Whose "War on Coal"?

Dasom Isabella Ham*

University of Minnesota-Twin Cities

hamxx059@umn.edu

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Abstract

While it is widely agreed that coal power plant owners are retiring coal generators in large numbers, there has been a political discussion whether the "War on Coal" is occurring or not. Some have argued that federal regulations or the "War on Coal" are causing premature coal power plant retirements. Others have argued that low natural gas prices are causing coal power plant retirements. To offer a much clearer picture, I use publicly-available, generator-level data to analyze the impact of the Environmental Protection Agency's emissions regulation, Mercury Air Toxics Standards, and the relative price ratio of coal price and natural gas price on the United States coal generator retirements. I show that both sides of the "War on Coal" are not showing full picture when they promote their position. The federal regulation impact the economic viability of coal power plants while low natural gas prices also play a critical role in recent coal power plant retirements.

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Contents

1 Introduction

"The War Against Coal is Over"- former EPA chief administrator, Scott Pruitt (2017)[11]

Across the United States, coal power plant owners are shutting down coal plants in large numbers in recent years. This trend has led to a political discussion on possible causes. Some have argued that the federal environmental regulations or the "War on Coal" are causing premature coal power plant retirements. Others have argued that the federal regulations are not causing the retirements. Instead, low natural gas prices from fracking technology are causing coal power plant retirements [21].

To find a possible answer, I use publicly-available, generator-level data from the United States Energy Information Administration (EIA), Federal Energy Regulatory Commission (FERC), and the Environmental Defense Fund (EDF) to analyze the impact of the Environmental Protection Agency (EPA)'s Mercury Air Toxics Standards (MATS) and relative price ratio of coal price and natural gas price on United States coal generator retirements. I show that both sides of the "War on Coal" are only showing a partial picture. I show that the federal regulation impacts the economic viability of coal power plants while low natural gas prices also play a critical role in recent coal power plant retirements.

This paper is organized into six sections. I first introduce background information on the United States effluent emission regulations and the United States electricity industry. Furthermore, I discuss the how market participants interact within the United States electricity wholesale markets and give background information about independent system operators (ISO) and regional transmission organizations (RTO). In the second section, I explore literature on the role of low natural gas prices and renewable generation on electricity prices, coal generation, and investment in power plants and literature on firm decision-making to replace equipment. In the third section, I introduce the data and discuss descriptive statistics. Afterwards, I discuss the model I use in my empirical section. In the fifth section, I introduce methodology and examine empirical results. Lastly, I talk about the implications of the results, limitations of my study, and conclude about the findings.

2 Background

2.1 U.S. Emissions Regulations: "War on Coal?"

The first major federal regulation to limit emissions was the Clean Air Act (CAA).[1] The CAA, signed in 1970 by former Republican President Richard Nixon, allowed the EPA to set emissions standards, required states to "adopt enforceable plans to achieve and maintain air quality" and enforced states to control emissions across state borders [15]. The CAA was later updated in 1977 and 1990 under former Democratic President Jimmy Carter and Republican President George H.W. Bush respectively.

Since the passing of the CAA, the EPA continued to monitor and propose emissions regulations. The goal of these ongoing regulations was to reduce the probability of people, especially children, to receive neurological issues [19]. The EPA further argued that the purpose of the effluent limitations was to decrease the likelihood of "premature deaths, asthma attacks, and heart attacks" [19].

Certainly mercury emissions fell under the updated CAA but power plants remained the largest "man-made source of mercury emissions" [17]. In response, the EPA issued the 2005 Clean Air Mercury Rule (CAMR) to limit mercury emissions from power plants. However, it was shortly vacated under the D.C. Circuit Court of Appeal lawsuit ruling [16], [2]

To comply with the legal ruling, the EPA revised and issued MATS in 2012. Like the CAMR, MATS limited mercury emissions and air pollutants generated by power plants and required existing and new coal and oil generators to meet emission standards by adopting

[1]There has been federal legislation prior to the CAA, such as the Air Quality Act. But these legislations allow the federal government to conduct activities to study air pollutions rather than enforcing emissions regulations [22].

[2]See "United States Court of Appeals for the District of Columbia Circuit Case No. 05-1097"

emissions control technologies [19]. Coal generators are specifically required to limit mercury emissions and other pollutants. Because installing new equipment required some time, the EPA offered coal and oil-fired generator owners to comply by April 2015. If a coal power plant owner did not comply, then the owner was required to shut down the coal generator.

Since 2012, EPA updated MATS multiple times and faced a legal challenge. The first modification occurred in 2013 where the EPA updated emissions limits for future coal and oil-fired generators [18]. A year later, the EPA issued "updated definitions and work standards" [18]. In 2015, the EPA faced another federal lawsuit by the state of Michigan (*Michigan vs. EPA*). The Supreme Court justices ruled that the EPA inappropriately excluded the costs to justify the regulation of affected power plants [20]. Despite the ruling, MATS was not repealed but was modified to consider the costs for the next final report and corrections [20].

Because of the increasing concern over the possible negative health effects of greenhouse gas emissions and in response to the Paris Climate Change Agreement, the Obama administration and the EPA introduced the 2015 Clean Power Plan (CPP). The proposed policy required reduction of carbon emissions and pollutants from power plants [39]. Because of the potential costs to meet the standards, 27 states and several companies filed a lawsuit [33]. In this case, the Supreme Court ruled "to grant a request" to block the CPP and thus stay the CPP [33].

With increasing federal and state regulations, there has been a debate about whether the federal and state regulations cause premature coal power plant retirements. Some have argued that the MATS and CPP, the "War on Coal" under the Obama Administration, have caused premature coal power plant retirements [20]. The opponent's largest concern is that these regulations can negatively affect coal-producing state economies, such as West Virginia, by reducing the need for coal [33]. In addition, they argue that stricter environmental regulations would lead to the premature replacement of older coal power plants to newer plants and therefore the U.S. economy incurs unnecessary costs to produce electricity [9].

In contrast to the "War on Coal" believers, others have argued that market and individual factors have caused coal power plant retirements over the last several years. Some have argued that the "plant-specific factors," such as the nameplate size and the age of the plant, have played a larger role in the coal power plant retirements [21]. Others suggested that low natural gas price is the cause of coal power plant retirements. This is because energy produced by natural gas generators can crowd-out coal generators from the market if the natural gas electricity production cost is lower than coal power plant's production cost [10]. Since the natural gas industry employed technological advancement in natural gas production, natural gas prices in the United States have decreased significantly [10].

2.2 The United States Electricity Market

2.2.1 History

Prior to the mid-1990s, the electricity industry was a natural monopoly due to the nature of industry, large fixed cost for generators, transmission, and distribution systems [30]. As a result, many United States residents received electricity from regulated monopoly utilities such as vertically-integrated investor-owned utilities (IOUs), municipal utilities or electric cooperatives [3]. Since the regulated monopoly received guaranteed cost recovery, it was possible for the industry to overbuild or overinvest in generation and transmissions and distribution systems even with low electricity demand growth [30]. The overbuilding and overinvesting in the electric system infrastructure led to higher electricity rates [30].

Because of the ongoing high rates, both the federal and state governments started to introduce competition in the electricity market. On the federal level, the first deregulation effort occurred under the 1978 Public Utilities Regulatory Policies Act (PURPA) [30]. This act required utilities to buy electricity from smaller power plants under utilities created standard contracts, which promoted competition in the generation market [30].

At the end of the 1990s, the industry faced more deregulations efforts. Generation, transmission, and retail markets were deregulated by varying degrees [3]. RTO and ISO were created to implement open access transmission tariff and to control the energy production schedules within designated regions under open access rule [3]. For the generation portion, the generators faced a market-based pricing model and mainly earned revenue from the produced output [3]. However, the deregulated efforts stalled after the 2000 electricity crisis in the West Coast [5].

While the industry was being restructured, it also faced environmental regulations from federal and state governments. Because of increasing concerns about effluents and climate change, major policies were passed to reduce emissions from power plants [6]. This resulted in the coordinated state and federal efforts to implement regulations [32]. On the federal level, the government established standards and left the states to determine the strictness of the standards [32].

2.2.2 Infrastructure

The United States electric grid can be divided into three interconnections: the Eastern Interconnection, the Western Interconnection, and the Electricity Reliability Council of Texas Interconnection (ERCOT) [30]. Within each interconnection, power plants are interconnected and synchronized, but interconnections are not synchronized and hardly coordinated with each other [30]. If there were to be electricity flows among the three interconnections, then the current is converted either from alternating current (AC) power to direct current (DC) power or vice versa [30].

2.2.3 Entities

There are several regulating entities in the electricity industry. One is the North American Electricity Reliability Corporation (NERC). NERC regulates the reliability of the bulk power system across eight regional entities [30]. The NERC's regional entities include the following: Western Electricity Coordinating Council (WECC), Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), Reliability First (RF), Southeastern Electric Reliability Council (SERC), Florida Reliability Coordinating Council

(FRCC), Southwest Power Pool (SPP RE), and Texas Reliability Entity (Texas RE) [30]. The NERC's regional entities carry out NERC's reliability rules at its own region.

Another regulating entity is the Federal Energy Regulatory Commission (FERC). FERC regulates the rates of wholesale electricity market and interstate transmission lines [30]. Furthermore, FERC reviews reliability standards and monitors the wholesale markets to prevent market manipulations and the standards violations [30].

In addition to the regulators, there are independent system operators and regional transmission organizations, which provide open access to the grid and efficient energy markets by planning, scheduling, and monitoring the supply of electricity in the wholesale markets [30] The ISO and RTO include the California independent system operator (CASIO), Southwest Power Pool (SPP), Electric Reliability Council of Texas (ERCOT), Midcontinent independent system operator (MISO), PJM Interconnection (PJM), New York independent system operator (NY-ISO), and independent system operator New England (ISO-NE).

Along with regulators and ISO/RTO, there are also electric utilities. There are five-types of electric utilities. The first is the publicly owned utilities or municipal utilities. These are owned and operated by local governments to serve municipalities [30]. The second is electric cooperatives. These utilities serve rural areas [30]. The third is the investor-owned utilities (IOU). IOU are privately-owned companies serving highly populated areas [30]. The fourth type is the federal power agencies. These agencies generate electricity in federally owned plants and sell the electricity [30]. The last type of utility is the power marketers. They simply buy and sell electricity for profit [30].

2.2.4 Wholesale Energy Market and ISO/RTO

The wholesale energy market is a market where sellers and buyers buy and sell energy at the wholesale market clearing price or locational marginal pricing (LMP) [37]. LMPs are the locational marginal costs of supplying energy or consuming energy at a specific location and determined by three components: marginal energy charge, marginal congestion charge, and marginal loss charge at the location [44]. RTO and ISO dispatch power plants in the order of the least cost energy production power plant to the highest cost energy production power plant including congestion cost and line loss cost subject to reliability constraint ([7]), [44]).

In the wholesale market, there are seven RTO and ISO in the United States: NY-ISO, ISO-NE, PJM, CAISO, MISO, SPP, and ERCOT.[3] NYISO is an independent system operator that only serves the state of New York [27]. ISO-NE is a Northeastern independent system operator that serves six states: Maine, Vermont, New Hampshire, Connecticut, Rhode Island, and Massachusetts [26]. PJM is a regional transmission organization that facilities electricity among 13 states: Illinois, Michigan, Indiana, Kentucky, Ohio, Pennsylvania, Tennessee, West Virginia, Virginia, Maryland, Delaware, Maryland, New Jersey, and the District of Columbia [38]. CAISO is an independent system operator that serves a significant portion of California and parts of Nevada [8]. MISO is an independent system operator and regional transmission organization that offers services to 15 states and the Canadian province, Manitoba [36]. The states include Minnesota, Wisconsin, North Dakota, South Dakota, Michigan, Iowa, Illinois, Indiana, Kentucky, Missouri, Arkansas Louisiana, Mississippi, Texas, and Montana. MISO serves only parts of Montana, Texas, Louisiana, Illinois, Indiana, Kentucky, Missouri, Arkansas, and Mississippi [36]. SPP is a regional transmission organization that serves fourteen states. These states include: Arkansas, Montana, North Dakota, South Dakota, Minnesota, Iowa, Missouri, Kansas, Nebraska, Louisiana, Texas, New Mexico, Oklahoma, and Wyoming [28]. ERCOT only serves Texas [24].

There are two groups of market structures that RTO/ISO serve: traditionally-regulated states and deregulated states. Traditionally-regulated states have vertically-integrated utilities, where power plant owners can recover costs through state regulatory rate decision process [23]. In contrast, utilities in deregulated states do not recover costs through state regulatory rate decision process. Instead, they recover their cost through market mechanisms [23].

[3] See Appendix B for maps of ISO/RTO

Table 1: Types of ISO and RTO

Type	Name of ISO/RTO	Missing Money Problem?	Market Mechanism
Deregulated States	ERCOT	Y	Energy-only Market
	ISO-NE, NY-ISO, CAISO, & PJM	Y	Centralized Capacity Market
Traditionally-regulated States	MISO	N*	Voluntary Capacity Market
	SPP	N	N/A

Note: ‘Y’ means ’yes’ and ‘N’ means no. * Illinois is the exception

Because of no financial assurance in deregulated states, power plant owners in those states can face the missing money problem. The missing money problem is the issue of deficiency in the full recovery of fixed costs of generation [2]. If a utility is uncertain about the recovery of fixed costs over time through energy sales, then there is a high risk of insufficient investment in generation capacity in the market [4].

To manage the missing money problem, several ISOs and RTOs use market mechanisms (high scarcity energy pricing or centralized capacity market) to supplement revenue to power plant owners. In an energy-only market, generators are supposed to recover full fixed costs from scarcity energy prices.[4] In theory, if there is a shortage of generation capacity, then the energy price will go up significantly [5]. Unlike other markets, energy-only markets do not set the energy-price caps or has significantly high energy-price caps so generators can receive very high revenue at the time of energy scarcity [5]. ERCOT is the only ISO/RTO to utilize an energy-only market. The centralized capacity market is a market that provides revenues to generator who agree to supply capacity regardless of energy sales [34]. This ensures that there are enough resources, also known as resource adequacy, to meet demand [34]. ISO-NE, NY-ISO, PJM, and CAISO use centralized capacity markets.

For power plant owners operating in traditionally-regulated states, they do not face the missing money problem. These power plant owners do not face this issue since the state cost

[4]Scarcity price is the energy price during the energy shortage [5].

recovery process allows them to recover the fixed cost regardless of capacity usage [23]. SPP and MISO do not have a capacity market [34]. But MISO facilitates a voluntary capacity market as a service to partially or fully deregulated states [23].[5]

3 Literature Review

There has been past work on the effects of renewable generation and natural gas prices on investment in power plants, electricity prices, and coal power plant emissions. These past works can be categorized into simulation studies and empirical studies. One simulation paper is by Traber and Kemfert (2010) [43]. Using German data, they analyze the impacts of wind generation on electricity prices and investment [43]. They use a model, the Electricity Supply and Demand Match Under Emission Trading and Renewable Energy (ESYMMETRY), that specifically captures the start-up costs of operating generation [43]. Simulating a single week for a year, the authors found that greater wind generation led to insufficient investments to thermal power plants, such as natural gas power plants [43].

Another simulation work is by Sensfub, Rawitz, and Genose (2008) [42]. It focused on the effects of wind generation on spot market prices in Germany. Using a calibration model called PowerACE cluster model, they simulated the electricity market prices in the reserve and spot markets to observe the merit-order effect [42]. Through scenarios, the Sensfub, Rawitz, and Genose were able to show that the merit-order effect was "sensitive" to changes in fuel prices [42]. In fact, their results showed that average prices significantly decreased [42].

The other type is the empirical studies. Fell and Kaffine's paper analyzed the effect of renewable generation, low natural gas prices, and the combination of the two on coal generation in four ISO (ERCOT, MISO, PJM, and SPP) [25]. Including the relative price ratio of coal price and natural gas price, carbon emissions from generators, and daily generator capacity in their analysis, Fell and Kaffine compared the impact of renewable generation and

[5] Michigan is partial retail choice state and Illinois is fully deregulated state.

low natural gas prices on coal generation among the ISO.

The second paper by Gelabert, Labandeira, and Linares (2011) focuses on the effects of renewable energy generation on electricity prices [31]. Unlike the previous two papers, this paper used electricity prices to determine what happens to the long-term investments when electricity prices decrease. According to the authors, theoretically, as renewable generation penetration increases, the electricity prices would decrease because renewable generations with zero or lower marginal costs would displace the generations with higher marginal costs. If electricity prices decrease, then this would signal to long-term investments and therefore deter future investments [31]. To analyze the topic, the authors use multivariate regression with daily data from 2005 to 2010. They found a negative relationship between electricity prices and amount of energy produced by renewable generation.[6]

There also has been past work on firm decision-making to replace equipment. One such paper is John Rust's 1987 "Optimal Replacement of GMC Bus Engines: An Empirical Model of Harold Zurcher." Using data of 162 Madison Metro buses from 1947-1985, Rust showed that the Harold Zurcher's choice to overhaul a bus engine or replace the engine when the engine fails follows the optimal stopping rule [41].[7] Conceptually, Zurcher chose to investment in new equipment based on the bus engine characteristics (whether the bus had low mileages or high mileages) [29]. Rust suggested that if a component of a bus with low mileage failed, then Zurcher should repair or replace the failed part of the bus engine [29]. On the other hand, if a component of bus with high mileage failed, then Zurcher should invest in a new engine because of expected frequent engine failures [29].

While there has been works on the effects of low natural gas price and renewable generation on investment, electricity prices, and effluent emissions, there has been limited or no work on the combination role of federal regulation and economic market forces on coal generator retirements. This paper set out to analyze the combination impact of the federal

[6] There are other empirical studies analyzing different combinations of effects on coal generation and carbon emissions. For instance, see Knittel, Metaxoglou, and Trindade (2015) [35].

[7] The theory of optimal stopping rule states there is an optimal time to maximize your expected payoff and minimize your expected costs based on "sequentially observed random variables" [29].

regulation and economic factors on coal generator retirements.

4 Data & Descriptive Statistics

4.1 Data

In this paper, I use the following sources for the data set: U.S. Energy Information Administration (EIA), Federal Energy Regulatory Commission (FERC) natural gas market archives, and the Environmental Defense Fund (EDF).[8] From the EIA, I use the EIA-860 data set. The EIA-860 is an annual survey on United States generators that have at least 1 megawatt of combined nameplate capacity. The new version of data set is from 2001 to 2016 and the older version of data set is from 1990 to 2000. Within each annual survey, there are eleven files of data: 'Layout', 'Utility', 'Plant', 'Generator', 'Wind', 'Solar', 'Energy Storage', 'MultiFuel', 'Owner', 'Environment Association' and 'Environmental Equipment.' The 'Layout' sheet provides information on the data observations in the other sheets. Likewise, the 'Utility', 'Plant', and 'Generator' sheets provide information about the utilities, plants, and generators. The 'Generator' file specifically provides information on currently operating, proposed, and retired and canceled generators. The 'Wind', 'Solar', 'Energy Storage', and 'MultiFuel' provide information on operating, retired, and canceled wind, solar, energy storage technology, and multi-fuel generators. The 'Owner' file contains a directory of operators for each generator. Lastly, the 'Environment Association' and 'Environmental Equipment' provide information about the boilers and the environmental equipment utilized in each surveyed generator. For this paper, I utilize the 'Plant' and 'Generator' data sets. I use the 'Plant' sheets to identify power plants from 2010 to 2016 by Balancing Authority.[9]

I also use the EIA coal data browser. The coal database is a compilation from the EIA-293

[8]For more information about how I created the data set, see Appendix A.

[9]The data is limited because the EIA started to indicate Balancing Authority and ISO in 2010. Balancing Authority is an entity that "integrates resource plans ahead of time, maintains load-interchange-generation balance within a Balancing Authority Area and supports Interconnection frequency in real time" [14]

survey form, "Power Plant Operations Report" and the United States Department of Labor, Mine Safety and Health Administration "Quarterly Mine Employment and Coal Production Report." Within the data browser, there are data on the coal mine production, shipment, export and import, consumption and quality, coal market, and the coal consumption and capacity. For this analysis, I use the annual coal shipment price ($/short ton) to the electric power sector by state from 2008 to 2016. I use this as a proxy for coal prices because there is no publicly-available plant-level coal price data.

The third source is from the FERC natural gas market archives. The archived reports provide past monthly rolling average natural gas prices ($/MMBtu) for each major trading natural gas hubs. I compile annual day-ahead natural gas prices among each major natural gas trading hubs from 2005 to 2016. Because the annual prices are rolling averages, I select the latest archived reports for each year. Only data from the hub which has data from 2010 to 2016 are selected. Afterwards, I calculated the average for each corresponding FERC regions.[10]

Legal challenge information is collected from EDF. EDF is an American environmental nonprofit organization that provides research and information to the public and policy-makers [12]. From the website, I use their compilation of the District of Columbia Court of Appeals and Supreme Court MATS petitions to create a dummy variable, as a proxy for possible state biases for or against MATS.[11]

After merging the data sets from sources, the final data set ranges from 2010 to 2016. The retirement date of the coal power plants is very significant part of this research. However, there are two possible retirement dates since some plants have planned retirement year based on calendar year and physical retirement year based on the planning year, starting in June 1 and endings on May 31 of the following year. When I compile the retirement date, for this analysis, I use the physical retirement year as retirement date and compile generator data based on the date unless the EIA-860 survey data set did not have observations for the

[10]See Appendix A for details on the FERC regions.

