Proposal: Causes of the Great Coal Decline: An Examination of the Interaction Between Natural Gas Price Shocks, Environmental Regulation and Generator Exit

Sam Krumholz

1 Introduction

The decline of coal-powered electricity generation in the United States over the past decade has been well-documented in both the economics literature and popular press. However, while economists have generally attributed this decline to a dramatic decrease in the price of natural gas due to fracking, popular attention has focused more closely on a series of new regulations propagated by the EPA since 2008 (Knittel, Metaxoglou, and Trindade, 2016; Linn, Muehlenbachs, and Wang, 2015; Grunwald, 2015). This project aims to synthesize these two arguments. I will make a simple, but important point: the economic and environmental impact of a positive price shock to a polluting input good will depend largely upon the regulatory environment in which the shock takes place. Similarly, the economic and environmental impact of new regulations will depend on the price environment in which they are enacted.

I will demonstrate this idea in two steps. First, I will formalize a theoretical model of the above intuition, showing how understanding the interaction between current and expected input prices and current and expected regulations is necessary to determine the overall impact of both an input price shift and a change in regulations. Doing so will allow me to derive new theoretical results about how existing regulations can either amplify or dampen the environmental effects of an input price shock. Additionally, I will also integrate expectations about future dispatch order into a firm's dynamic decision about whether to retire a generator. This will provide new and important insight into how existing and expected input prices and regulations interact to guide generators' exit decisions. Although this finding is motivated by a specific American context, it applies more broadly across a variety of governance structures and regulatory environments.

Second, I will test these hypotheses empirically, using variation in current and expected relative coal price created by the US fracking boom and variation in current and expected regulation caused by several different state and national regulatory programs in which coal boilers are differentially affected based on location or baseline pollution intensity. This paper will provide novel evidence about the degree to which the existing regulatory environment affects intensive and extensive margin movement away from coal generation in response to a shock to relative coal prices. This finding will have important implications not only for estimating the effect of future input shocks and calculating the cost-efficiency of future regulations. This analysis will also provide new evidence about how changes in regulatory expectations affect the exit of high-polluting boilers, helping us better understand over what time scale firms begin adapting to new regulations as well as how regulatory proposals with uncertain probabilities of enactment may still shift firm behavior.

2 Literature Review and Institutional Background

Coal-powered electricity generation in the United States has fallen by more than a third between 2008 and 2015. The economics literature examining this decline has focused on both how this fall in generation is related to the large decrease in natural gas price beginning in 2009 (Johnsen, LaRiviere, and Wolff, 2016), as well as how the effects of this decrease in gas price was mediated by various market-forces including deregulation of electricity markets (Knittel, Metaxoglou, and Trindade, 2015), the presence of renewable energy (Fell and Kaffine, 2015), and the potential existence of bulk energy storage (Holladay and LaRiviere, 2014). In the paper closest to this proposal, Linn, Muehlenbachs, and Wang (2015) show that there is an inherent tradeoff between price reductions and pollution reductions caused by a negative shock to natural gas prices depending on whether the price shock is large enough to move natural gas plants ahead of coal plants in the dispatch order. However, although these papers have greatly advanced how we think about the causes and effects of the drop in coal generation over the past decade, none of them address two crucial factors that I will argue played a significant role in the decline of coal: changes in environmental regulations and coal boiler exit.

The potential significance of these factors can be seen in Figures 1,2 and 3. Figure 1 shows log monthly generation produced by boiler NOX pollution intensity and emission quartiles. The overall reduction in coal generation came disproportionately from the highest polluting boilers, but there is little relationship between boiler efficiency and relative generation reduction. Figure 2 shows generation by boiler age from 2001-2007 and 2009-2015. Almost the entire reduction in coal generation between these two time periods occurred in boilers built before 1980. These results suggests that the factors causing coal generation to decline since 2008 must differentially affect older and more-polluting boilers. In this proposal, I will argue that both new regulation and the interaction between existing regulations and decreases in natural gas prices play exactly this role.

Figure 3 shows the *total* monthly megawatts produced by coal boilers which are not planned to be retired by 2020 relative to production by boilers that have either retired or are planned to retire by 2020. Plants that either retired or planned to retire produced about one-fifth of total coal generation in 2001, but less than 1/25th of all generation in 2015. These boilers account for roughly half of the total decline in coal production since 2008, suggesting that coal boiler exit is a major determinant of overall coal decline. Thus, to understand the sharp decrease in coal generation over the past decade, it is necessary to understand the dynamics of firm decision-making about boiler retirements.

