obtain proprietary data on delivered fuel prices to each electric power plant in the U.S. This data will allow Becky to more accurately assess the price uncertainty facing generating units and identify regional variation in price volatility. She has also be utilizing a technique developed by Dr. Holladay to identify when generating units switch fuel sources based on readily available EPA data on the pollution profile of the plant. This will allow her to avoid using aggregate data which may mask the influence of price volatility.

Third, Becky possesses that rare combination of good technical skills, common sense, and an exceptional work ethic that characterize the most successful graduate students. Throughout my experience working with Becky, she has been self-motivated and has shown an ability to engage in independent research. Perhaps most impressively, Becky has shown a desire to "dig deep" on each research project she has been involved with. She is not satisfied with a superficial knowledge of the topic. And, more than any other student I have worked with, Becky has an insatiable desire to understand all the relevant existing literature devoted to the topic. Typically I have to push students to move beyond the two or three most relevant papers when developing a literature review. Becky has an uncanny ability to see connections and implications of her work on seemingly disparate research areas. This trait has allowed her to competently perform technical research while also conveying her findings in a relatable way.

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I believe her work ethic in the classroom, independent research on large federally-funded research projects, and prior experience working with computational real options models make Becky a prime candidate for the NBER pre-doctoral fellowship. Please feel free to contact me if more details are needed.

Sincerely,

Charles Sims