[11]See Appendix A for list of states that support, oppose, or remain neutral towards MATS.

physical retirement year.

4.2 Descriptive Statistics

4.2.1 United States Coal Generators

As shown in Table 2, we find that the average coal generator is relatively small and old. The mean coal generator age is about 42.66 years old. The oldest coal generator is 89 years old while the youngest coal generator is less than 1 years old. Furthermore, the average annual nameplate capacity is about 247.73 MW. The largest coal generator has a nameplate size of 1,425.6 MW and the smallest coal generator has a nameplate size of 0.4 MW.

Table 2: Summary Statistics of All Coal Generators

Variables	**Description**	**Observations**	**Mean**	**SD**	**Min**	**Max**
Nameplate Capacity	MW	9,556	247.73	275.55	0.4	1425.6
Size Group	1-9 Category	9,556	3.00	2.54	1	9
Age	Years of Operation	9,556	42.66	15.86	0	89
Age Group	1-9 Category	9,556	4.73	1.59	1	9
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$		9,556	14.42	6.36	3.84	58.50

For detailed description of the ‘Size Group’ and ‘Age Group’, see Appendix A. ‘Nameplate Capacity’ is the annual nameplate capacity is the “maximum output of electricity a generator can produce” [13].

On the state-level, the concentration of coal generators varies across United States regions.[12] States around the Great Lakes, such as Michigan, Ohio, and Indiana, have the largest numbers of coal generators. On the other hand, Northeastern and Western states have the least number of operating coal generators.

Shown below in Table 3, a significant number of coal generators are relatively old and small. The largest number of coal generators is between 51 to 60 years old and has a nameplate size of 0 to 100 MW. In contrast, the smallest number of coal generators is at

[12]See Table 12 for the specific number of operating coal generators by state.

least 81 years old and had annual nameplate capacities of 701 to 800 MW.

Table 3: Age and Size of All Coal Generators

Age Group	Years of Operation	Number of Coal Generators
1	0-10	396
2	11-20	399
3	21-30	1,355
4	31-40	1,880
5	41-50	2,015
6	51-60	2,460
7	61-70	884
8	71-80	126
9	81+	41

Size Group	Nameplate Capacity (MW)	Number of Coal Generators
1	0-100	4,216
2	101-200	1,632
3	201-300	799
4	301-400	481
5	401-500	412
6	501-600	609
7	601-700	593
8	701-800	306
9	801+	508

When observing year-by-year, the number of United States coal generators generally decreases (see Table 4 below).[13] Between 2010 and 2012, the number of operating coal generators steadily declines from 1,547 to 1,509 coal generators. In comparison to the small drop in coal generators between 2010 and 2012, the number of operating coal generators drops after the MATS compliance. Between 2012 and 2013, the number of operating coal generator drops from 1,509 to 1,382. This drop in operating coal generators continues after the MATS compliance period to 1,049 coal generators in 2016.

[13]See Figure 2

Table 4: Number of Operating Coal Generators by Year

Year	**Number of Coal Generators**
2010	1,547
2011	1,540
2012	1,509
2013	1,382
2014	1,310
2015	1,219
2016	1,049

4.2.2 Retired Coal Generators

Compare to the average operating coal generator, the average retired coal generator is relatively older and has a smaller nameplate capacity. In Table 5, on average, the retired coal generator is 54.29 years old. The oldest retired coal generator operated for 89 years old and the youngest retired coal generator is 1 year old. In addition, the mean retired coal generator has an annual nameplate capacity of 122.53 MW. The smallest retired coal generator has a nameplate capacity of 0.4 MW while the largest retired coal generator has a nameplate capacity of 818.1 MW.

Table 5: Summary Statistics of Retired Coal Generators

Variables	**Description**	**Observations**	**Mean**	**SD**	**Min**	**Max**
Nameplate Capacity	MW	475	122.53	134.97	0.4	818.1
Size Group	1-9 Category	475	1.78	1.28	1	9
Age	Years of Operation	475	54.29	13.98	1	89
Age Group	1-9 Category	475	5.89	1.43	1	9
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$		475	16.44978	6.81	5.27	35.30

For detailed description of the 'Size Group' and 'Age Group', see Appendix A. 'Nameplate Capacity' is the annual nameplate capacity is the "maximum output of electricity a generator can produce" [13].

When comparing among geographic regions, states with the largest concentration of coal generators have the largest number of coal generator retirements.[14] Ohio has the largest

[14]See Appendix C for the specific number of retired coal generators for each state.

coal generator retirements of 59 retired coal generators. Furthermore, many of the states by the Great Lakes and the Appalachian region have the largest concentration of coal generator retirements. In contrast, many of the Western states have the smallest number of coal generator retirements between 2010 and 2016.

As shown in Table 6, many of the retired coal generators are in the same categories that operating coal generators are in. The largest number of coal generator retirements is in the 51 to 60 years old category. In addition, the largest number of retired coal generator has a nameplate capacity of 0 to 100 MW.

Table 6: Age and Size of Retired Coal Generators

Age Group	**Years of Operation**	**Number of Retired Coal Generators**
1	0-10	8
2	11-20	5
3	21-30	31
4	31-40	16
5	41-50	66
6	51-60	184
7	61-70	141
8	71-80	13
9	81+	11

Size Group	**Nameplate Capacity (MW)**	**Number of Retired Coal Generators**
1	0-100	253
2	101-200	151
3	201-300	38
4	301-400	10
5	401-500	5
6	501-600	12
7	601-700	3
8	701-800	0
9	801+	3

Once again, Table 7 shows that the number of retired coal generators varies year-by-year.[15] Between 2010 and 2011, the number of retired coal generators decreases from 40 to 35 generators. However, as the MATS compliance period begins, the number of retirements increases by 87 coal generators. Then the number of retired coal generators decreases to

[15]See Figure 3

57 coal generators and 53 coal generators in 2013 and 2014 respectively. Once again, the number of retired generators significantly increase to 139 coal generator retirements in 2015. Afterwards, in 2016, only 64 coal generators were retired.

Table 7: Number of Retired Coal Generators by Year

Year	**Number of Retired Coal Generators**
2010	40
2011	35
2012	87
2013	57
2014	53
2015	139
2016	64

4.2.3 Fuel-Switched Coal Generators

Along with operating and retired coal generators, there are fuel-switched coal generators.[16] As shown in Table 8, the average fuel-switched coal generator is relatively younger than those of retired coal generators. The mean age of the fuel-switched coal generators is about 48.34 years old. The oldest fuel-switched coal generator is 88 years old and the youngest fuel-switched coal generator is 2 years old. In addition, the average fuel-switched coal generator has a nameplate size of 57.14 MW. The largest fuel-switched coal generator has a nameplate capacity of 626 MW and the smallest fuel-switched coal generator has a nameplate capacity of 0.8 MW.

On the state-level, the number of fuel-switchers varies.[17] The largest number of fuel-switchers are in Michigan, Virginia, and Wisconsin. Western, Southwestern, Northeastern states generally have the smallest number of fuel-switchers.

From Table 9, the largest concentration of fuel-switched coal generators is in the small nameplate group and neither in the youngest nor oldest age group. The largest number of fuel-switched coal generators has operated for about 51 to 60 years and has a nameplate

[16]In this paper, I treat fuel-switched coal generators as 'retired' coal generators.

[17]See Table 12 for the specific number of fuel-switched coal generators.

Table 8: Summary Statistics of Fuel-Switched Coal Generators

Variables	Description	Observations	Mean	SD	Min	Max
Nameplate Capacity	MW	195	57.14	88.79	0.8	626
Size Group	1-9 Category	195	1.28	0.77	1	7
Age	Years of Operation	195	48.34	17.49	2	88
Age Group	1-9 Category	195	5.31	1.76	1	9
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$		195	16.47	7.84	5.88	58.50

For detailed description of the 'Size Group' and 'Age Group', see Appendix A. 'Nameplate Capacity' is the annual nameplate capacity is the "maximum output of electricity a generator can produce" [13].

capacity of 0 to 100 MW.

Table 9: Age and Size of Fuel-Switched Coal Generators

Age Group	Years of Operation	Number of Fuel-Switched Coal Generator
1	0-10	5
2	11-20	10
3	21-30	24
4	31-40	12
5	41-50	40
6	51-60	53
7	61-70	36
8	71-80	14
9	81+	1

Size Group	Nameplate Capacity (MW)	Number of Fuel-Switched Coal Generator
1	0-100	160
2	101-200	25
3	201-300	7
4	301-400	0
5	401-500	1
6	501-600	1
7	601-700	1
8	701-800	0
9	801+	0

When comparing year-to-year, the number of fuel-switched coal generators does not follow the coal generator retirement trend (see Table 10 below).[18] The number of fuel-switching coal generators increases from 2010 to 2013. During the MATS compliance periods, the number of fuel-switching coal generators decreases in 2014. However, the number of fuel-switching coal generators increases to 67 coal generators after the MATS compliance period.

Table 10: Number of Fuel-Switched Coal Generators by Year

Year	Number of Fuel-Switched Coal Generators
2010	-
2011	9
2012	15
2013	48
2014	19
2015	37
2016	67

4.2.4 Fuel Price

The annual day-ahead natural gas prices across FERC-designated regions follow similar trends.[19] From 2005 to 2006, the prices in all regions decrease from about 6 to 10 $/MMBtu to about 4 to 7.5 $/MMBtu. Between 2006 and 2008, the natural gas prices increase to the highest levels of 5.25 to 10 $/MMBtu. After 2008, natural gas prices significantly decrease to nearly 2.5 to 5 $/MMBtu. Two years prior to the MATS compliance period, the day-ahead natural gas prices steadily increase. During the MATS compliance period, the natural gas prices increase above the 2010 to 2012 natural gas prices across all FERC regions. After 2015, the natural gas prices decrease to 2008 price levels.

In contrast, coal shipment prices by state do not vary as much from 2008 to 2016. During this period, many of the coal shipment prices by states range from 12.5 to 112 $/short ton. North Dakota has the lowest coal shipment prices of about 20 $/short ton. In contrast, Maine and New Hampshire, Northeastern states far from coal basins, have the highest coal shipment prices.

[18] See Figure 3

[19] See Figure 5

4.2.5 Relative Price Ratio & Coal Generator Exit Ratio

Since the net revenue of a coal power plant depends on the relative price ratio of the coal price to the price of competing fuels, I analyze the relationship between the relative price ratio and the coal generator exit ratio.[20] Based on Figures 7 to 19, there are no clear indication what cause coal generators to retire when comparing among the entire United States, FERC regions and ISO/RTO. On the national-level, the national exit ratio and the price ratio follow each other at several points from 2010 to 2016. Between 2010 and 2011, both the national relative price ratio and the exit ratio stagnate: the exit ratio remains around 3% while the relative price ratio remains at nearly 11. From 2011 to 2012, the national exit ratio increases to 6% and the national relative price ratio increases to 15. During the MATS compliance period, the relative price ratio steadily decreases to 2010 relative price ratio levels. After 2014, the national exit ratio increases to about 15% in 2015 and then decreases to about 12%. In contrast, the national relative price ratio increases between 2014 and 2016. In fact, it increases to about 16.

The relationship between the relative price ratio and the exit ratio by FERC regions also shows varying trends. In the Gulf region, both the Gulf relative price ratio and the exit ratio follow each other.[21] From 2010 to 2011, the Gulf exit ratio decreases to 0% and the Gulf relative price ratio decreases to 9. Between 2011 and 2012, both ratios increase: the exit ratio increases to 3% and the relative price ratio increases to about 13. During the MATS compliance period, the exit ratio decreases to 0% and the relative price ratio decreases to 9. After 2014, both ratios increase in 2015 and then diverge in 2016. The Gulf exit ratio increases to nearly 5% but then decreases to 4% while the Gulf relative price ratio increases and remains at about 15.

Similarly, for the Southeastern FERC region, both the Southeast relative price ratio

[20] I calculate the *exit ratio* as the total number of retired and fuel-switched coal generators over the total number of coal generators in each corresponding year. For only the relative price ratio, see Figure 7. See Figure 8 for national exit ratio with relative price ratio

[21] See Figure 9

and the exit ratio follow each other.[22] Between 2010 and 2012, both ratios increase. The Southeast exit ratio increases to 10% as the relative price ratio increases to 26. During the MATS compliance period, both ratios decrease: the Southeast exit ratio decreases to 10% and the Southeast relative price ratio decreases to 16. Afterwards, both increase and then decrease. In 2016, the exit ratio drops to about 9% and the relative price ratio decrease to 24.

In contrast to the combination graphs for Gulf and Southeastern regions, the Midwestern, Western, and Northeastern relative price ratios and exit ratios converge and diverge at several points. For the Midwest FERC region, the Midwest relative price ratio and the Midwest exit ratio diverge between 2010 and 2012.[23] While the Midwest relative price ratio increases from about 7.5 to 12.5, the Midwest exit ratio steadily decreases to about 4%. During the MATS compliance period, the Midwest exit ratio increases to about 6% in 2014 as the Midwest relative price ratio decreases. However, after the compliance period, both the Midwest relative price ratio and exit ratio drastically increase to the highest levels of about 15 and 15%, respectively.

For the West FERC region, both the West relative price ratio and the West exit ratio both decrease and then increase between 2010 and 2012, respectively.[24] The West exit ratio ranges from about 0% to 5%. The West relative price ratio ranges from 10 to 15. However, the West relative price ratio and exit ratio converge during the MATS compliance period. From 2012 to 2014, the West exit ratio increases as the West relative price ratio decreases. The trends reverse in 2015, where the West exit ratio decreases as the relative price ratio increases. However, in 2016, both the West exit and relative price ratios increase to about 8% and 16, respectively.

Lastly, for the Northeast FERC region, the Northeast relative price and exit ratio converges and diverges at some points.[25] From 2010 to 2011, the Northeast exit ratio decreases

[22]See Figure 10
[23]See Figure 11
[24]See Figure 12
[25]See Figure 13

to 2% while the Northeast relative price ratio increases from 15 to 18. From 2011 to 2012, the Northeast relative price ratio and the exit ratio increase. In fact, the relative price ratio reaches the highest level of about 37. However, between 2012 and 2013, the Northeast relative price ratio and exit ratio increase together. While the Northeast relative price ratio decreases from 2012 to 2014, the Northeast exit ratio increases until 2013 and then decrease in 2014. After the MATS compliance period, the Northeast relative price ratio continues to increase as the Northeast exit ratio increases to about 15% in 2015 but then decreases to about 12% in 2016.

When comparing among the combination graphs of ISO/RTO, there are also variations in the relationship between the exit ratios and the relative price ratios.[26] For CAISO, the exit ratio increases from 0% to 20% between 2010 and 2012 while the relative price ratio decreases and then increases from 20 to 24.[27] During the MATS compliance period, the exit ratio continues to increase to 25% as the relative price ratio decreases to 15. After the compliance period, the exit ratio increases to nearly 35% and then drops to 0% in 2016. CAISO's relative price ratio increases to about 25.

For ERCOT, the exit ratio remains constant as the relative price ratio varies.[28] ERCOT's exit ratio is 0% from 2010 to 2016. In contrast, ERCOT's relative price ratio decreases and then increases to 10 in 2012. During the MATS compliance period, it decreases to around 7. Afterwards, the ERCOT relative price ratio increases to 12 and then to 11.

In the ISO-NE market, the exit ratio and the relative price ratio follow similar trends except after the MATS compliance period.[29] Between 2010 and 2012, both exit ratio and relative price ratio increase to 5% and 35 respectively. During the MATS compliance, the relative price ratio decreases to 11 as the exit ratio increases to 26% and then decreases to 24%. After 2014, the exit ratio decreases to 0% while the relative price ratio continues to increase to 33.

[26] I do not include the coal generators exited from the RTO/ISO market in the exit ratio.

[27] See Figure 14

[28] See Figure 15

[29] See Figure 16

PJM's exit ratio and relative price ratio similarly follow each other from 2010 and 2016 at many years.[30] Between 2010 and 2011, the PJM exit ratio decreases from 4% to 2% while the PJM relative price ratio increases from 11 to 16. A year later, both exit ratio and the relative price ratio increase to 24. Between 2012 and 2014, the relative price ratio decreases to 11. The exit ratio increases to 14% and then decreases to 6% during the same time period. After 2014, the relative price ratio increases to 25 as the exit ratio increases to 21% and then decreases to 7%.

In contrast, the relationship between NY-ISO exit ratio and the relative price ratio changes after different times.[31] Prior to the MATS compliance period, the exit ratio remains 0% as the relative price ratio increases from 13% to 21%. From 2012 to 2014, the exit ratio increases from about 17% to 0%. The relative ratio decreases from 20 to 10 between 2012 and 2014. After 2014, both the exit ratio and the relative price ratio increase to the highest levels of 16% and 25.

For the MISO market, the MISO exit ratio and the relative price ratio follow each other during certain periods.[32] Before 2012, the MISO relative price ratio steadily increases from 8 to 14. MISO's exit ratio decreases from 5% to 3% and then increases to 5% in 2012. During the MATS compliance period, the exit ratio steadily increases to about 5% while relative price ratio decreases from 14 to 8. After 2014, both the MISO exit ratio and the relative price ratio increase to 20% and 15, respectively.

Lastly, the SPP exit ratio and the relative price ratio both increase and decrease together.[33] Both the exit ratio and the relative price ratio increase to 1% and 11 respectively. During the MATS compliance period, both ratios decrease to 7% and 1 respectively. After 2014, the exit ratio increases to nearly 9% to 6% as the relative price ratio increase to about 14.

[30]See Figure 17
[31]See Figure 18
[32]See Figure 19
[33]See Figure 20

5 Model

To analyze how the EPA's regulation, MATS, and low natural gas prices impact the likelihood of a coal generator retirement, I first build a dynamic discrete choice model and then find the choice probability to form a logit model.[34] For each period t, a coal generator owner decides whether to continue to operate or to retire. Let us call these decisions the decision variable, i_t, where

$$i_t = \begin{cases} 1 & \text{if owner chooses to retire} \\ 0 & \text{if owner chooses to operate the generator} \end{cases}$$

For each period t, a coal generator owner's decision is influenced by the relative fuel costs between coal price and natural gas price and the enforced government regulation to install technology. Thus, the relative fuel costs and enforced government regulation are our state variables. I denote the state variables as

$$\mathbf{x_t} = \{x_{t_1}, x_{t_2}\} = \{\text{relative fuel cost, enforced government regulation}\}$$

The first state variable, relative fuel cost, changes the revenue stream. For instance, an introduction of technology, such as fracking, can bring natural gas prices lower than coal prices. So this can displace coal generators and thus coal generator owners are unable to generate revenue. Another case is when the coal price is relatively lower than the natural gas price and the natural gas price decreases. If the natural gas generator sets the market clearing price, then the revenue from the coal generator decreases. Hence, in both cases, the coal generator owner receives less net revenue from the market.

The second state variable, enforced government regulation, also changes a coal generator owner's revenue stream. A government mandate, such as MATS, requires the coal generator owner to invest in equipment to reduce effluent emissions by a deadline. Once the policy is

[34]We use John Rust (1987)[41] and Arcidiacono and Ellickson (2011)[1] to build the model.

in effect, the owner must install the technology or exit the market.

In every period t, a coal generator owner receives the following utility:

$$u(\mathbf{x_t}, i_t, \theta) + \epsilon(i_t) = \begin{cases} 0 + \epsilon(1) & \text{if exits } (i_t = 1) \\ -c(x_{t_2}, \theta) + \pi(x_{t_1}, \theta) + \epsilon(0) & \text{if operates } (i_t = 0) \end{cases}$$

The owner's utility depends on two cases. Firstly, if the owner chooses to exit the market, then he or she receives 0. Secondly, if the owner chooses to operate, then he or she receives revenue, $-c(x_{t_2}, \theta) + \pi(x_{t_1}, \theta)$, where $c(x_{t_2}, \theta) \geq 0$ is the equipment cost to comply with the government mandate. $\epsilon(i_t)$ is payoff unknown to econometricians but known to only the coal generator owner knows.