3 Empirical Strategy and Data

To test the idea that the effect of an input price shock on intensive margin generation is mediated by the regulatory environment, I will run various triple-difference models where I regress log annual generation on interactions of various boiler characteristics, boiler state annual natural gas price and an indicator for whether or not the boiler is under a given regulatory regime, along with boiler and year fixed-effects. Boiler characteristics will include boiler age, boiler pollution intensity in year $y-1$ and boiler efficiency in year $y-1$. The three policy regimes I will consider are whether the boiler is included under NOX or SO2 allowance trading program, whether the boiler is in a county violating the National Ambient Air Quality Standards (NAAQS) and the stringency of the boilers state- emissions laws.

The basic intuition behind this strategy is that if the theoretical model is correct, we should expect the price shock to disproportionately affect low-efficiency boilers in low regulation states

and high-polluting boilers in states with strong regulation. These quantities map directly into the coefficients on the various triple interactions in the model. The identifying assumption in these regressions is that there are no time-varying factors that differentially affect generation in response to natural gas prices inside and outside a certain regulatory regime. Although, one can construct stories within each of the three policy regimes that may lead to a violation of the exclusion restriction, it is difficult to create a coherent story in which such an omitted variable is operating across all three regulatory contexts.

Using a similar empirical strategy, I next test the idea that changes in regulatory expectations both independently and in interaction with input price shocks affect rates of boiler exit. I will first perform a simple difference-in-difference, comparing changes in rates of announced future retirements among plants with differential likelihood of being affected by the Mercury and Toxic Standards Acts (MATS) and the Clean Power Plan (CPP), two new major regulations, before and after the regulations announcements. Plants should have differential expectations of being affected by the regulations after announcement based on baseline pollution/CO2 levels. I next will perform a triple-difference, adding an interaction term with natural gas prices. This will test whether the regulations effect on exit rates is amplified by a higher (expected) relative coal price. Lastly, as a final test of this hypothesis, I perform the same triple-difference using a third policy-lever, the increasing restrictions on fossil fuel generation created by a states renewable portfolio standard.

My data on boiler generation, pollution intensity and other characteristics will come from the EPAs Continuous Emissions Monitoring System (CEMS) database, which has collected continuous generations and emissions data on most major coal boilers in the United States since 2001. Data on which boilers are affected by which regulatory regimes will come largely from EPA documentation including the EPA Green Book, EPA reports on SO2 and NOX allowance programs (NOX Budget Program, CAIR and CSPAR), and EPA factsheets and settlement documents regarding MATS and the CPP. Finally, I will provide a detailed survey of state-level emissions laws and renewable portfolio standards thresholds by year through a detailed state-by-state search of legislative (session journals) and documentary (newspaper) sources. Part of the money from this fellowship will be used to hire a research assistant to help facilitate this data collection process.

4 Deliverables

This project will have three main deliverables. First, I will have a finalized working paper based on this proposal ready for submission to a major journal by May 2018. Prior to May 2018, I aim to have presented this work at several conferences, both to gain feedback and to disseminate the results. Second, I will generate two new datasets: one panel data set of state emissions laws including information on year of passage and stringency and a second panel data set of renewable portfolio standard targets by year. Third, I will have drafts of two other papers arising out of the work on this project. First, I plan to examine how the stock prices of electric generating companies with differential exposure to natural gas, clean coal plants and dirty coal plants changed in response to various regulatory announcements and natural gas price shifts. Second, I will write a theoretical paper describing how in regimes with uncertain political control, it may be optimal for politicians to write second-best regulations that incentivize exit of polluting plants, rather than marginal reductions in pollution, because the exit decision cannot be easily undone by their political opponents. In sum, my goal for this project is to create several papers describing novel evidence on what causes firms to switch away from coal generation and how this switch affects firm value, as well as several public datasets that can be used to further our understanding of the interaction between the legislative process and electricity markets.

References

[1] Harrison Fell and Daniel Kaffine. "Hhe Fall of Coal: Joint Impacts of Fuel Prices and Renewables on Generation and Implications for Policy". In: *Working Paper* (2015).

[2] Michael Grunwald. "Inside the War on Coal". In: *Politico* (2015).

[3] J Scott Holladay and Jacob LaRiviere. "How does welfare from non-pecuniary policies vary with market prices? Evidence from fracking, natural gas and emissions from electricity generation". In: *Work. Pap., Univ. Tenn., Knoxv* (2014).

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[5] Christopher Knittel, Konstantinos Metaxoglou, and Andre Trindade. "Are we fracked? The impact of falling gas prices and the implications for coal-to-gas switching and carbon emissions". In: *Oxford Review of Economic Policy* 32.2 (2016), pp. 241–259.