Using utility function, the coal generator's maximization problem is

$$\max[u(\mathbf{x_t}, i_t) + \epsilon(i_t) + E(\sum_{j=t+1}^{T} \beta^{j-t}[u(\mathbf{x_j}, i_j) + \epsilon(i_j)])] \tag{1}$$

We can further rewrite equation (1) as

$$V_t(\mathbf{x_t}, \epsilon_t) = \max E(\sum_{j=t}^{T} \beta^{j-t}[u(\mathbf{x_j}, i_j) + \epsilon(i_j)|\mathbf{x_t}, \epsilon_t])) \tag{2}$$

Using Bellman's optimality rule, equation (2) becomes

$$V_t(\mathbf{x_t}, \epsilon_t) = \max_{i_t}[u(\mathbf{x_t}, i_t) + \epsilon_t + \beta E(V_{t+1}(\mathbf{x_{t+1}}, \epsilon_{t+1}|\mathbf{x_t}, i_t))] \tag{3}$$

The probability of a coal generator owner choosing retirement, $(i_t = 1)$, is

$$\begin{aligned} P(i_t = 1|\mathbf{x_t}) =& P(V(\mathbf{x_t}, 1) > V(\mathbf{x_t}, 0)) \\ &= P(u(\mathbf{x_t}, 1) + \epsilon(1) + \beta EV(1) > u((\mathbf{x_t}, 0) + \epsilon(0) + \beta EV(0)) \end{aligned}$$

Now I further assume the probability follows the Type 1 extreme distribution in order to form a logit model. The probability of choosing retirement becomes

$$P(i_t = 1|\mathbf{x_t}) = \frac{exp(\mathbf{x_t}, 1)}{\sum_{i'_t=\{0,1\}} exp(v_t(\mathbf{x_t}, i'_t))}$$

Thus, the choice probability for arbitrary choice i_t becomes

$$p_t(i_t|\mathbf{x_t}) = \frac{exp(v_t(\mathbf{x_t}, i_t))}{\sum_{i'_t=\{0,1\}} exp(v_t(\mathbf{x_t}, i'_t))} \tag{9}$$

which is a binary logit model I will use in our econometric analysis.

6 Methodology & Empirical Results

6.1 Methodology

I use a logit model with clustering by plants and with robustness to analyze the effects of the exogenous shocks, MATS and low natural gas prices, on coal generator retirements.[35] I include the following independent variables: age of a coal generator, annual nameplate capacity of a coal generator, the relative price ratio of annual coal shipment price and the average annual day-ahead natural gas price, year dummies, individual ISO/RTO dummy variables, and a state legal challenges dummy variable. The dependent variable is whether a generator retired. It takes a value of 1 if the coal generator retired or switched fuel source other than coal and takes a value of 0 if not.[36]

My key independent variables are the year dummy variables and the relative price ratio. I include year dummy variables from 2010 to 2016 to represent the pre-MATS period, MATS compliance period, and post-MATS period. I exclude the 2016 year dummy variable from the model. 2010 and 2011 year dummy variables represent the pre-MATS period. 2012, 2013,

[35] See Appendix D for more detailed description of the variables.

[36] For sensitivity checks, I exclude different control variables and use another specification. This specification replaces the individual ISO/RTO dummy variables with a general ISO/RTO dummy variable. See Appendix E for results in log-odds.

and 2014 year dummy variables represent the MATS compliance period. I do not include the 2015 year dummy variable from the compliance period because coal generator owners follow a fiscal calendar year schedule and I expect noncomplying coal generator owners to continue to operate until the end of the compliance early 2015 deadline. Thus, I expect a coal generator owner is more likely to physically retire the coal generator in 2015 relative to the probability of retiring in 2016. I also include relative price ratio, where the coal shipment price is on the numerator and the day-ahead natural gas price on the denominator. I include this variable to capture the effects of low natural gas prices from fracking technology. If the coal shipment price is held constant, then low natural gas price would increase the price ratio. Thus, I expect low natural gas prices to increase the likelihood of a coal generator retirement.

My other independent variables are controls. The first control variable is the generator's characteristics, age and annual nameplate capacity. I include these characteristics to control for efficiency in generating electricity. I expect a relatively larger or a younger coal generator to be more efficient than a smaller or older coal generator and thus less likely to retire. The second control variable is the individual ISO/RTO dummy variables to control the difference in market structures. If a coal generator operates in the specific ISO/RTO, then I give that generator a value of 1. I include CAISO, MISO, SPP, NYISO, ISO-NE, and PJM with respect to ERCOT. Lastly, I include the state legal challenges dummy variable, AgainstMATS, to capture the state governments' biases against MATS. I expect states opposing MATS to be more lenient towards coal power plant owners during the MATS compliance period. The dummy variable takes the value of 1 if the state attorney general's name appeared on the documents against MATS.

Hence, I use the following regression

$$y_{it} = \alpha + \boldsymbol{\gamma_1}\mathbf{year}_t + \beta_1\text{fuel}_{it} + \beta_2\text{age}_{it} + \beta_3\text{size}_i + \boldsymbol{\gamma_2}\text{ISO}_{it} + \beta_4\text{legal challenge}_{it} + \epsilon_{it}$$

where y_{it} is a dummy variable to indicate whether the coal generator retired or not, *year* is the dummy variables to indicate pre-MATS period, MATS compliance period, *fuel* is the relative fuel cost ratio of coal price and natural gas price, *age* is the age of the coal generator, *size* is the annual nameplate capacity or size of the coal generator, *ISO* is the dummy variables to indicate whether the coal generator operates in one of the ISOs/RTOs, and the post-MATS, and *legal challenge* is the dummy variable to indicate whether the coal generator operates in a state that legally challenged the MATS regulations in court. ϵ_{it} is the random error terms.

6.2 Empirical Results

In the first model, I use the logit model with clustering by plants. As shown in Table 12, I find that the generator characteristics are significant determinants of whether a coal generator retires or not. Annual nameplate capacity is statistically significant and has a negative average marginal effects coefficient of -0.0002. This indicates that larger coal generators are less likely to retire. So one megawatt increase in annual nameplate capacity is associated with 0.02% decrease in probability of a coal generator retirement. I also find age has a positive average marginal effect coefficient and is statistically significant. This suggests that an older coal generator is more likely to retire. An additional year of operating a coal generator is associated with 0.2% increase in the likelihood of the coal generator retiring.

I also find the relative price ratio between coal price and natural gas price to be another significant cause. I find the coefficient to be statistically significant at the 10% level and the average marginal effect coefficient is positive. This suggest that low natural gas price is associated with higher probability of a coal generator retirement. So, a unit increase in the relative price ratio from low natural prices may increase the likelihood of a coal generator retirement by 0.2%.

The results also suggest that the MATS rule increased the probability of a coal generator retirement. I find that 2012, 2013, and 2014 year dummy variables are statistically insignificant. This suggest that a coal generator is equally likely to retire in the MATS compliance period compared to in 2016. However, the 2015 year dummy variable is positive and statistically significant. This supports the expectation that noncomplying coal generator owners operated the coal generators until the end of the compliance period in early 2015 and then shut-down the coal generators. Thus, the positive coefficient indicates that the probability of an owner retiring a coal generator in 2015 is more likely than the same owner retiring the generator in 2016.

Lastly, I find that only one ISO/RTO, PJM, to be statistically significant. Because the PJM coefficient is positive, this indicates that a coal generator is more likely to retire in the PJM market than in the ERCOT market.

In the second model, I use the logit model with robustness. I find that the generator characteristics, the relative fuel price ratio, and the year dummy variables have the same signs and coefficients; but, I find the relative fuel price ratio and the 2012 year dummy variable, the beginning of the MATS compliance period, are statistically significant. For the relative fuel price ratio, the p-value decreases to 1% level, which supports our expectation that low natural gas price may indeed increase the probability of a coal generator to retire. The 2012 year dummy variable is statistically significant at the 5% level. Because the coefficient is positive this suggest that a coal generator owner is more likely to retire a coal generator in 2012 than in 2016.

Table 11: Logit Average Marginal Effects

Dependent Variable: Retirement =1		
Variables	**Logit w/ Cluster by Plant Code**	**Logit w/ Robustness**
Pre-MATS Period		
Year2010	-0.032*	-0.032***
	(0.0195)	(0.0121)
Year2011	-0.036*	-0.036***
	(0.0203)	(0.0121)
MATS Compliance Period		
Year2012	0.019	0.019**
	(0.0154)	(0.00958)
Year2013	-0.002	-0.002
	(0.0181)	(0.0113)
Year2014	0.019	0.019
	(0.018)	(0.011)
Post-MATS Period		
Year2015	0.072***	0.072***
	(0.0136)	(0.00932)
Relative Price Ratio		
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$	0.002*	0.002***
	(0.0009)	(0.0005)
Generator Characteristics		
Nameplate Capacity	-0.0002***	-0.0002***
	(2.87e-05)	(1.72e-05)
Age	0.002***	0.002***
	(0.0003)	(0.0002)
Regions by ISOs/RTOs		
CAISO	0.0543	0.0543**
	(0.051)	(0.026)
MISO	0.003	0.003
	(0.011)	(0.007)
SPP	-0.004	-0.004
	(0.02)	(0.014)
NYISO	0.009	0.009
	(0.039)	(0.02)
ISO-NE	0.0025	0.0025
	(0.036)	(0.021)
PJM	0.022*	0.022***
	(0.012)	(0.0064)
State Legal Challenge		
Against MATS	0.004	0.004
	(0.011)	(0.006)
Observations	9,556	9,556

*** $p<0.01$, ** $p<0.05$, * $p<0.1$
Standard errors in parentheses

7 Discussion & Conclusion

The empirical results show that both sides of the “War on Coal” debate are not telling the full story about the coal generator retirements. Noncomplying coal generator owners are operating coal generators until the end of the MATS compliance period. In addition, low natural gas prices are deteriorating coal generator owners’ revenues and thus forcing coal generators to retirement.

While this paper offers a possible answer to the “War on Coal” debate, this paper has a shortcoming. I use a data set with limited pre- and post-MATS compliance data, so it is difficult to clearly separate the impact of MATS rule and low natural gas prices. This restriction also leads to the inability to capture retirements and fuel-switches prior to 2010 and after 2016. For instance, ERCOT did not have coal generator retirements from 2010 to 2016. However, in 2017, coal power plants in ERCOT started to retire [40]. Since year 2017 is well outside of MATS compliance, I can safely assume that these retirements are due to deterioration of economics of coal power plants not due to MATS rule. This new data may change the magnitude of the coefficient of fuel price ratio; however, it will not change the conclusion that both MATS and low natural gas price drive the coal power plants to early retirement.

This paper attempts to analyze the effect of the U.S. effluent emissions regulation, MATS, economic factors, and market structures on coal generator retirements. Analyzing United States coal generators from 2010 to 2016, I find that both MATS and low natural gas price are driving the coal generator retirements. Moreover, if natural gas prices continue to be low, coal power plant owners may face a more difficult time to survive in the electricity market. Hence, the “War on Coal” is not over as former EPA chief administrator, Scott Pruitt, insisted. Instead, the “War on Coal” continues by economic forces not by government policy.

8 Figures

Figure 1: Number of 2010-2016 Retired Coal Generators by State

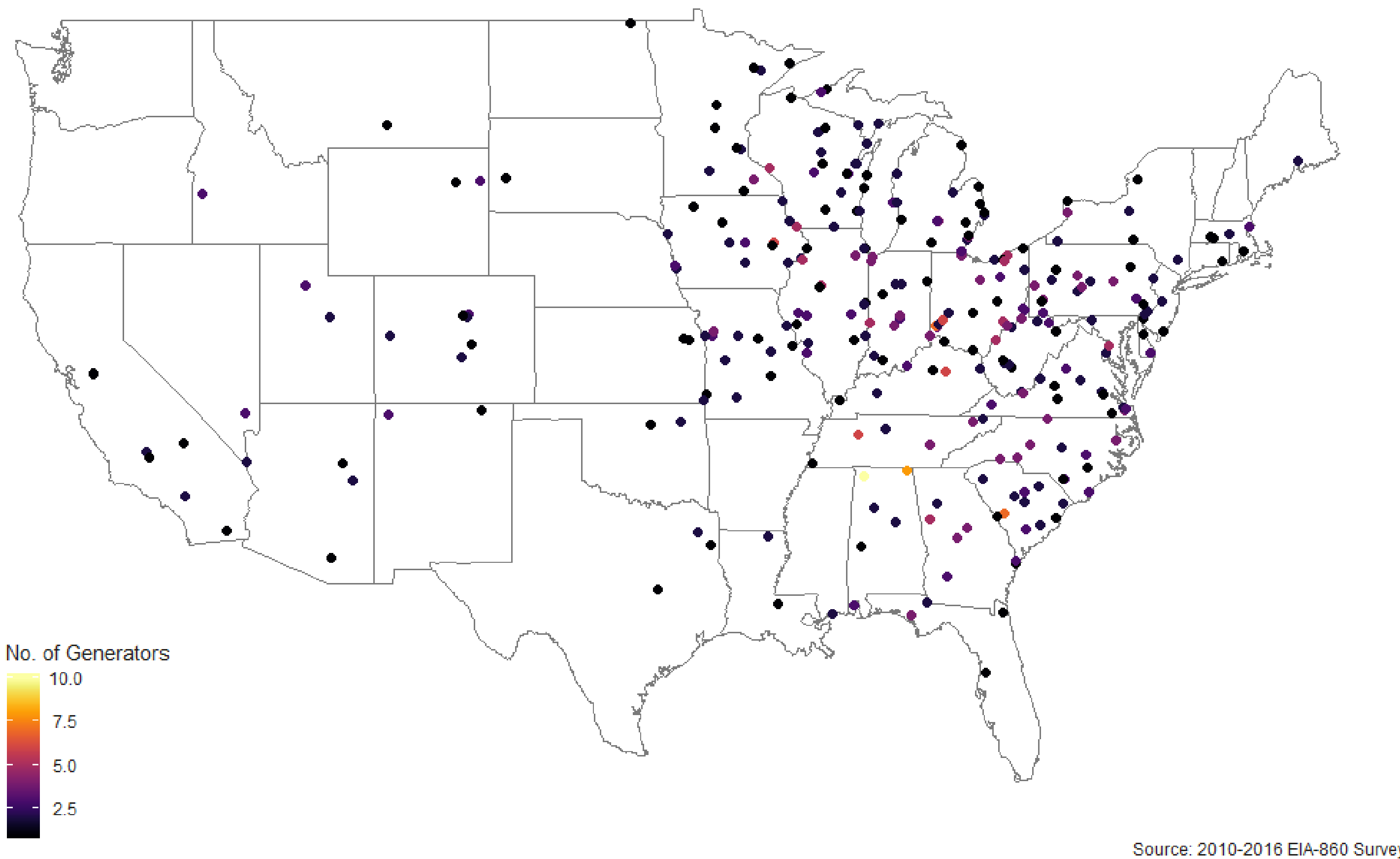


Figure 2: Operating Coal Generators by Regions

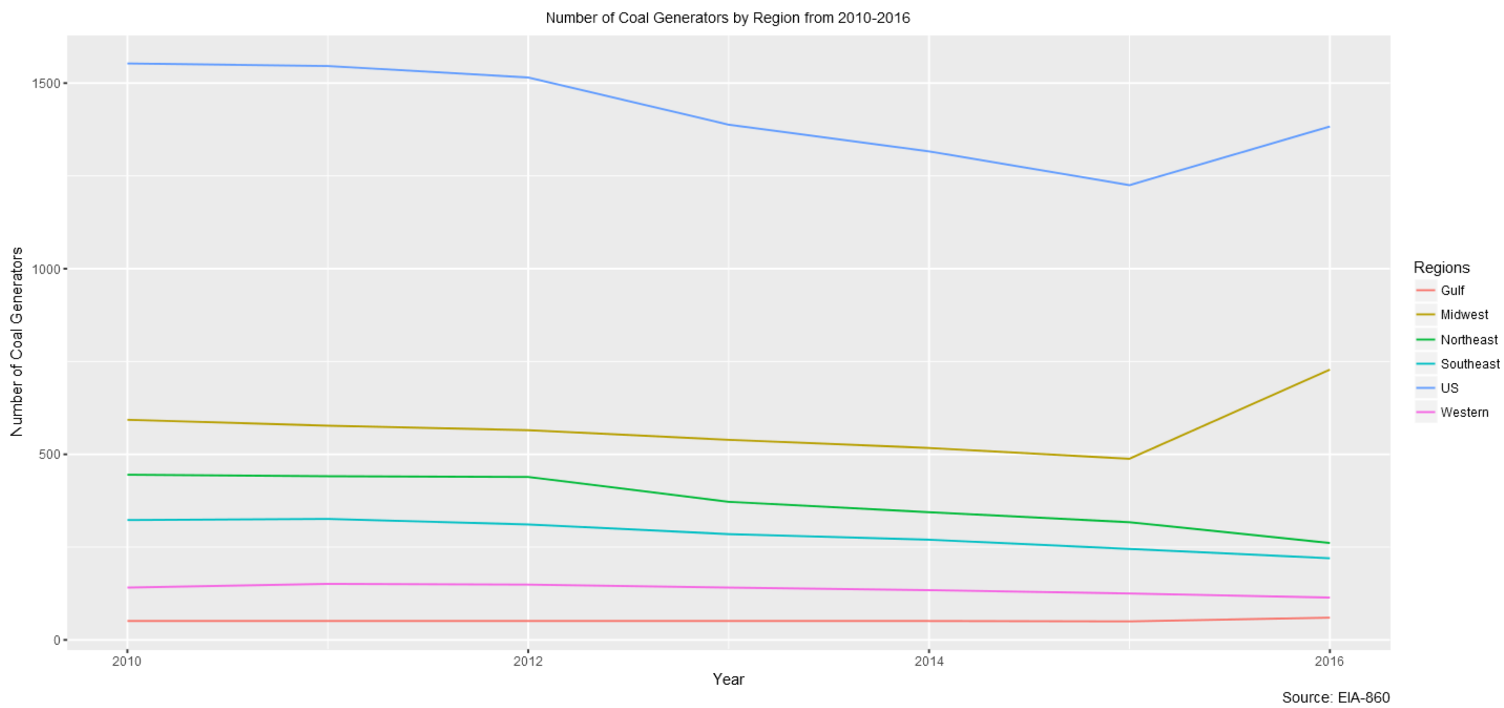


Figure 3: Retired Coal Generators by Regions

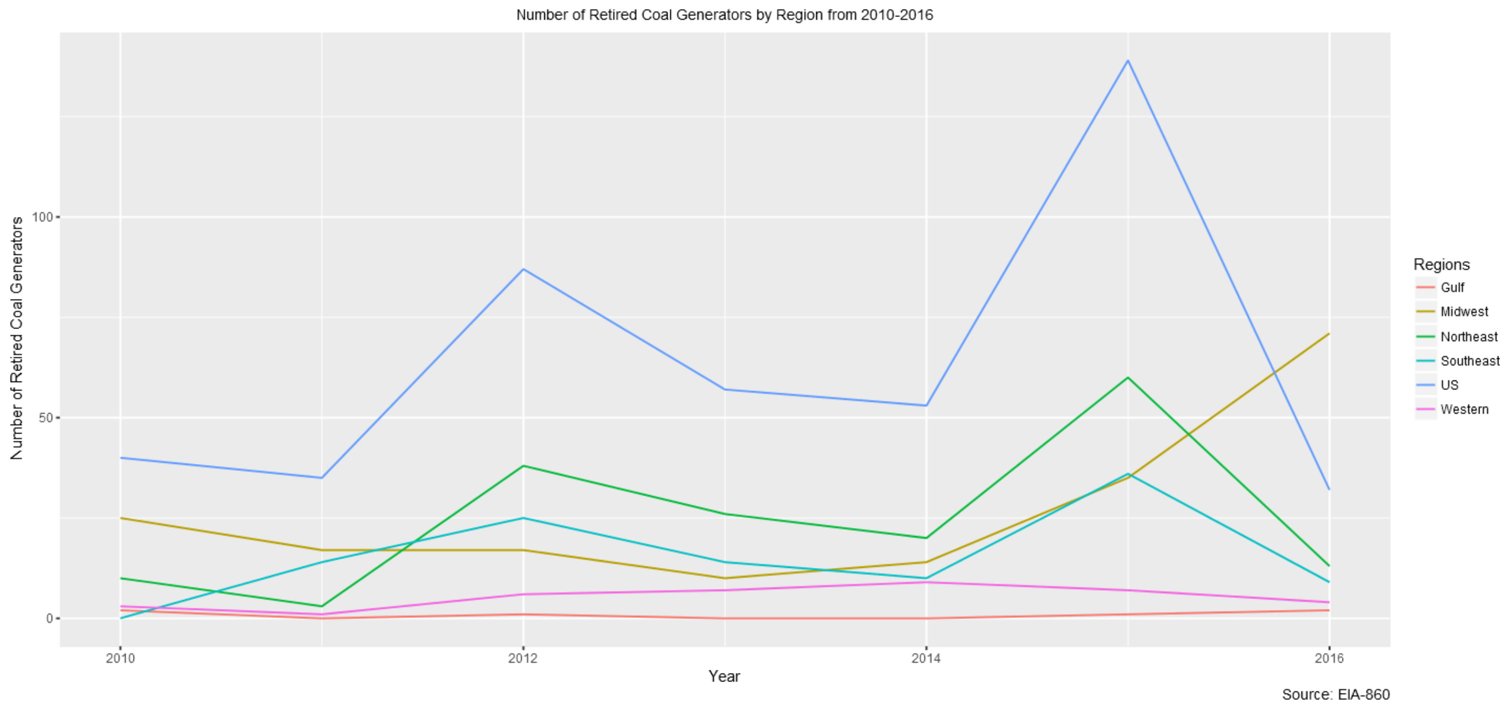


Figure 4: Fuel-Switched Coal Generators by Regions

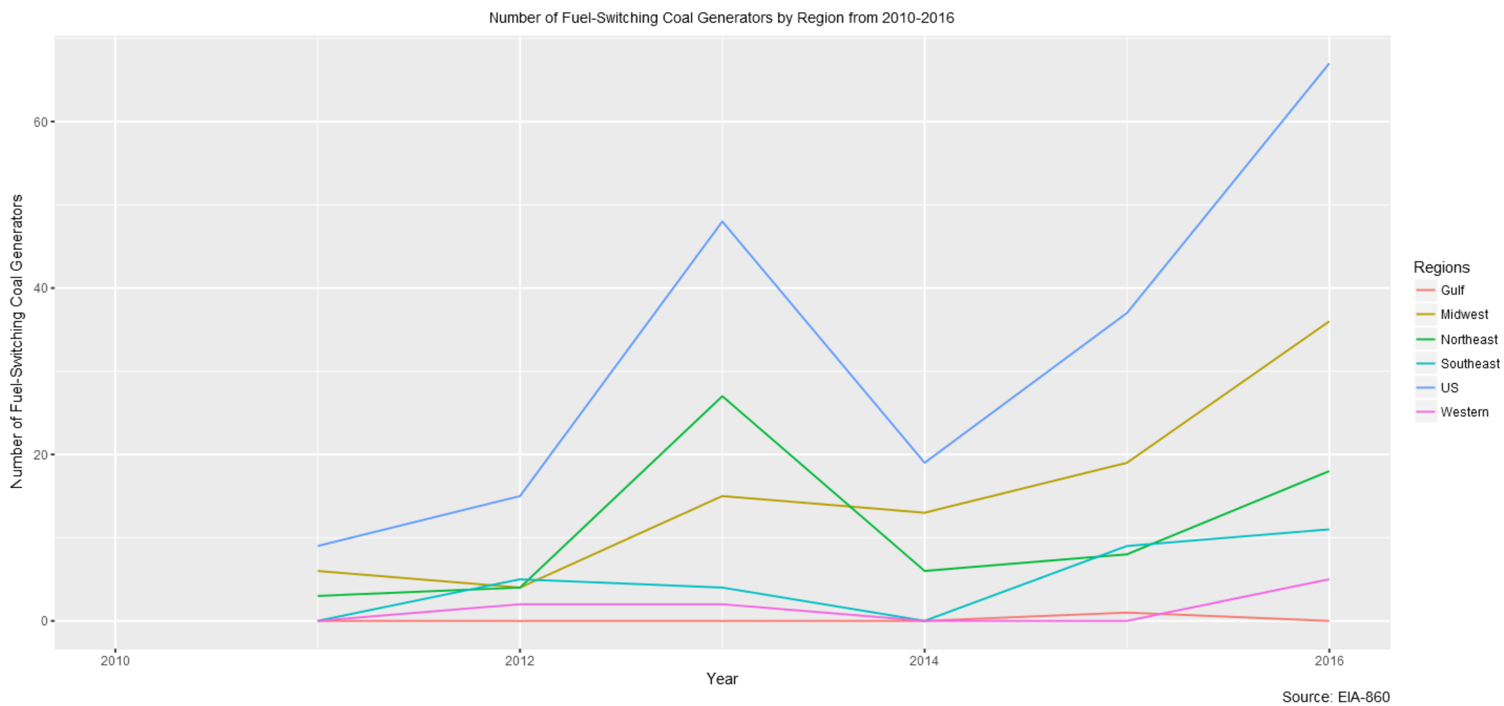


Figure 5: Average Annual Day-ahead Natural Gas Price 2005-2016

Source: FERC Natural Gas Market Archives

Figure 6: Average Annual Coal Shipment Price by State from 2008-2016

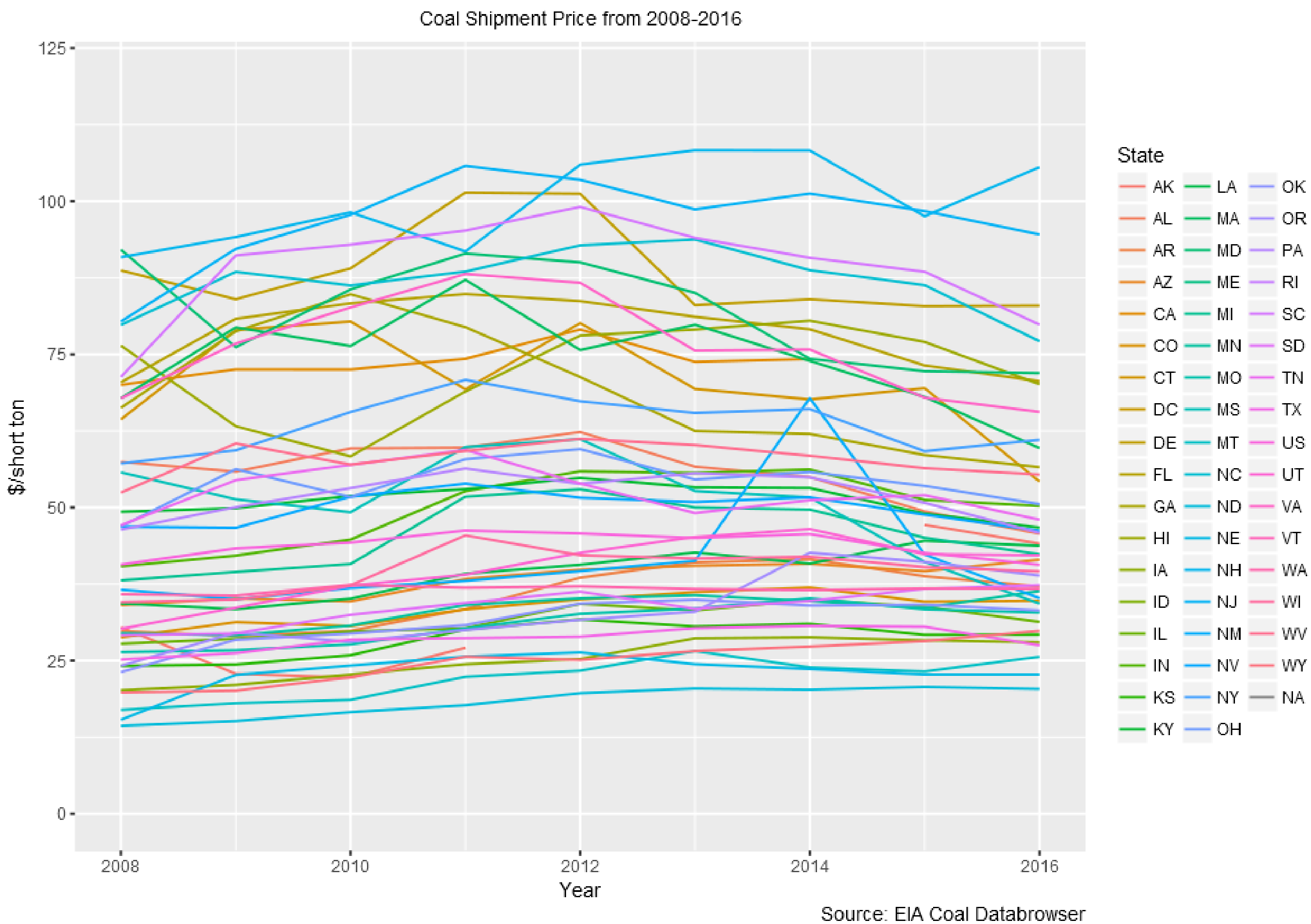


Figure 7: Relative Price Ratio from 2008-2016

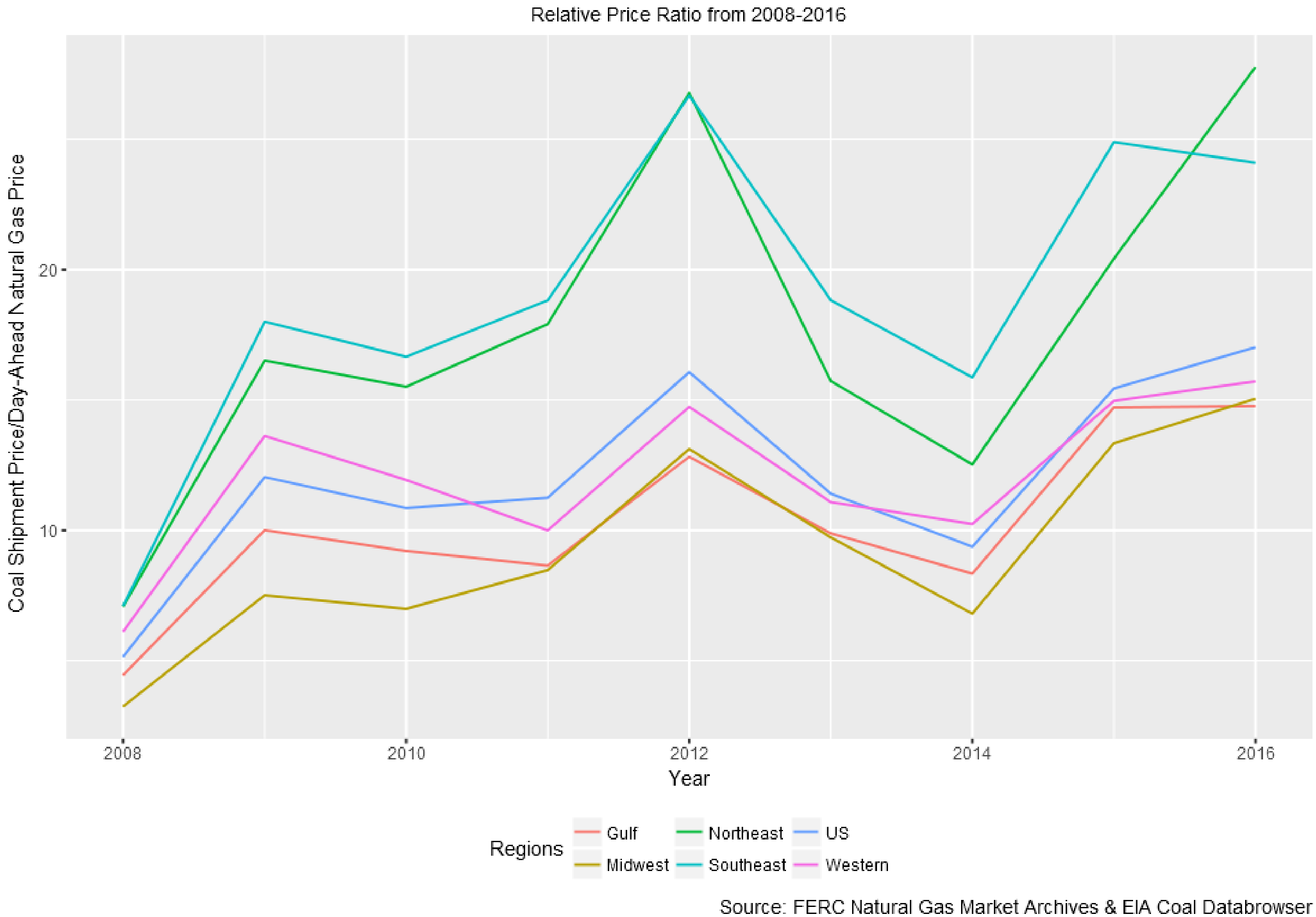


Figure 8: National Exit Ratio with Relative Price Ratio

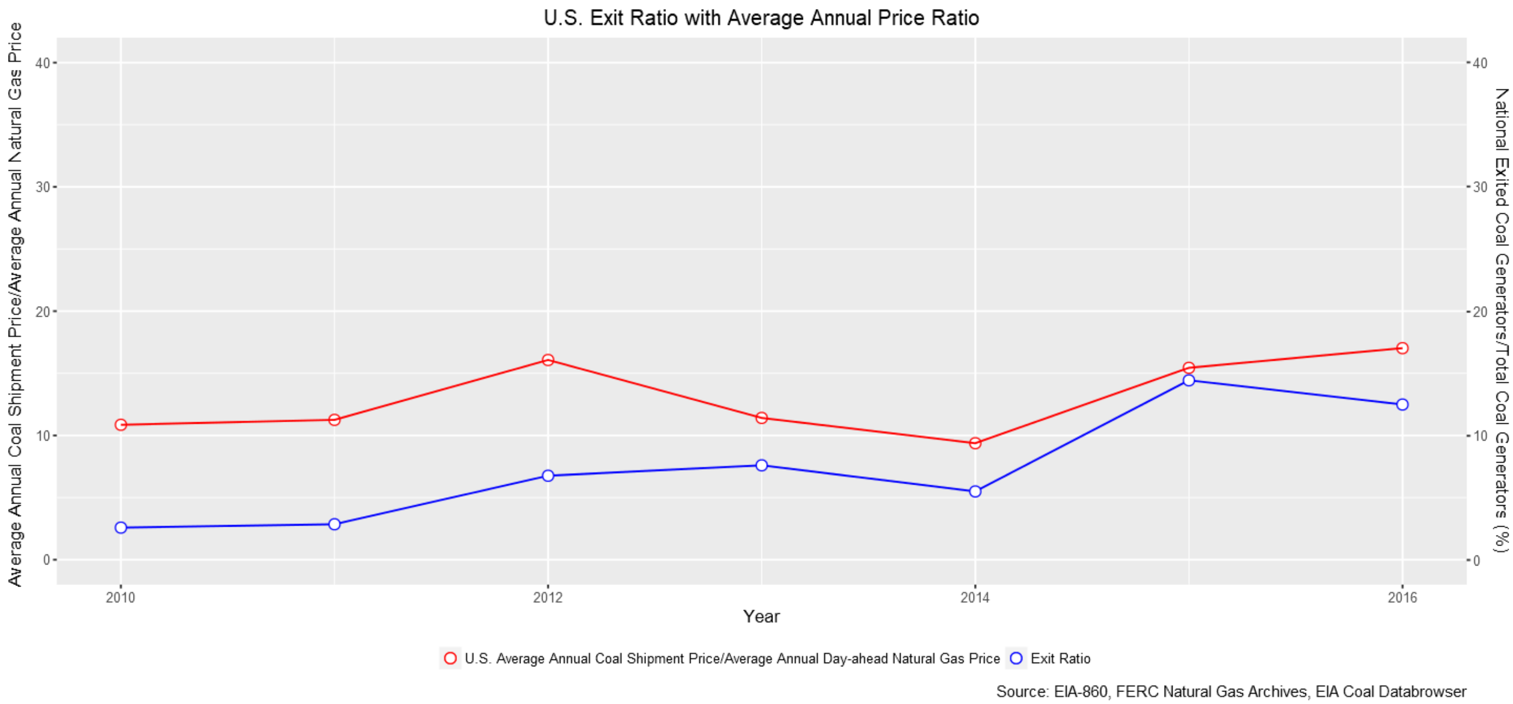
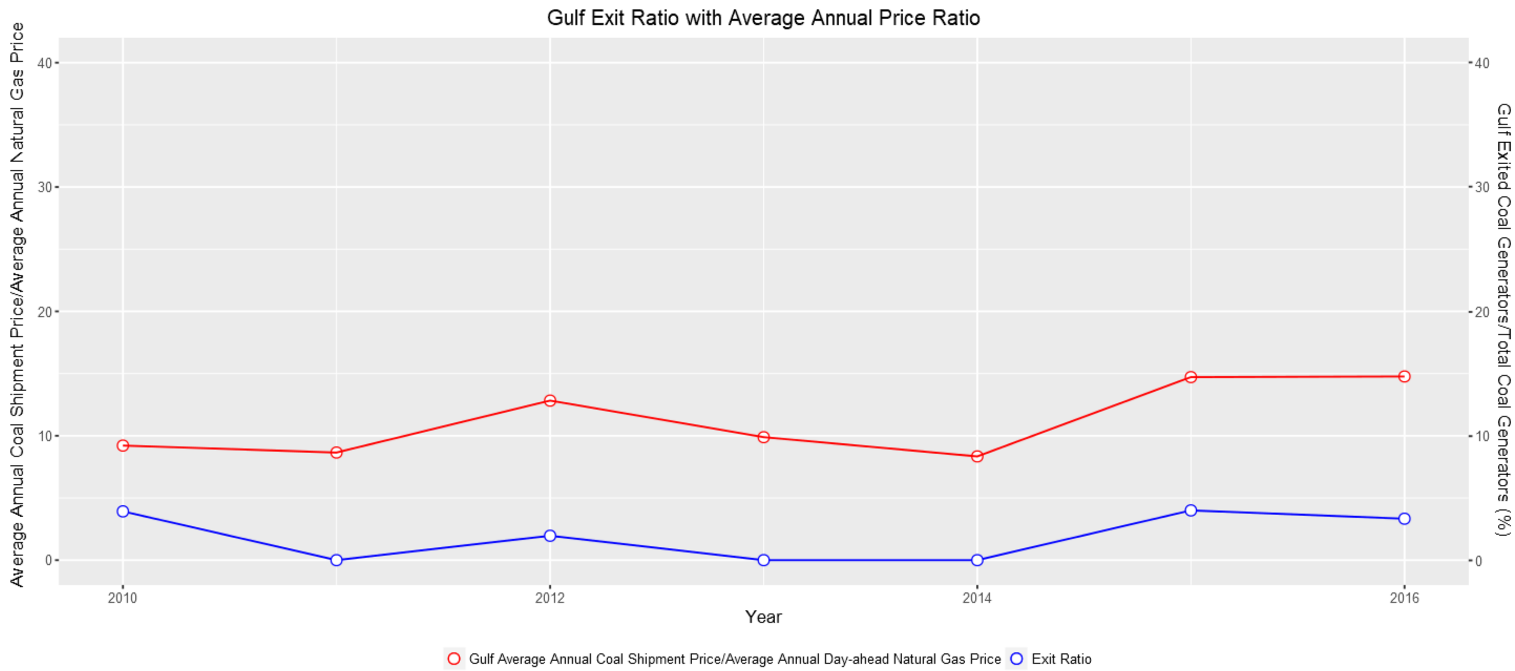