[6] Christopher R Knittel, Konstantinos Metaxoglou, and Andre Trindade. "Natural gas prices and coal displacement: Evidence from electricity markets". In: *National Bureau of Economic Research* (2015).

[7] Joshua Linn, Lucija Muehlenbachs, and Yushuang Wang. "Production Shifting and Cost Pass-Through: Implications for Electricity Prices and the Environment". In: (2015).

Figure 1: Changes in Electricity Generation over Time by Coal Boiler Pollution Intensity and Efficiency

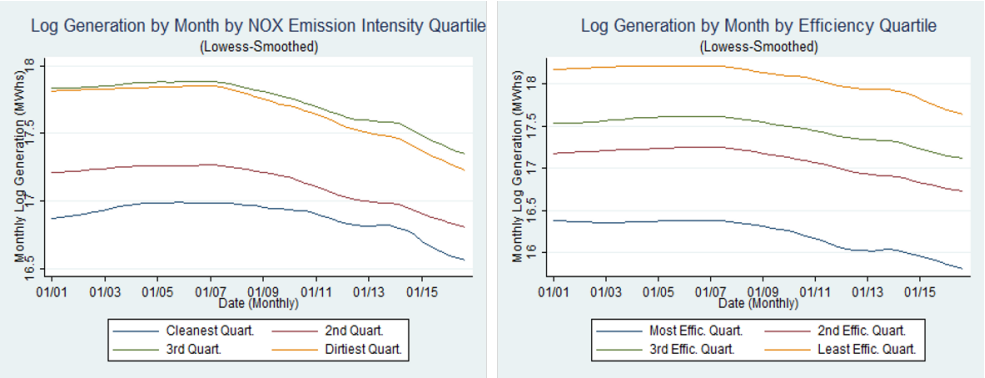


Figure 2: Change in Coal Electricity Generation between 2001-2007 and 2009-2015 by Boiler Age

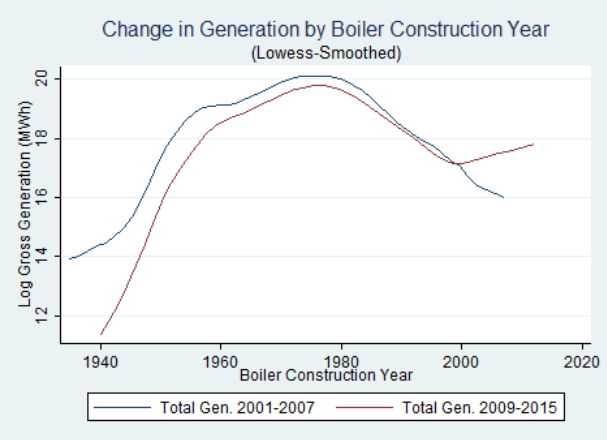
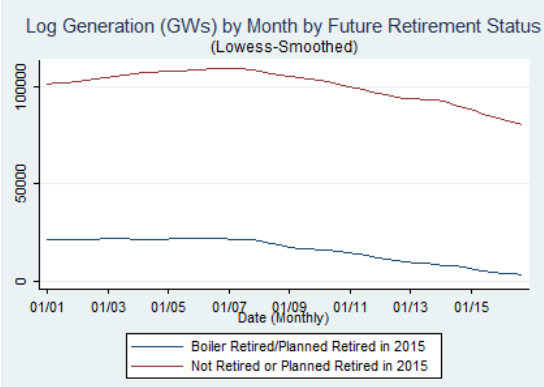


Figure 3: Change in Coal Electricity Generation by Boiler Retirement/Planned Retirement Status



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Education

August 2014-	PhD in Economics, **University of California, San Diego** Qualifying Exams Completed: June 2015 Fields: Environmental, Development, Labor
June 2014	Masters in Public Policy, **University of California, Los Angeles**,
June 2009	Bachelor of Arts in International Relations, **Tufts University**

Research Experience

October 2016-	Research Assistant for Professor Paul Niehaus at University of California, San Diego
June 2014-	Research Assistant for Professor J.R. Deshazo at UCLA Luskin Center for Innovation
Summer 2012 and 2013	Research Assistant at China Center for Health Economics Research, Peking University, Beijing China

Skills

Computer Skills: Stata (advanced), R (advanced), GIS (proficient), Matlab (proficient)
Language Skills: Chinese (proficient), Spanish (proficient)

Published Articles and Book Chapters

Liu, Gordon G., and Samuel Krumholz. "Economics of health transitions in China." The Oxford Companion to the Economics of China (2014): 449.