Figure 9: Gulf Exit Ratio with Relative Price Ratio



Source: EIA-860, FERC Natural Gas Archives, EIA Coal Databrowser

Figure 10: Southeast Exit Ratio with Relative Price Ratio

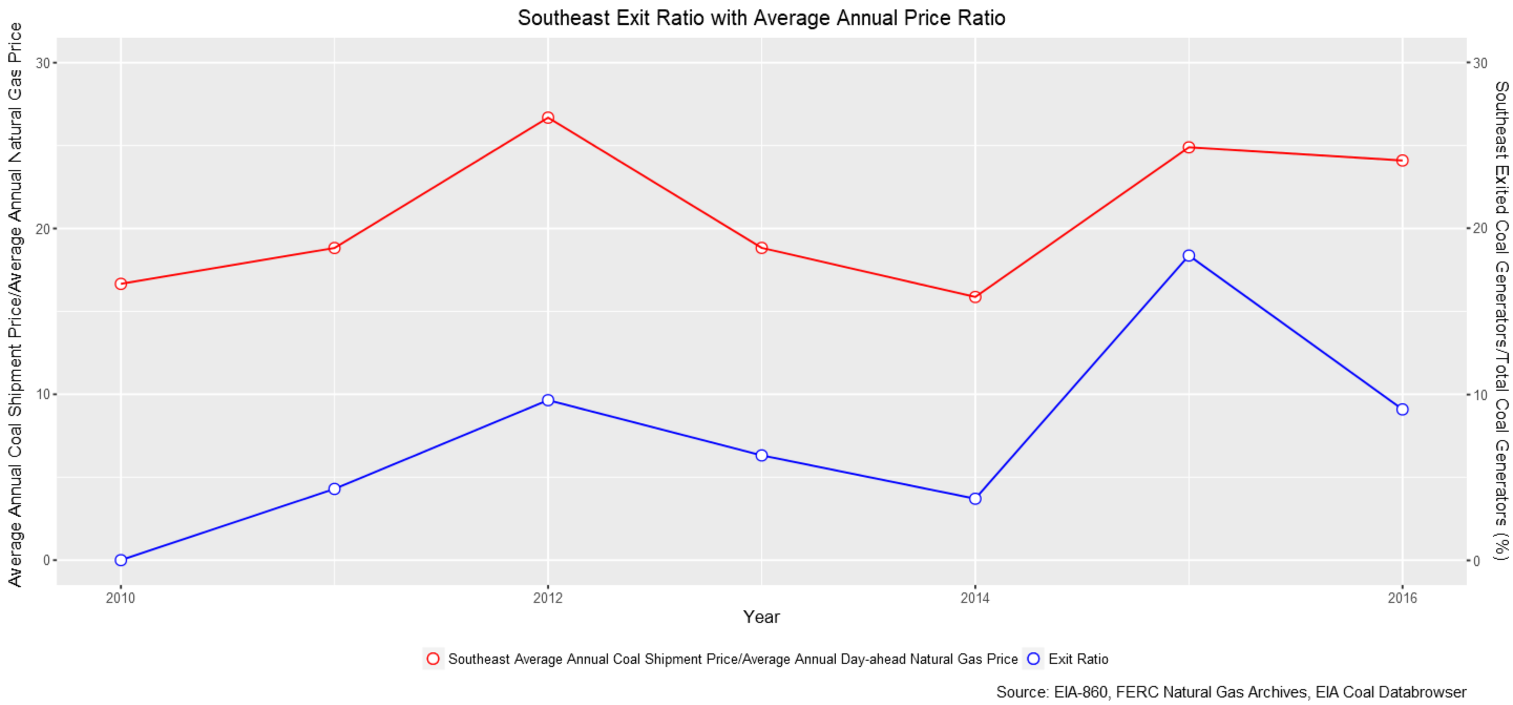


Figure 11: Midwest Exit Ratio with Relative Price Ratio

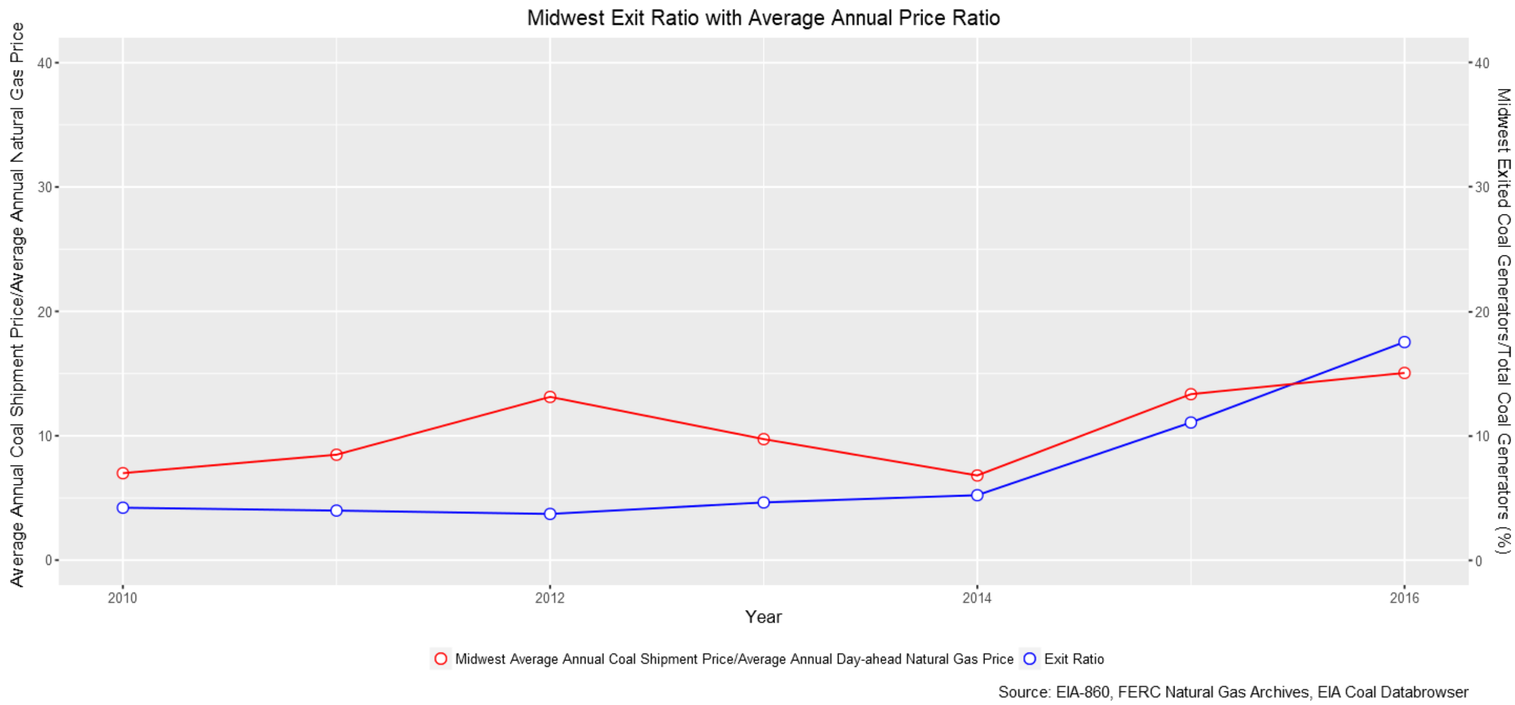


Figure 12: West Exit Ratio with Relative Price Ratio

Figure 13: Northeast Exit Ratio with Relative Price Ratio

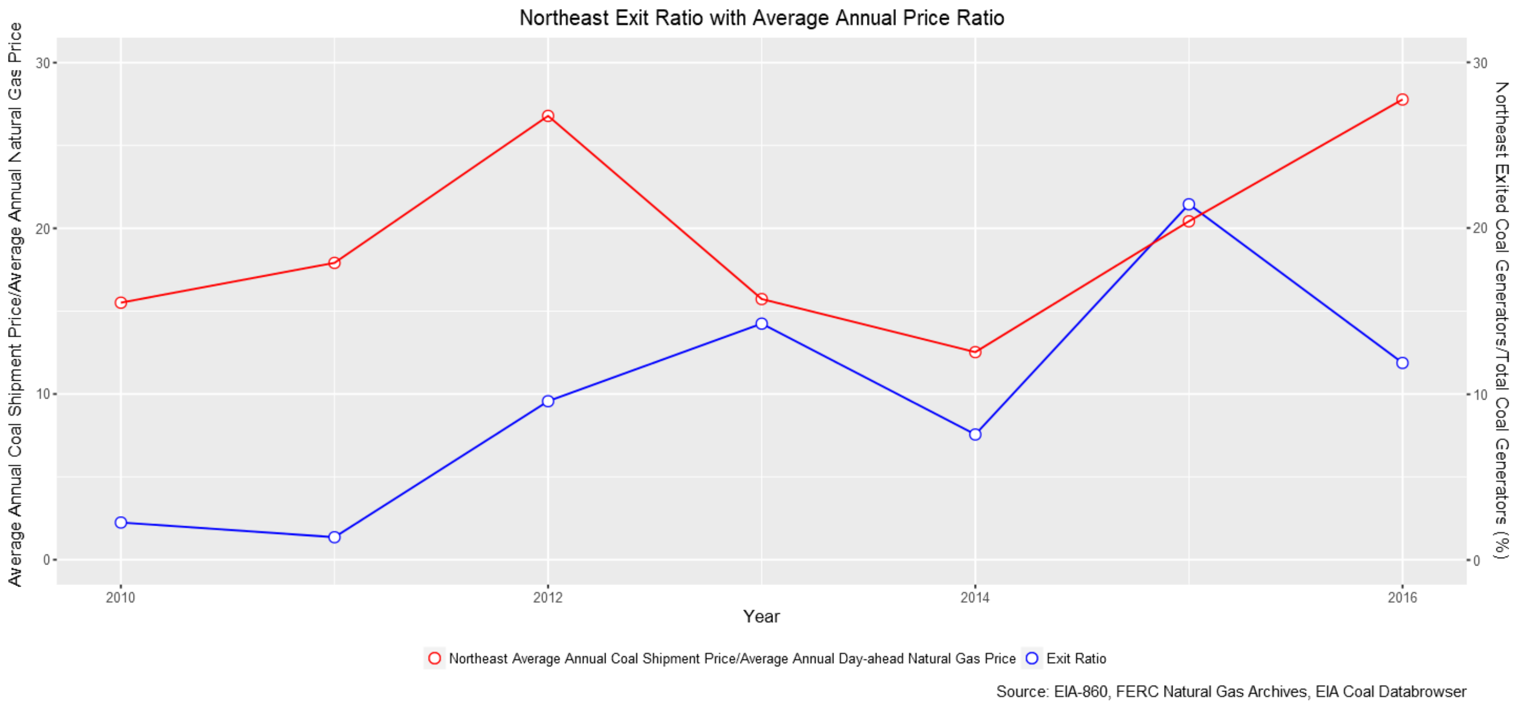


Figure 14: CAISO Exit Ratio with Relative Price Ratio

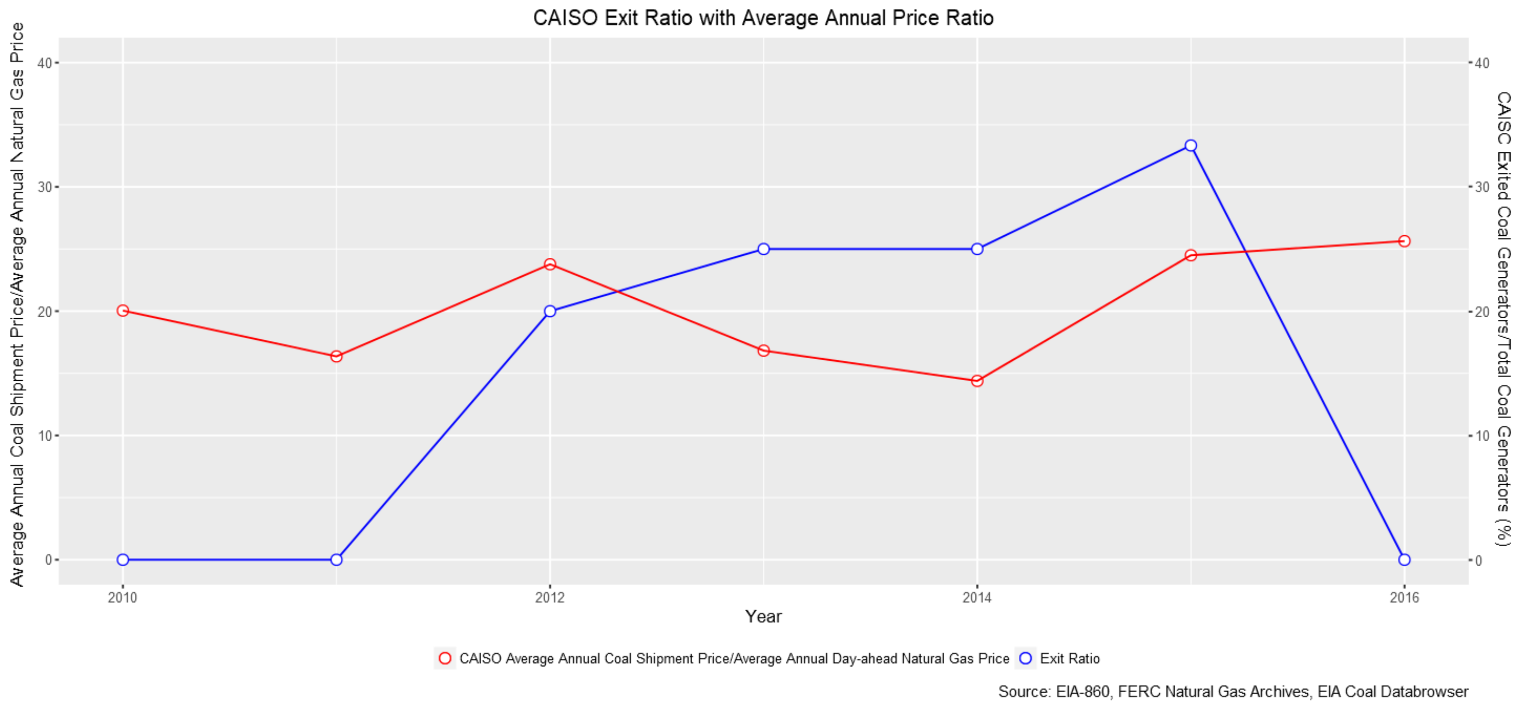


Figure 15: ERCOT Exit Ratio with Relative Price Ratio

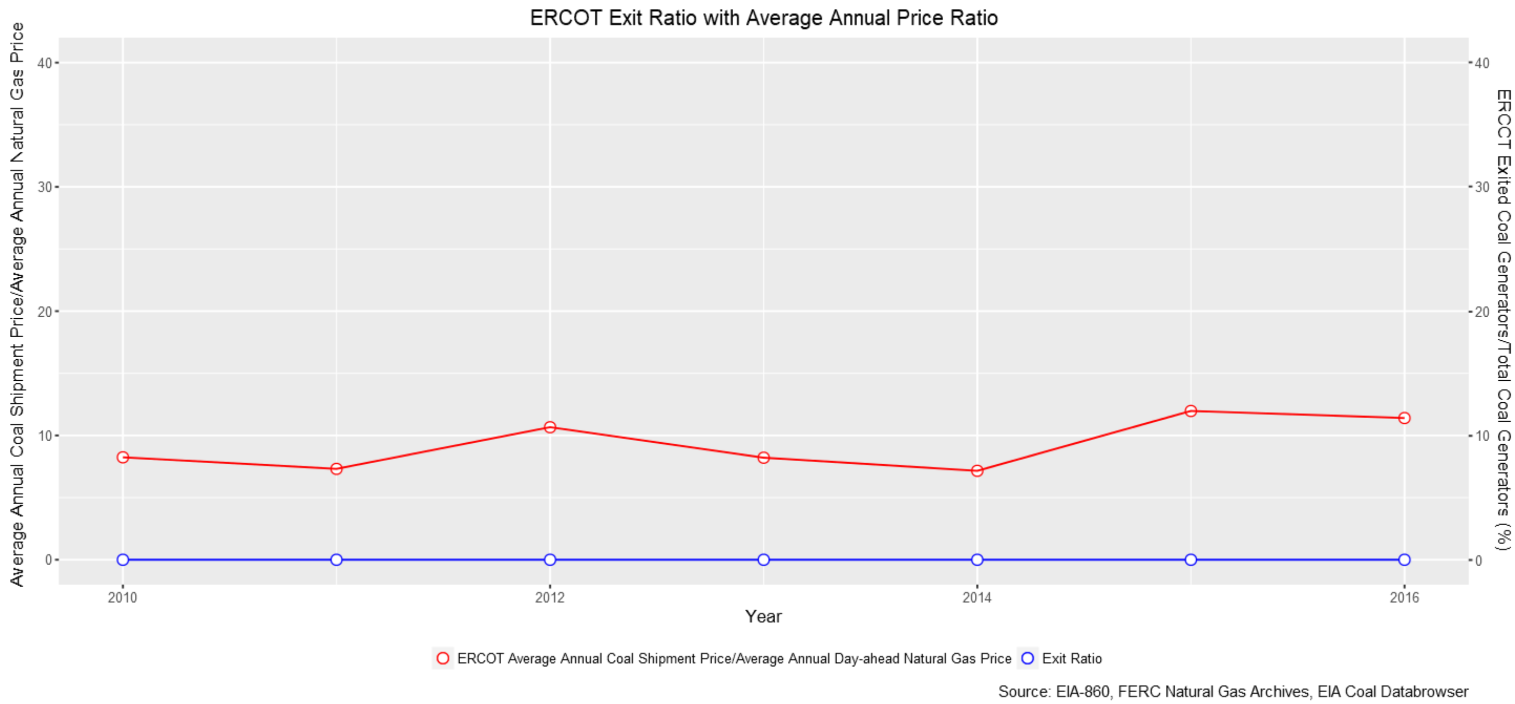


Figure 16: ISO-NE Exit Ratio with Relative Price Ratio

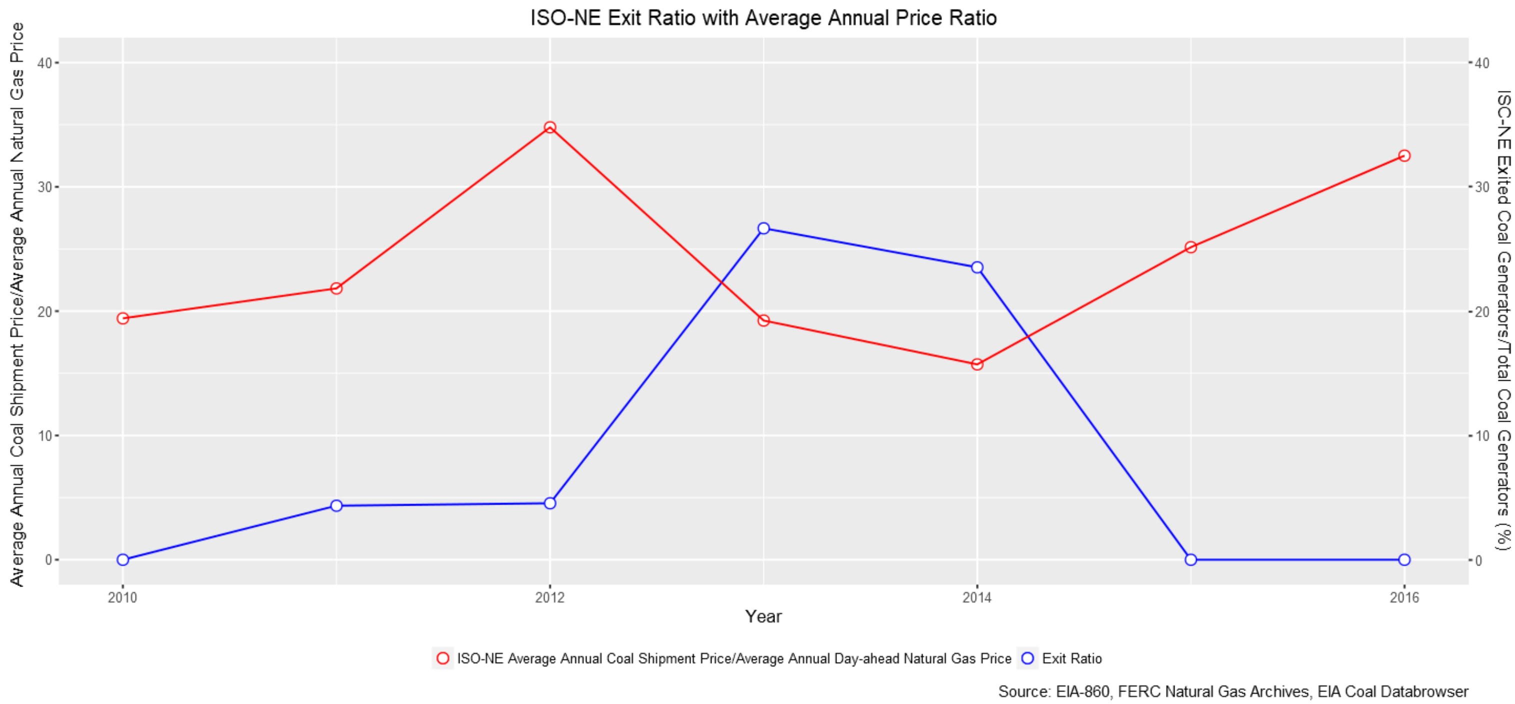


Figure 17: PJM Exit Ratio with Relative Price Ratio

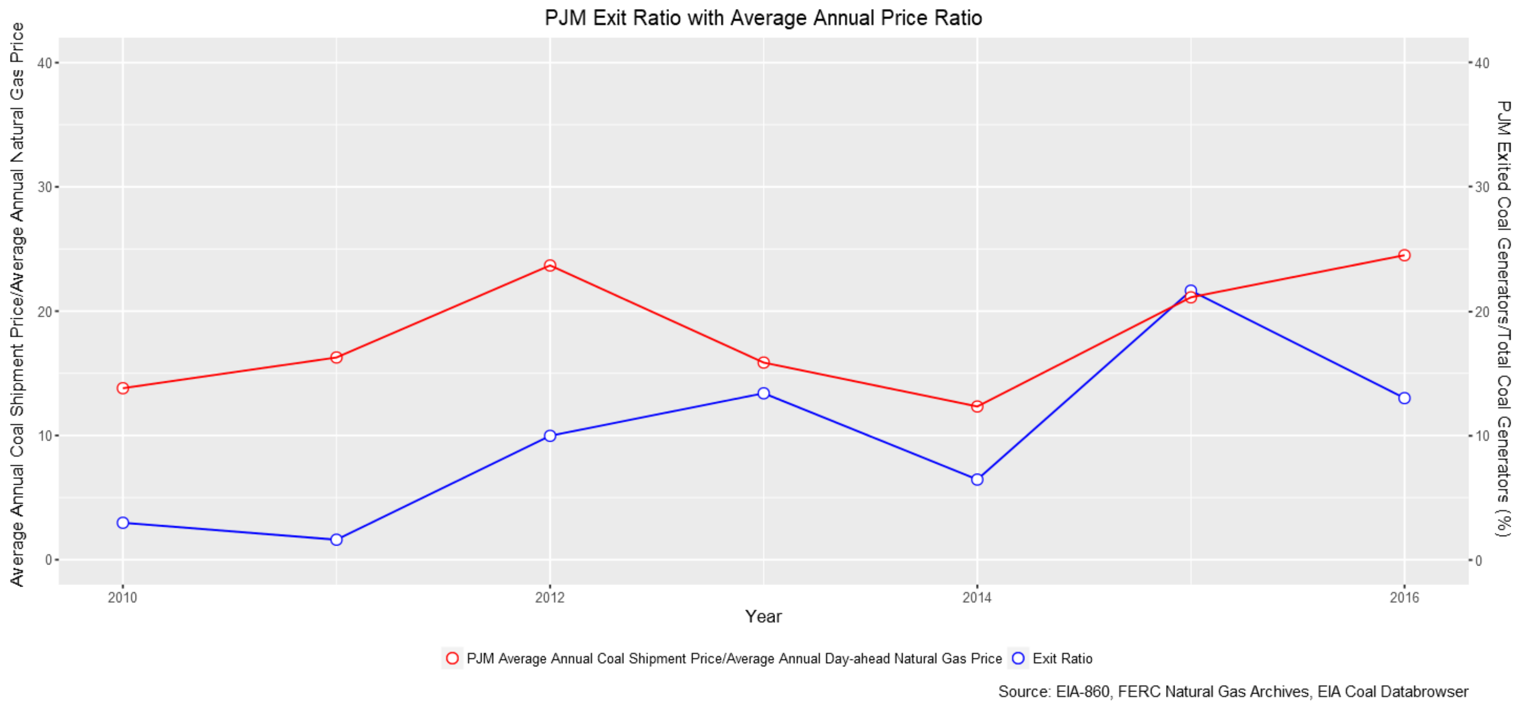


Figure 18: NYISO Exit Ratio with Relative Price Ratio

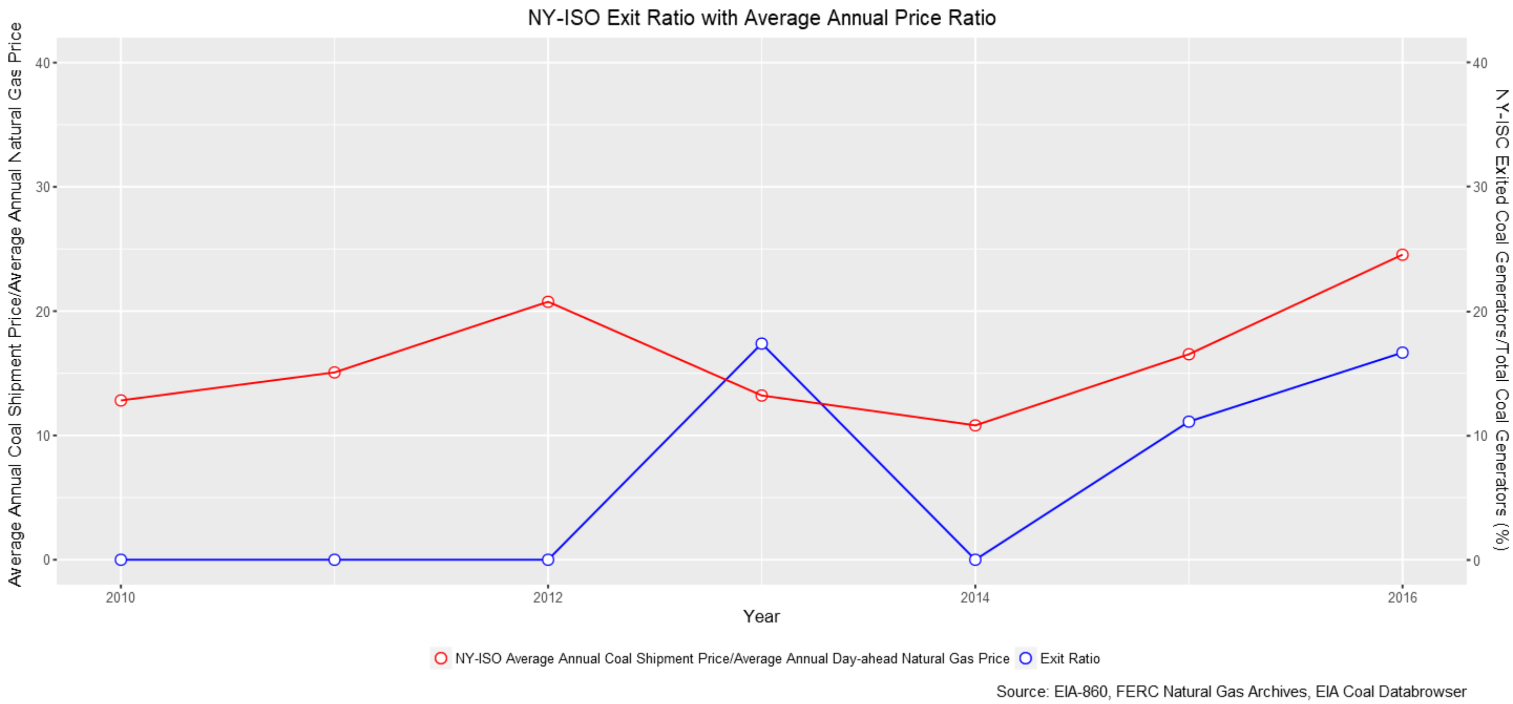


Figure 19: MISO Exit Ratio with Relative Price Ratio

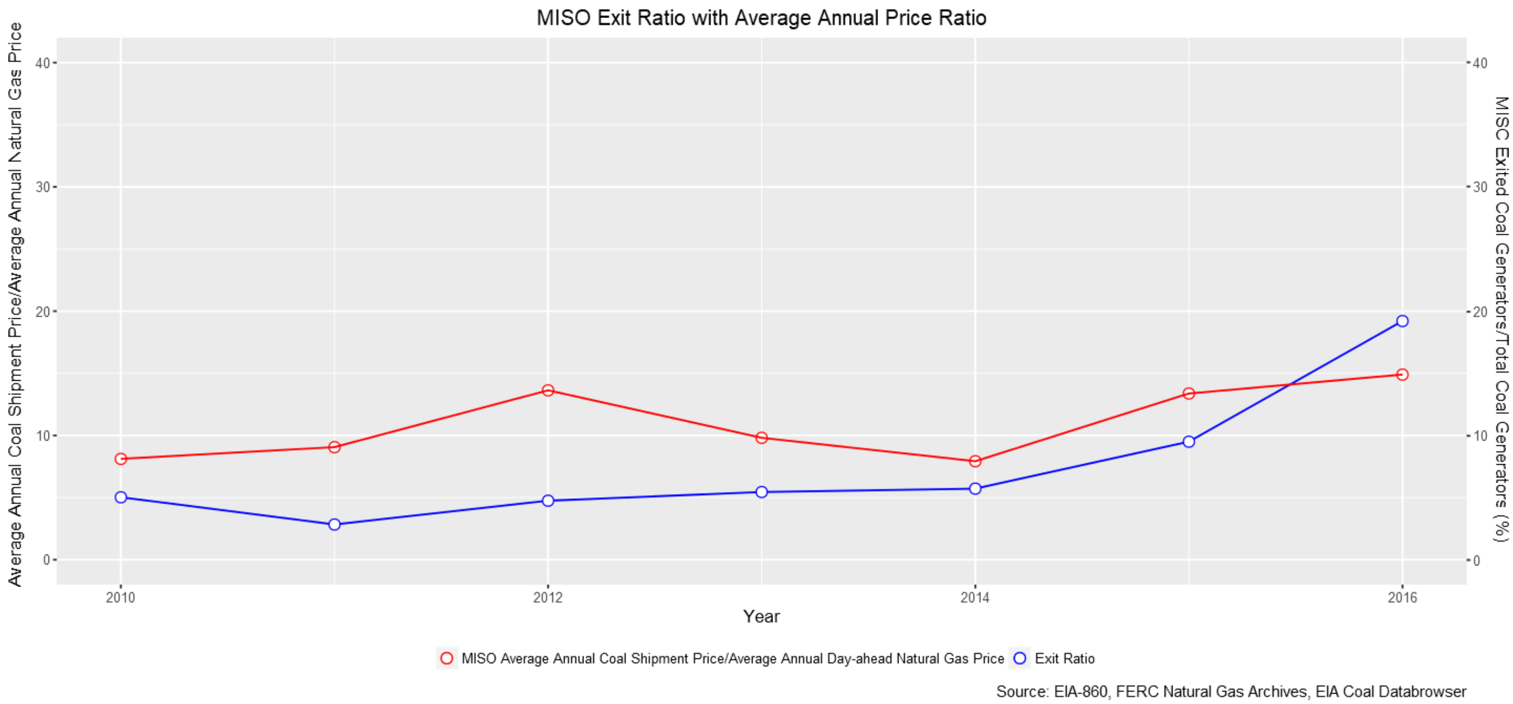
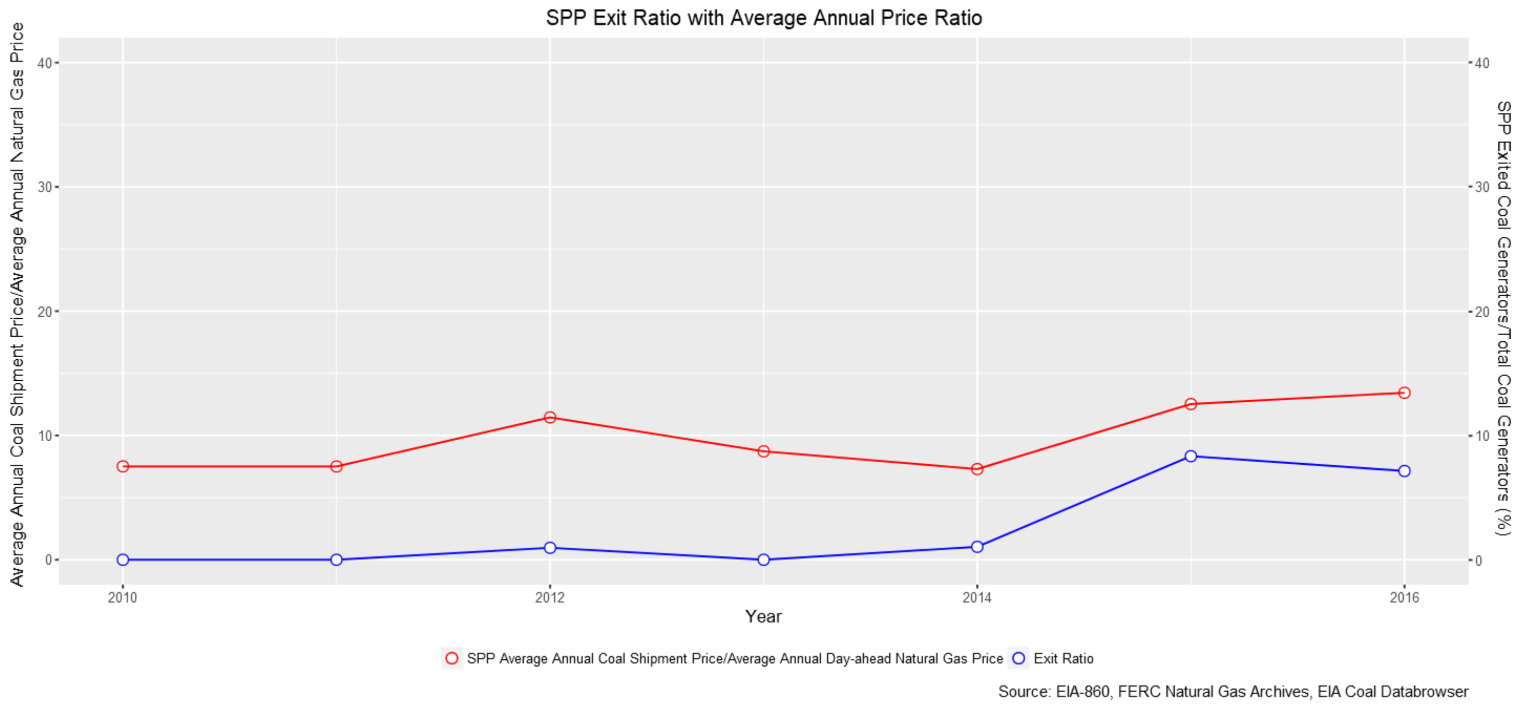


Figure 20: SPP Exit Ratio with Relative Price Ratio



Bibliography

[1] P. Arcidiacono and P. B. Ellickson. Practical Methods for Estimation of Dynamic Discrete Choice Models. 2011.

[2] S. Borenstein. Missing Money. *Energy Institute Blog*, 2017.

[3] S. Borenstein and J. Bushnell. The US Electricity Industry After 20 Years of Restructuring. *Annual Review of Economics*, 7:437–463, 2015.

[4] J. Bushnell. Building blocks: Investment in Renewable and Non-renewable Technologies. *Energy Institute at Haas Working Paper Series*, 159, 2010.

[5] J. Bushnell, M. Flagg, and E. Mansur. Capacity Markets at a Crossroads. *Report to the Department of Energy, Office of Energy Policy and Systems Analysis, Washington, DC*, 2017.

[6] J. B. Bushnell, S. P. Holland, J. E. Hughes, and C. R. Knittel. Strategic Policy Choice in State-Level Regulation: The EPA's Clean Power Plant. *American Economic Journal: Economic Policy*, 9(2):57–90, 2017.

[7] C. Cain and J. Lesser. A Common Sense Guide to Wholesale Electricity Markets. 2007.

[8] CAISO. Understanding the ISO. June 2018.

[9] J. Copeland Nagle. The War on Coal. *LSU J. Energy L. & Resources*, 5:21–44, 2017.

[10] K. W. Costello. Why Natural Gas has an Uncertain Future. *The Electricity Journal*, 30(7):18–22, 2017.

[11] B. Dennis and J. Eilperin. EPA Chief Scott Pruitt tells coal miners he will repeal power plant rule Tuesday: 'The war against coal is over'. *Washington Post*, 2017.

[12] EDF. About Environmental Defense Fund. 2018.

[13] EIA. Frequently Asked Questions: What is the difference between electricity generation capacity and electricity generation? 2018.

[14] EIA. Glossary EIA. 2018.

[15] EPA. Clean Air Act Requirements and History. *EPA*.

[16] EPA. History of the MATS Regulation. *EPA*.

[17] EPA. Progress Cleaning the Air and Improving People's Health. *EPA*.

[18] EPA. Regulatory Actions - Final Mercury and Air Toxics Standards (MATS) for Power Plants. *EPA*.

[19] EPA. Fact Sheet: Proposed Updates of the Limits for New Power Plants under the Mercury and Air Toxics Standards (MATS). *EPA*, pages 1–2, 2012.

[20] EPA. Fact Sheet: Consideration of Cost in the Appropriate and Necessary Finding for the Mercury and Air Toxics Standards for Power Plants. *EPA*, pages 1–3, 2015.

[21] EPA. Fact Sheet: Final Consideration of Cost in the Appropriate and Necessary Finding for the Mercury and Air Toxics Standards for Power Plants. *EPA*, pages 1–3, 2016.

[22] EPA. Evolution of the Clean Air Act. 2018.

[23] EPA. U.S. Electricity Grid and Markets. 2018.

[24] ERCOT. About ERCOT. 2018.

[25] H. Fell and D. T. Kaffine. The Fall of Coal: Joint Impacts of Fuel Prices and Renewables on Generation and Emissions. *American Economic Journal: Economic Policy*, 10(2):90–116, 2018.

[26] FERC. Electric Power Markets: New England (ISO-NE) . 2018.

[27] FERC. Electric Power Markets: New York (NYISO) , 2018.

[28] FERC. Electric Power Markets: Southwest Power Pool (SPP). 2018.

[29] T. S. Ferguson. Chapter 1. Stopping Rule Problems.

[30] F. Flores-Espino, T. Tian, I. Chernyakhovskiy, I. Chernyakhovskiy, and M. Miller. Competitive Electricity Market Regulation in the United States: A Primer. Technical report, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2016.

[31] L. Gelabert, X. Labandeira, and P. Linares. An Ex-post Analysis of the Effect of Renewables and Cogeneration on Spanish electricity Prices. *Energy Economics*, 33:S59–S65, 2011.

[32] L. H. Goulder and R. N. Stavins. Challenges from State-Federal Interactions in US Climate Change Policy. *American Economic Review*, 101(3):253–257, 2011.

[33] L. Hurley and V. Volcovici. *Scientific American*.

[34] T. Jenkin, P. Beiter, and R. Margolis. Capacity Payments in Restructured Markets under Low and High Penetration Levels of Renewable Energy. Technical report, National Renewable Energy Laboratory (NREL), 2016.

[35] C. R. Knittel, K. Metaxoglou, and A. Trindade. Natural Gas Prices and Coal Displacement: Evidence from Electricity Markets. Technical report, National Bureau of Economic Research, 2015.

[36] MISO. MISO: Corporate Fact Sheet. *MISO Energy*.

[37] PJM. Market for Electricity. *PJM*.

[38] PJM. About Who We Are. 2018.

[39] B. Plumer. Could the Supreme Court Block Obama's Big Crackdown on Mercury Pollution? *Vox*, 2015.

[40] J. Rhodes. Wind capacity is estimated to overtake coal capacity in ERCOT given recent retirement announcements and planned additions, 2017.

[41] J. Rust. Optimal Replacement of GMC Bus Engines: An Empirical Model of Harold Zurcher. *Econometrica*, 55(5):999–1033, 1987.

[42] F. Sensfub, M. Ragwitz, and M. Genoese. The Merit-order Effect: A Detailed Analysis of the Price Effect of Renewable Electricity Generation on Spot Market Prices in Germany. *Energy Policy*, 36(8):3086, 2008.

[43] T. Traber and C. Kemfert. Gone with the Wind? — Electricity market Prices and Incentives to Invest in Thermal Power Plants under Increasing Wind Energy Supply. *Energy Economics*, 33(2):249–256, 2011.

[44] R. Treinen. Locational Marginal Pricing (LMP): Basics of Nodal Price Calculation. *CAISO*, 2005.

9 Appendix

9.1 Appendix A: Data Compilation Procedure

To create the data set, I use the EIA-860 survey, EIA coal data-browser, FERC natural gas markets archives, and the EDF's compilation of the District of Columbia (D.C.) Circuit Court of Appeals and Supreme Court documents on MATS. I first use the EIA-860 'Generator' and 'Plant' data sets. Using the 'Plant' data, I first append the list of coal plants from 2010 to 2016. The data set is limited because the EIA-860 data does not explicitly state ISO/RTO-affiliations prior to 2010. Furthermore, the 2016 data set was the most recent data when I gathered data.

I then use the EIA-860 'Generator' data set. From 2010 to 2016, each annual data set contains three sheets: 'Operable', 'Proposed', and 'Retired and Cancelled.'[37] I first merge the 'Operable' and 'Retired and Cancelled' sheets into one data set for each year. Next, I append the merged every yearly 'Generator' data sets into one data set.

Afterwards, I merge the appended 'Plant' and 'Generator' data sets into one data set. To limit the data set to only 'coal' generators, I use the EIA-860 definition as the following:

Table 12: EIA Coal Energy Source Code

Energy Source	EIA Code
Anthracite Coal	ANT
Bituminous Coal	BIT
Lignite Coal	LIG
Coal-Derived Synthesis Gas	SGC
Subbituminous Coal	SUB
Refined Coal	RC
Waste/Other Coal	WC

Because the EIA-860 data survey indicates six energy sources for each generator, I create six dummy variables that takes the value of 1 if the generator utilizes the EIA coal source definition and 0 if otherwise. Afterwards, I drop the generators that do not use at least one

[37] Over the years, the EIA uses varying names for the sheets.

of coal source.

I then assign each coal generators to corresponding FERC-designated regions. See table below for the regions.

Table 13: List of States by FERC-Designated Regions

Regions	**States**
Gulf	Louisiana, Texas
Midwest	Arkansas, Kansas, Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, and South Dakota
Northeast	Connecticut, Delaware, District of Columbia, Kentucky, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, Virginia, and West Virginia
Southeast	Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee
West	Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming

In addition to fuel source dummy variables and the FERC-regions assignment, I create the 'ISO' dummy variable and the individual ISO/RTO dummy variables. For the former dummy variable, a coal generator has a value of 1 if the coal generator is under the ISO/RTO. If not, then it receives the value of 0. For the latter dummy variables, I code 1 if the coal generator is part of the specific ISO/RTO with respect to ERCOT. If not, then, I code 0. For the list of the ISO/RTO, see Table 14.