Liu, Gordon G., and Samuel Krumholz. "China's Epidemiological Transition and Health Reform." China's Healthcare System and Reform (Forthcoming).

Krumholz, Samuel D., David S. Egilman, and Joseph S. Ross. "Study of neurontin: titrate to effect, profile of safety (STEPS) trial: a narrative account of a gabapentin seeding trial." Archives of internal medicine 171.12 (2011): 1100-1107.

Works in Progress

The Effect of State Prosecutors on Local Criminal Justice and Economic Outcomes

Early Childhood Health and Development in India: A Review of the Evidence and Recommendations for the Future) (with Achyuta Adharvyu and Prashant Bhardawaj)

Learning and Hassle Costs in Energy Conservation: Evidence from a Field Experiment (with JR Deshazo and KC McKenna)

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Attn: Meredith Fowlie and Ryan Kellogg
Pre-Doctoral Fellowship in Energy Economics
National Bureau of Economic Research

December 8, 2016

Dear Selection Committee,

It is with great pleasure that I write this letter to offer my strongest recommendation in support of Sam Krumholz application for the NBER Pre-Doctoral Fellowship in Energy Economics. Sam is a highly organized, motivated, and intelligent individual who possesses an intellectual maturity that far surpasses his career age. He shows considerable promise in empirical microeconomics with a keen sense for important research questions in the field of environmental/energy economics and creative approaches to answering them. He is among the best graduate students I have advised in the past decade and I believe he is an ideal candidate for this fellowship.

I first met Sam in our environmental economics seminar several years ago. I was immediately struck by his insightful questions and intellectual curiosity. Those initial impressions were only strengthened when Sam enrolled in my graduate course on the economics of pollution. He was clearly the star pupil and even identified some important features of several papers on the syllabus that had eluded my attention despite my intimate familiarity with them. I was delighted when Sam approached me to serve as his dissertation adviser.

Sam's fellowship proposal offers an innovative approach addressing a fundamental question in energy economics. Much work in energy economics has focused on understanding the independent relationships between input prices, regulations and electricity output. However, to date, relatively little is known about how the interactions between input prices and regulatory regimes affect electricity generation and pollution. Sam's project attempts to quantify this effect, showing that both new regulations and changes in input prices can have vastly different economic and environmental effects depending on existing regulatory and/or price levels. His analysis will exploit the decline in US coal generation since 2008 on top of several regulatory changes that occurred before and during this time period to disentangle these effects. I believe that this project has the potential to generate important insights that will generalize to settings well beyond the US electricity market.

In addition to the project described in his proposal, Sam has several other exciting research projects under development that I believe have the potential to make important contributions to energy economics. With J.R. Deshazo at UCLA, Sam is working on a large randomized-controlled trial

examining how different types of price and messaging incentives affect household responses to critical peak pricing events. This project has access to appliance-level data for a subset of participants, and so will be among the first to measure the specific ways in which households change their energy consumption in response to incentives. It also will provide novel measurements of the "hassle costs" associated with changing behavior in response to a critical peak price event, and will study how these hassle costs change with household learning and in response to different demand setting (times of day, temperature, etc).

Sam is also in the early stages of work on a project analyzing the political determinants of support for environmental policies. Unlike previous work, Sam focuses on state-level policies, creating a much larger sample of votes from which to draw inference. Using a regression discontinuity design, a difference-in-difference approach based on exposure to shale plays, and changes in constituent composition induced by redistricting, Sam attempts to decompose the effects of legislator ideology, constituent economic interest and constituent ideology on the probability that a legislator votes in favor of pro-environmental regulation. These results should both further our understanding of the political economy of environmental regulation and help policy makers craft environmental policies that appeal to the broadest possible constituencies. In addition, this project will generate several new datasets on state environmental laws and state legislative voting patterns, which should facilitate further work in this area by economists and political scientists.

In short, I think Sam is an ideal applicant for the NBER fellowship program. The support provided will enable him to focus on his research at a critical juncture in his professional development. He will undoubtedly benefit from increased interaction with the broad network of energy and environmental researchers with the NBER family. This fellowship will also ensure that a budding young economist with tremendous promise continues to focus on energy-related research topics of huge policy importance. Sam has proven successful in all endeavors he has undertaken and I have no doubts that his success will continue in the future. It is without hesitation that I offer my strongest recommendation in support of his application.

Please do not hesitate to contact me should you have additional questions about his candidacy.

Sincerely,



Joshua Graff Zivin