Table 14: List of ISO/RTO with Served States

Name of ISO/RTO	**Served States**
California ISO (CAISO)	California, Nevada
Electric Reliability Council of Texas (ERCOT)	Texas
New England ISO (ISO-NE)	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont
Midcontinent ISO (MISO)	Arkansas, Illinois, Indiana, Iowa, Kentucky, Louisiana, Minnesota, Michigan, Montana, Missouri, Mississippi, North Dakota, South Dakota, Texas, Wisconsin, and Manitoba (Canadian province)
New York ISO (NY-ISO)	New York
Pennsylvania-New Jersey-Maryland (PJM)	Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and District of Columbia
Southeast Power Pool (SPP)	Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming

The second source is the EIA coal data browser. From this database, I select the 2008-2016 annual coal shipment prices on the state-level. There is one discrepancy. The Californian coal shipment prices are unavailable during the last few years. While the prices differ from year-to-year, the Californian coal shipment price has been consistent. So I calculate the average price from the previous prices and use the average for the missing observations.

I also use the FERC natural gas market archives. In this paper, I use reports that contain the annual average day-ahead natural gas prices for each major natural gas trading hubs (see Table 15). Because FERC typically publishes each month and thus contains a rolling average, I select archived reports from the latest available reports for each year. Some major trading hubs are not included because they are not consistently recorded within the $2005 - 2016$ period. This could possibly impact the magnitude of the natural gas effects on coal plant retirements, so future research should include more trading hubs. See Table 15 for the major trading hubs that I use.

Table 15: Major Natural Gas Trading Hubs

FERC Region	Natural Gas Major Trading Hub	Country
Midwest	Chicago Citygates	United States
	MI Consolidated Citygates	United States
	NNG-Ventura	United States
	Dawn Ontario	Ontario, Canada
	AECO	Alberta, Canada
Gulf	Houston Ship Channel	United States
	Katy	United States
	Henry Hub	United States
	Waha Hub	United States
	Carthage	United States
Southeast	Florida Gas Transmission- Zone 3	United States
	Transco Station 65	United States
	TETCO-M1	United States
Northeast	Algonquin Citygates	United States
	Transco Zone6 NY	United States
	Transco Zone6 (Non-NY)	United States
	Columbia Gas Applachia	United States
Western	SoCal Citygate	United States
	Opal	United States
	El Paso San Juan	United States
	PG&E Malin Oregon	United States

Lastly, I use the petitions compiled by the EDF. I select the following D.C. Circuit Court of Appeals documents: Briefs opposing MATS, briefs supporting MATS, petitions to review, petitions for intervene, petitions for vacatur, and petitions against vacatur. I also limit the Supreme Court documents: briefs opposing for certiorari, petitions for writ of certiorari, petition for merits, petition against merits, petition for stay, and petition against stay. I do not include brief openings. Afterwards, I code whether the state *supported*, *opposed*, or *neither* supported nor opposed MATS. I consider a state's position regarding MATS by recording whether or not a state's attorney general appear on the documents. I ignore associations and coalitions. See Table 16 for the lists of states *supporting*, *opposing*, or *remaining neutral*.

Using the compilation of the states' positions on MATS, I create the state legal challenge dummy variable. I gave a coal generator the value of 1 if the coal generator is in a state that

Table 16: States' Positions on MATS

States Opposing MATS
Alaska, Alabama, Arkansas, Arizona, Florida, Iowa, Idaho, Indiana, Kentucky, Michigan, Missouri, Mississippi, North Dakota, Nebraska, Ohio, Oklahoma, Pennsylvania, South Carolina, Texas, Utah, Wisconsin, West Virginia, and Wyoming

States Supporting MATS
California, Connecticut, Delaware, Illinois, Massachusetts, Maryland, Maine, Minnesota, North Carolina, New Hampshire, New Mexico, New York, Oregon, Rhode Island, Virginia, Vermont, and Washington

States neither Supporting nor Opposing MATS
Colorado, Georgia, Hawaii, Louisiana, Montana, New Jersey, Nevada, South Dakota, and Tennessee

petitioned *against* MATS at least once. If not, then I give a 0.

With the EIA-860, coal shipment prices, day-ahead natural gas prices, and state legal challenge data sets, I merge all four data sets. I drop the observations that are not matched. After merging, I create the dummy variable "Retirement" dummy variable, where the variable tales the value of 1 if coal generator has a "Retirement" status in the EIA-860 survey. Next, I create the dummy variables 'Year2010,' 'Year2011,' 'Year2012', 'Year2013,' 'Year2014,' 'Year2015' and 'Year2016.' These take the value of 1 if the planning year occurs and 0 if otherwise. I then create the relative price ratio variable using the annual coal shipment prices (numerator) and the average annual day-ahead natural gas prices (denominator). Furthermore, I create the size group and age group for the descriptive statistics. See Table 17 for the characteristics.

Table 17: Description of the Age and Size Group

Age Group	Years of Operation
1	0-10
2	11-20
3	21-30
4	31-40
5	41-50
6	51-60
7	61-70
8	71-80
9	81+

Size Group	Nameplate Capacity (MW)
1	0-100
2	101-200
3	201-300
4	301-400
5	401-500
6	501-600
7	601-700
8	701-800
9	801+

Some states are not in the analysis. Because of no observations for either the day-ahead natural gas prices or the coal shipment prices, Alaska, District of Columbia, Hawaii, Idaho, Rhode Island, and Vermont observations are not included.

Because of the duplicity issues, I export the data to cross-check by using flag indicators. I should note that some plants are labeled as 'Retired' in one year but physically retired the following year. For these cases, I include the latest information for each coal generator.

In addition to the duplicity check, I also check the status of the generators. There are instances where coal generators with certain statuses are part of the operating data set in certain years but not in other years. I only include the following status:

Table 18: Description of Coal Generator Status (Based on EIA-860 definition)

Status	**Description**
OP	Operating generator
RE	Retired generator
OA	Currently not operating generator but expected to operate the coming year
OS	Currently not operating generator but expected to not operate the coming year
SB	Standby generator

Lastly, I looked for outliers: fuel-switched coal generators. If the coal generator either exit the market or switch fuel source, then I replace the "Retirement" dummy variable to 2. For the empirical analysis, I consider fuel-switched coal generators as retirements so these generators receive a value of 1 for the "Retirement" dummy variable.

9.2 Appendix B: Maps of ISO and RTO

Figure 21: CAISO

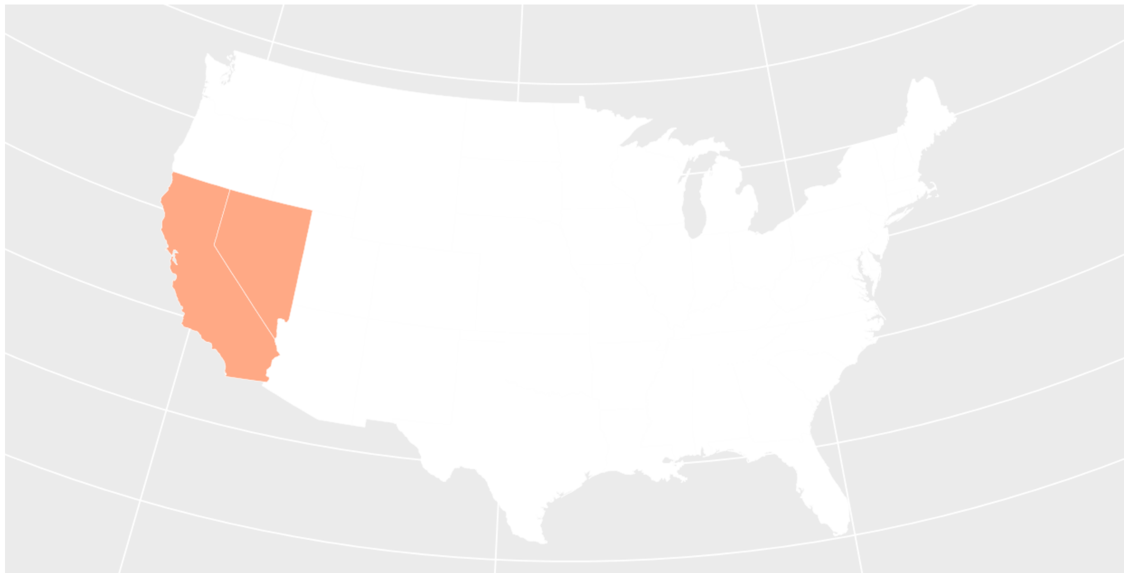


Figure 22: ERCOT

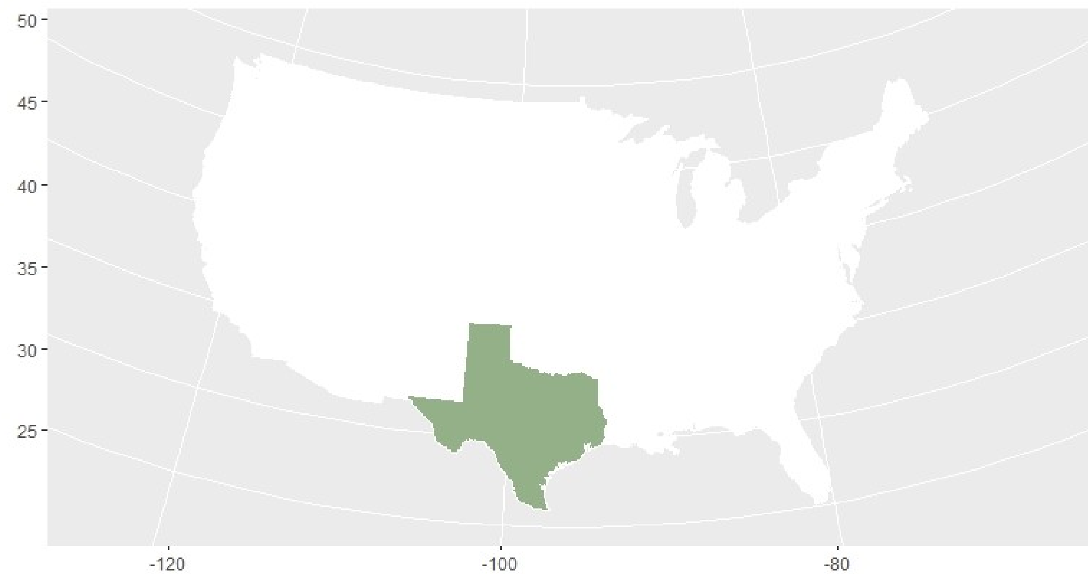


Figure 23: ISONE

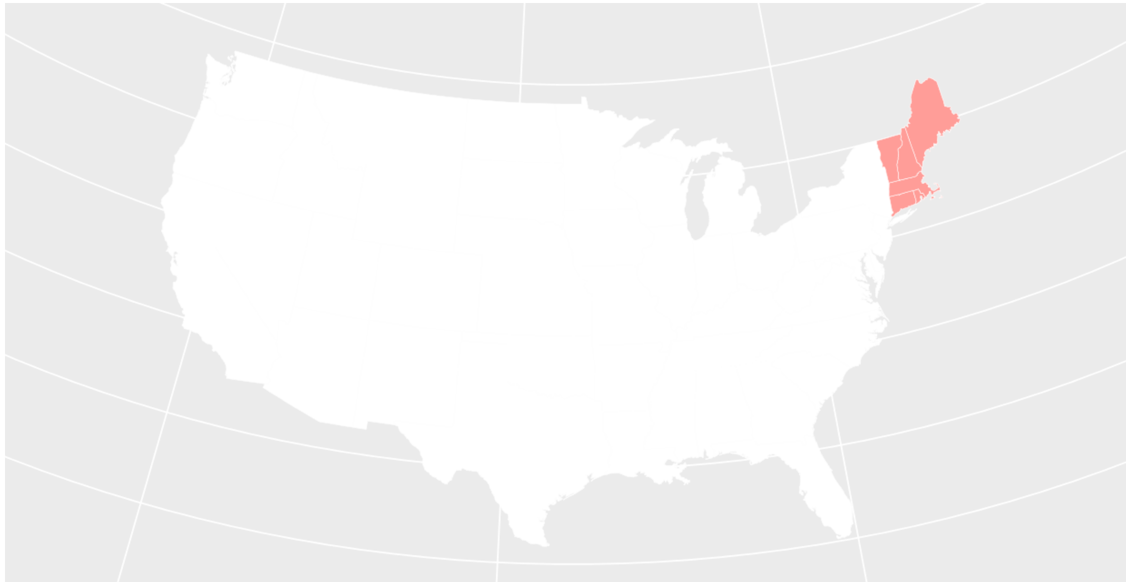


Figure 24: MISO (Excluding Manitoba)

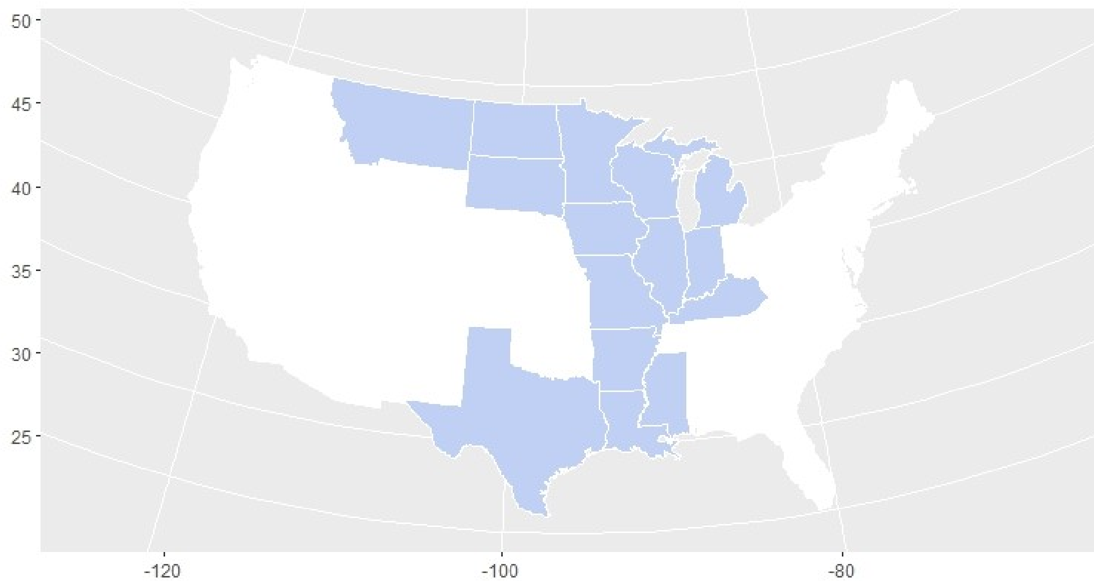


Figure 25: NYISO

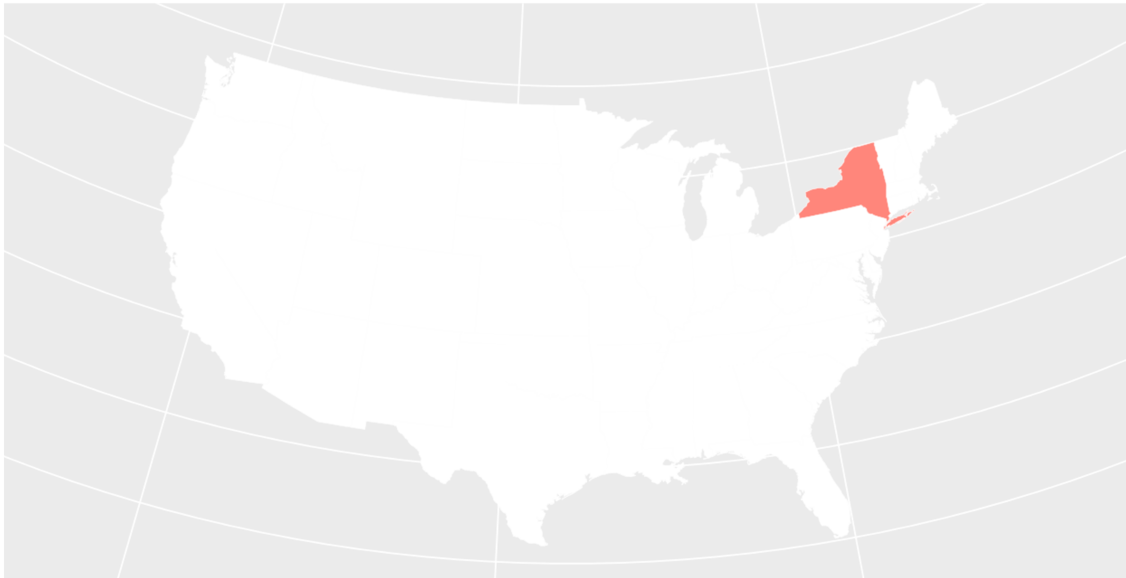


Figure 26: PJM

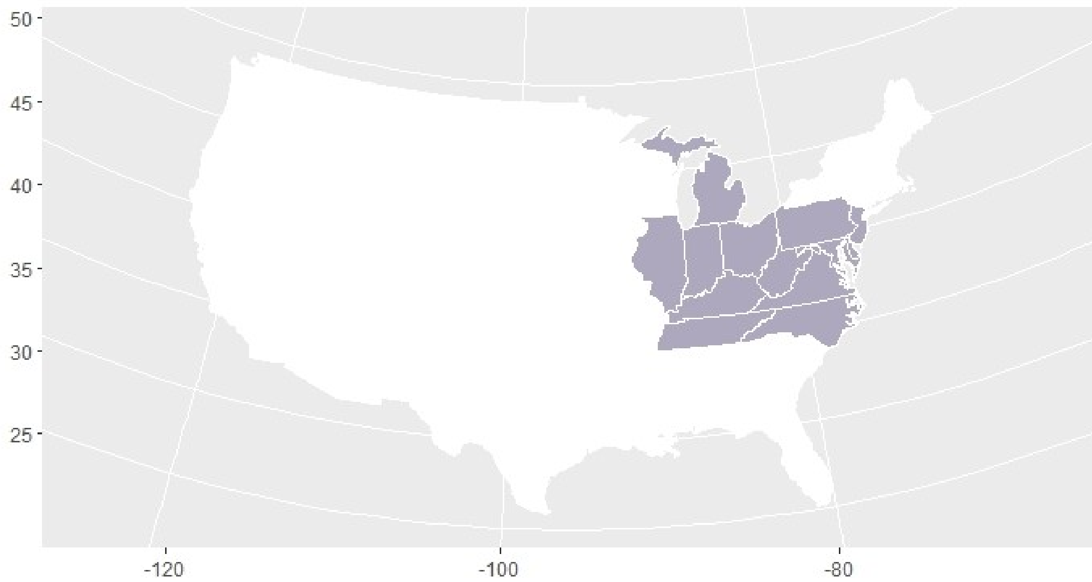
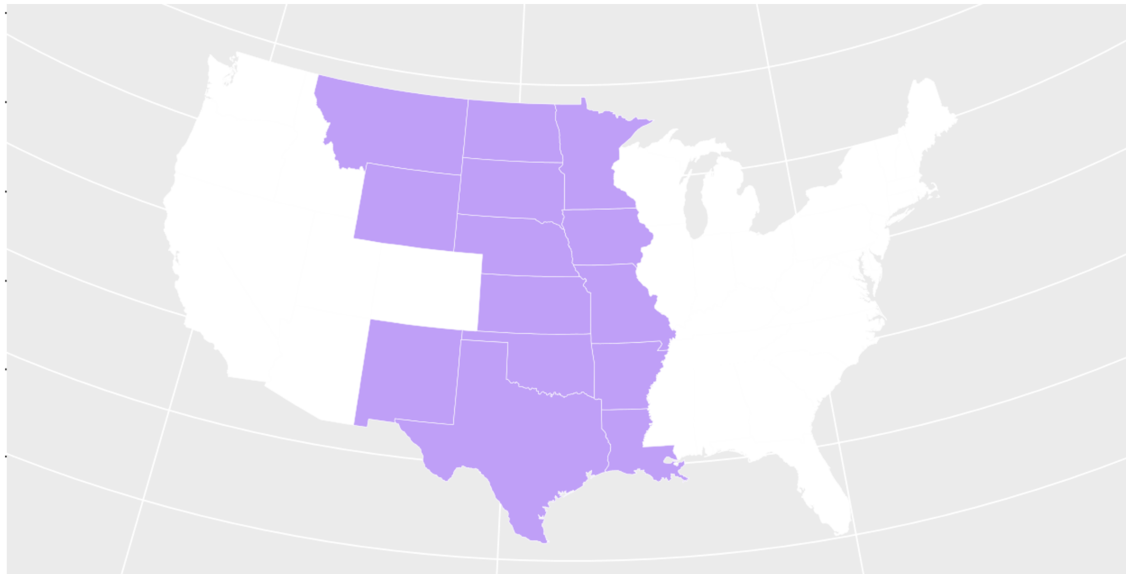


Figure 27: SPP



9.3 Appendix C: Number of Operating, Retired, & Fuel-Switched Coal Generators by State

Table 19: Operating, Retired, & Fuel-Switched Coal Generators by State

State	Number of Coal Generators	Number of Retired Coal Generators	Number of Fuel-Switched Coal Generators
AL	306	22	4
AR	75	0	1
AZ	116	3	0
CA	56	4	5
CO	219	11	0
CT	10	1	0
DE	25	3	3
FL	246	7	1
GA	341	17	5
IA	362	22	10
IL	507	24	12
IN	562	32	11
KS	103	4	2
KY	377	14	1
LA	70	2	1
MA	52	5	3
MD	130	4	0
ME	27	0	2
MI	575	22	21
MN	298	9	7

MO	403	15	9
MS	91	0	2
MT	67	1	0
NC	361	27	6
ND	104	1	0
NE	135	0	3
NH	35	0	0
NJ	48	3	1
NM	62	4	0
NV	49	5	0
NY	153	7	6
OH	624	59	11
OK	106	2	0
OR	7	0	0
PA	474	30	10
SC	239	18	9
SD	12	1	0
TN	392	17	2
TX	285	3	0
UT	103	5	0
VA	399	23	23
WA	21	0	0
WI	460	24	18
WV	255	20	6
WY	215	4	0

9.4 Appendix D: Description of Variables Used in Empirical Analysis

Table 20: Description of Variables

Variable	Description
Retirement	Retirement is a dummy variable that takes the value of 1 if the coal generator retired and switched fuel sources other than coal. The value is 0 if otherwise.
AgainstMATS	Against MATS is a dummy variable that takes the value of 1 if the coal generator is in the state that publicly opposed MATS. The value is 0 if the state publicly supported MATS.
CAISO, MISO, SPP, NY-ISO, ISO-NE, PJM	These are the dummy variables indicating whether the coal generator operated in the corresponding ISO/RTO. If the coal generator operates in the ISO/RTO, it takes the value of 1. These dummy variables are with respect to the ISO/RTO dummy variable, ERCOT.
Year2010, Year2011, Year2012,Year2013, Year2014,Year2015	These are dummy variables indicating whether the corresponding year occurs. If the corresponding year occurs, then the value is 1. The 'Year2010' and 'Year2011' are dummy variables that represent pre-MATS compliance period. The 'Year2012,' 'Year2013,' and 'Year2014' are dummy variables that represent the MATS compliance period. Lastly, the 'Year2015' is the dummy variable that represent the post-MATS compliance period. The dummy variables are with respect to 2016.
Nameplate Capacity (MW)	Nameplate Capacity is the annual nameplate capacity for each coal generator.
Age	Age is the number of operating years since the coal generator first operated.height

9.5 Appendix E: Sensitivity Checks

Table 21: Probit Results Part 1

Variables	Probit w/ Robust	Probit w/ Cluster Plant Code	Probit w/ Robust	Probit w/ Cluster Plant Code	Probit w/ Robust	Probit w/ Cluster Plant Code
Prior-MATS Period						
Year2010	-0.259***	-0.259*	-0.239**	-0.239	-0.257***	-0.257*
	(0.0968)	(0.146)	(0.0975)	(0.149)	(0.0965)	(0.146)
Year2011	-0.302***	-0.302**	-0.290***	-0.290*	-0.300***	-0.300**
	(0.0967)	(0.153)	(0.0969)	(0.154)	(0.0960)	(0.152)
MATS Compliance Period						
Year2012	0.167**	0.167	0.169**	0.169	0.167**	0.167
	(0.0818)	(0.129)	(0.0819)	(0.129)	(0.0818)	(0.129)
Year2013	-0.00118	-0.00118	0.00886	0.00886	-0.000240	-0.000240
	(0.0927)	(0.143)	(0.0931)	(0.144)	(0.0924)	(0.142)
Year2014	0.169*	0.169	0.184*	0.184	0.170*	0.170
	(0.0944)	(0.146)	(0.0950)	(0.147)	(0.0944)	(0.146)
Post-MATS Period						
Year2015	0.639***	0.639***	0.642***	0.642***	0.639***	0.639***
	(0.0810)	(0.114)	(0.0810)	(0.114)	(0.0809)	(0.114)
Relative Price Ratio						
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$	0.0155***	0.0155**	0.0170***	0.0170***	0.0157***	0.0157**
	(0.00364)	(0.00650)	(0.00375)	(0.00654)	(0.00373)	(0.00651)
Generator Characteristics						
Nameplate Capacity	-0.00155***	-0.00155***	-0.00151***	-0.00151***	-0.00155***	-0.00155***
	(0.000133)	(0.000207)	(0.000131)	(0.000200)	(0.000134)	(0.000206)
Age	0.0171***	0.0171***	0.0173***	0.0173***	0.0171***	0.0171***
	(0.00168)	(0.00233)	(0.00167)	(0.00229)	(0.00168)	(0.00235)
Regions by ISO/RTO						
CAISO						
MISO						
SPP						
NYISO						
ISONE						
PJM						
ISO			0.0785*	0.0785		
			(0.0453)	(0.0758)		
State Legal Challenge						
Against MATS					0.00790	0.00790
					(0.0447)	(0.0808)
Constant	-2.358***	-2.358***	-2.449***	-2.449***	-2.364***	-2.364***
	(0.133)	(0.208)	(0.141)	(0.214)	(0.135)	(0.210)
Observations	9,556	9,556	9,556	9,556	9,556	9,556

*** p<0.01, ** p<0.05, * p<0.1

Table 22: Probit Results Part 2

Variables	Probit w/ Robust	Probit w/ Cluster Plant Code	Probit w/ Robust	Probit w/ Cluster Plant Code	Probit w/ Robust	Probit w/ Cluster Plant Code
Prior-MATS Period						
Year2010	-0.269***	-0.269*	-0.238**	-0.238	-0.268***	-0.268*
	(0.0979)	(0.154)	(0.0972)	(0.149)	(0.0978)	(0.154)
Year2011	-0.318***	-0.318**	-0.289***	-0.289*	-0.316***	-0.316**
	(0.0968)	(0.159)	(0.0962)	(0.153)	(0.0964)	(0.159)
MATS Compliance Period						
Year2012	0.162**	0.162	0.169**	0.169	0.161**	0.161
	(0.0814)	(0.130)	(0.0819)	(0.129)	(0.0814)	(0.130)
Year2013	-0.0268	-0.0268	0.00974	0.00974	-0.0263	-0.0263
	(0.0942)	(0.150)	(0.0929)	(0.144)	(0.0941)	(0.149)
Year2014	0.143	0.143	0.185*	0.185	0.143	0.143
	(0.0956)	(0.153)	(0.0950)	(0.147)	(0.0957)	(0.152)
Post-MATS Period						
Year2015	0.625***	0.625***	0.643***	0.643***	0.625***	0.625***
	(0.0807)	(0.114)	(0.0810)	(0.114)	(0.0806)	(0.114)
Relative Price Ratio						
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$	0.0137***	0.0137*	0.0171***	0.0171***	0.0138***	0.0138*
	(0.00441)	(0.00758)	(0.00385)	(0.00657)	(0.00444)	(0.00756)
Generator Characteristics						
Nameplate Capacity	-0.00151***	-0.00151***	-0.00151***	-0.00151***	-0.00151***	-0.00151***
	(0.000131)	(0.000204)	(0.000132)	(0.000199)	(0.000133)	(0.000203)
Age	0.0173***	0.0173***	0.0173***	0.0173***	0.0173***	0.0173***
	(0.00167)	(0.00230)	(0.00167)	(0.00232)	(0.00168)	(0.00233)
Regions by ISO/RTO						
CAISO	0.486**	0.486			0.492**	0.492
	(0.227)	(0.412)			(0.228)	(0.414)
MISO	0.0298	0.0298			0.0281	0.0281
	(0.0575)	(0.0964)			(0.0576)	(0.0962)
SPP	-0.0350	-0.0350			-0.0412	-0.0412
	(0.112)	(0.160)			(0.113)	(0.162)
NYISO	0.0871	0.0871			0.0954	0.0954
	(0.165)	(0.324)			(0.167)	(0.328)
ISONE	0.0205	0.0205			0.0278	0.0278
	(0.180)	(0.281)			(0.181)	(0.285)
PJM	0.193***	0.193**			0.192***	0.192*
	(0.0551)	(0.0977)			(0.0550)	(0.0979)
ISO			0.0785*	0.0785		
			(0.0453)	(0.0758)		
State Legal Challenge						
Against MATS			0.00732	0.00732	0.0158	0.0158
Constant	-2.390***	-2.390***	-2.455***	-2.455***	-2.399***	-2.399***
	(0.149)	(0.235)	(0.143)	(0.217)	(0.151)	(0.235)
Observations	9,556	9,556	9,556	9,556	9,556	9,556

*** p<0.01, ** p<0.05, * p<0.1

Table 23: Logit Results Part 1

Variables	Logit w/ Robust	Logit w/ Cluster Plant Code	Logit w/ Robust	Logit w/ Cluster Plant Code	Logit w/ Robust	Logit w/ Cluster Plant Code
Prior-MATS Period						
Year2010	-0.550***	-0.550*	-0.512**	-0.512	-0.543***	-0.543*
	(0.203)	(0.313)	(0.204)	(0.318)	(0.201)	(0.312)
Year2011	-0.595***	-0.595*	-0.574***	-0.574*	-0.590***	-0.590*
	(0.204)	(0.330)	(0.204)	(0.332)	(0.203)	(0.329)
MATS Compliance Period						
Year2012	0.325**	0.325	0.326**	0.326	0.323**	0.323
	(0.162)	(0.260)	(0.162)	(0.261)	(0.162)	(0.260)
Year2013	-0.00117	-0.00117	0.0190	0.0190	0.00261	0.00261
	(0.188)	(0.294)	(0.189)	(0.296)	(0.187)	(0.293)
Year2014	0.345*	0.345	0.374**	0.374	0.350*	0.350
	(0.190)	(0.301)	(0.191)	(0.303)	(0.189)	(0.300)
Post-MATS Period						
Year2015	1.231***	1.231***	1.237***	1.237***	1.231***	1.231***
	(0.158)	(0.230)	(0.158)	(0.231)	(0.158)	(0.230)
Relative Price Ratio						
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$	0.0311***	0.0311**	0.0340***	0.0340**	0.0319***	0.0319**
	(0.00712)	(0.0133)	(0.00732)	(0.0133)	(0.00732)	(0.0133)
Generator Characteristics						
Nameplate Capacity	-0.00311***	-0.00311***	-0.00303***	-0.00303***	-0.00313***	-0.00313***
	(0.000279)	(0.000454)	(0.000274)	(0.000437)	(0.000282)	(0.000450)
Age	0.0357***	0.0357***	0.0358***	0.0358***	0.0356***	0.0356***
	(0.00354)	(0.00496)	(0.00352)	(0.00490)	(0.00355)	(0.00503)
Regions by ISO/RTO						
CAISO						
MISO						
SPP						
NYISO						
ISONE						
PJM						
ISO			0.152*	0.152		
			(0.0904)	(0.155)		
State Legal Challenge						
Against MATS					0.0489	0.0489
					(0.0891)	(0.165)
Constant	-4.469***	-4.469***	-4.642***	-4.642***	-4.507***	-4.507***
	(0.276)	(0.445)	(0.289)	(0.449)	(0.280)	(0.446)
Observations	9,556	9,556	9,556	9,556	9,556	9,556

*** p<0.01, ** p<0.05, * p<0.1

Table 24: Logit Results Part 2

Variables	Logit w/ Robust	Logit w/ Cluster Plant Code	Logit w/ Robust	Logit w/ Cluster Plant Code	Logit w/ Robust	Logit w/ Cluster Plant Code
Prior-MATS Period						
Year2010	-0.553***	-0.553*	-0.505**	-0.505	-0.549***	-0.549*
	(0.205)	(0.327)	(0.203)	(0.317)	(0.204)	(0.326)
Year2011	-0.610***	-0.610*	-0.570***	-0.570*	-0.608***	-0.608*
	(0.205)	(0.340)	(0.203)	(0.330)	(0.204)	(0.339)
MATS Compliance Period						
Year2012	0.323**	0.323	0.324**	0.324	0.321**	0.321
	(0.162)	(0.263)	(0.162)	(0.260)	(0.162)	(0.263)
Year2013	-0.0335	-0.0335	0.0228	0.0228	-0.0330	-0.0330
	(0.191)	(0.306)	(0.188)	(0.295)	(0.191)	(0.306)
Year2014	0.310	0.310	0.380**	0.380	0.313	0.313
	(0.192)	(0.313)	(0.190)	(0.302)	(0.192)	(0.312)
Post-MATS Period						
Year2015	1.218***	1.218***	1.238***	1.238***	1.218***	1.218***
	(0.158)	(0.231)	(0.158)	(0.231)	(0.158)	(0.230)
Relative Price Ratio						
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$	0.0285***	0.0285*	0.0348***	0.0348***	0.0290***	0.0290*
	(0.00885)	(0.0157)	(0.00754)	(0.0133)	(0.00893)	(0.0156)
Generator Characteristics						
Nameplate Capacity	-0.00301***	-0.00301***	-0.00305***	-0.00305***	-0.00303***	-0.00303***
	(0.000271)	(0.000441)	(0.000277)	(0.000433)	(0.000275)	(0.000435)
Age	0.0356***	0.0356***	0.0357***	0.0357***	0.0355***	0.0355***
	(0.00351)	(0.00489)	(0.00353)	(0.00497)	(0.00353)	(0.00498)
Regions by ISO/RTO						
CAISO	0.893**	0.893			0.919**	0.919
	(0.445)	(0.858)			(0.446)	(0.862)
MISO	0.0613	0.0613			0.0539	0.0539
	(0.115)	(0.194)			(0.115)	(0.193)
SPP	-0.0471	-0.0471			-0.0714	-0.0714
	(0.228)	(0.325)			(0.229)	(0.329)
NYISO	0.115	0.115			0.149	0.149
	(0.326)	(0.651)			(0.330)	(0.662)
ISONE	0.0140	0.0140			0.0417	0.0417
	(0.360)	(0.593)			(0.362)	(0.602)
PJM	0.375***	0.375*			0.371***	0.371*
	(0.108)	(0.197)			(0.108)	(0.197)
ISO			0.152*	0.152		
			(0.0904)	(0.155)		
State Legal Challenge						
Against MATS			0.0479	0.0479	0.0641	0.0641
			(0.0893)	(0.165)	(0.0932)	(0.178)
Constant	-4.549***	-4.549***	-4.678***	-4.678***	-4.583***	-4.583***
	(0.309)	(0.491)	(0.293)	(0.452)	(0.311)	(0.491)
Observations	9,556	9,556	9,556	9,556	9,556	9,556

*** p<0.01, ** p<0.05, * p<0.1

Table 25: Linear Probability Results Part 1

Variables	Linear w/ Robust	Linear w/ Cluster Plant Code	Linear w/ Robust	Linear w/ Cluster Plant Code	Linear w/ Robust	Linear w/ Cluster Plant Code
Prior-MATS Period						
Year2010	-0.0195**	-0.0195	-0.0163*	-0.0163	-0.0191**	-0.0191
	(0.00921)	(0.0142)	(0.00924)	(0.0144)	(0.00914)	(0.0141)
Year2011	-0.0222**	-0.0222	-0.0205**	-0.0205	-0.0219**	-0.0219
	(0.00923)	(0.0147)	(0.00921)	(0.0148)	(0.00917)	(0.0147)
MATS Compliance Period						
Year2012	0.0236**	0.0236	0.0238**	0.0238	0.0236**	0.0236
	(0.0102)	(0.0166)	(0.0102)	(0.0166)	(0.0102)	(0.0166)
Year2013	0.00107	0.00107	0.00261	0.00261	0.00137	0.00137
	(0.0100)	(0.0157)	(0.0100)	(0.0158)	(0.0100)	(0.0157)
Year2014	0.0198*	0.0198	0.0221**	0.0221	0.0203*	0.0203
	(0.0110)	(0.0173)	(0.0110)	(0.0173)	(0.0110)	(0.0172)
Post-MATS Period						
Year2015	0.108***	0.108***	0.108***	0.108***	0.108***	0.108***
	(0.0127)	(0.0184)	(0.0126)	(0.0184)	(0.0126)	(0.0184)
Relative Price Ratio						
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$	0.00185***	0.00185**	0.00210***	0.00210**	0.00190***	0.00190**
	(0.000513)	(0.000882)	(0.000520)	(0.000884)	(0.000523)	(0.000885)
Generator Characteristics						
Nameplate Capacity	-0.000101***	-0.000101***	-9.75e-05***	-9.75e-05***	-0.000102***	-0.000102***
	(6.78e-06)	(1.12e-05)	(6.69e-06)	(1.09e-05)	(6.93e-06)	(1.12e-05)
Age	0.00212***	0.00212***	0.00214***	0.00214***	0.00212***	0.00212***
	(0.000186)	(0.000264)	(0.000186)	(0.000260)	(0.000186)	(0.000265)
Regions by ISO/RTO						
CAISO						
MISO						
SPP						
NYISO						
ISONE						
PJM						
ISO			0.0134***	0.0134		
			(0.00510)	(0.00854)		
State Legal Challenge						
Against MATS					0.00337	0.00337
					(0.00543)	(0.00957)
Constant	-0.0355**	-0.0355	-0.0499***	-0.0499**	-0.0382***	-0.0382*
	(0.0140)	(0.0223)	(0.0147)	(0.0228)	(0.0145)	(0.0226)
Observations	9,556	9,556	9,556	9,556	9,556	9,556
R-squared	0.068	0.068	0.069	0.069	0.068	0.068

*** p<0.01, ** p<0.05, * p<0.1

Table 26: Linear Probability Results Part 2

Variables	Linear w/ Robust	Linear w/ Cluster Plant Code	Linear w/ Robust	Linear w/ Cluster Plant Code	Linear w/ Robust	Linear w/ Cluster Plant Code
Prior-MATS Period						
Year2010	-0.0204**	-0.0204	-0.0159*	-0.0159	-0.0202**	-0.0202
	(0.00930)	(0.0150)	(0.00918)	(0.0143)	(0.00927)	(0.0150)
Year2011	-0.0238***	-0.0238	-0.0202**	-0.0202	-0.0237**	-0.0237
	(0.00922)	(0.0153)	(0.00915)	(0.0147)	(0.00919)	(0.0153)
MATS Compliance Period						
Year2012	0.0236**	0.0236	0.0238**	0.0238	0.0235**	0.0235
	(0.0102)	(0.0167)	(0.0102)	(0.0166)	(0.0102)	(0.0167)
Year2013	-0.00171	-0.00171	0.00291	0.00291	-0.00166	-0.00166
	(0.0102)	(0.0164)	(0.0100)	(0.0157)	(0.0102)	(0.0164)
Year2014	0.0164	0.0164	0.0225**	0.0225	0.0166	0.0166
	(0.0110)	(0.0177)	(0.0110)	(0.0173)	(0.0110)	(0.0177)
Post-MATS Period						
Year2015	0.106***	0.106***	0.108***	0.108***	0.106***	0.106***
	(0.0126)	(0.0183)	(0.0126)	(0.0184)	(0.0126)	(0.0183)
Relative Price Ratio						
$\frac{\text{Coal Price}}{\text{Natural Gas Price}}$	0.00156***	0.00156	0.00215***	0.00215**	0.00159***	0.00159
	(0.000579)	(0.000982)	(0.000530)	(0.000888)	(0.000582)	(0.000980)
Generator Characteristics						
Nameplate Capacity	-9.81e-05***	-9.81e-05***	-9.83e-05***	-9.83e-05***	-9.89e-05***	-9.89e-05***
	(6.78e-06)	(1.16e-05)	(6.84e-06)	(1.09e-05)	(6.93e-06)	(1.15e-05)
Age	0.00212***	0.00212***	0.00213***	0.00213***	0.00211***	0.00211***
	(0.000186)	(0.000260)	(0.000186)	(0.000261)	(0.000186)	(0.000262)
Regions by ISO/RTO						
CAISO	0.0875*	0.0875			0.0894*	0.0894
	(0.0487)	(0.0797)			(0.0488)	(0.0799)
MISO	0.00462	0.00462			0.00445	0.00445
	(0.00622)	(0.0105)			(0.00622)	(0.0105)
SPP	-0.000178	-0.000178			-0.00153	-0.00153
	(0.00985)	(0.0141)			(0.00995)	(0.0144)
NYISO	0.00562	0.00562			0.00784	0.00784
	(0.0252)	(0.0494)			(0.0254)	(0.0498)
ISONE	-0.00102	-0.00102			0.000964	0.000964
	(0.0262)	(0.0404)			(0.0264)	(0.0409)
PJM	0.0275***	0.0275**			0.0274***	0.0274**
	(0.00713)	(0.0123)			(0.00712)	(0.0123)
ISO			0.0134***	0.0134		
			(0.00510)	(0.00853)		
State Legal Challenge						
Against MATS			0.00330	0.00330	0.00400	0.00400
			(0.00543)	(0.00953)	(0.00555)	(0.00998)
Constant	-0.0384**	-0.0384	-0.0526***	-0.0526**	-0.0409***	-0.0409
	(0.0154)	(0.0248)	(0.0152)	(0.0231)	(0.0157)	(0.0249)
Observations	9,556	9,556	9,556	9,556	9,556	9,556
R-squared	0.070	0.070	0.069	0.069	0.070	0.070

*** p<0.01, ** p<0.05, * p<0.1