Coal-lapse?
The Impacts of Coal Generation Retirements on Employment, Prices, and Communities

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c. Tom Hansell, *After Coal* (2016)

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Abstract

Low natural gas prices, better environmental regulations, and the growth of renewables and energy efficiency have led to retirements of coal power generation units that have supported local jobs and communities for decades. Headlines and congressional testimonies have spun power plant closures into narratives of lost jobs and unaffordable energy prices. This research explores these claims, particularly on employment, using the propensity score matching technique. Surprisingly, this thesis finds that closing coal power plants has not contributed to higher unemployment rates locally. The results of this research strengthens support for the role of citizens, organizations, and businesses at the early stages of electricity decarbonization. Through a combined effort, coalitions have helped to ease the shock of coal closures in certain areas, though more attention, strategic local governance, and coalition building will be necessary in the years to come.

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Introduction

There is a pressing need to decarbonize electricity systems in order to avoid the most devastating impacts and fat-tail risks of climate change. On December 12, 2015, 195 countries in attendance of the 21st United Nations Framework on Climate Change (UNFCC) Conference of Parties (COP) adopted the Paris Agreement, in which they agreed to hold the increase in global average temperatures to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C in order to significantly reduce the risks and impacts of anthropogenic climate change (UNFCCC 2015). With peak warming targets [soon to be] ratified in international law, efforts to limit peak warming have become a global goal, and thus efforts must focus on limiting the cumulative emissions of carbon dioxide into the atmosphere (Allen et al. 2009, Allen 2015). Fossil fuel burning is and has been the primary source of emissions to date, and half of the cumulative emissions of carbon released from the consumption of fossil fuels has occurred since the 1980s (IPCC 2013, Boden et al. 2015). All projected pathways to 2 °C or 1.5 °C will require a significant acceleration of efforts to reduce emissions, and eventually will require the decarbonization of the global electricity sector (Solomon and Kirshna 2011, Fay et al. 2015). [1]

Decarbonizing the electricity sector will require a phasing out of fossil fuel generation. Without the stranding of future fossil fuel assets or significant investment in carbon capture and storage, power generation plants built as soon as 2017 will fulfill the capital stock requirements that, if operating to or beyond their average lifetime of forty years, will push cumulative emissions beyond 2 °C (Pfieffer et al. 2016). Reserves of fossil fuels are far greater than the available carbon budget to remain below 2 °C, suggesting that many power generation assets will become "stranded;" recent research suggests that

[1] Particularly as the transport sector and potentially the heating sector move toward electrification.

over 80% of current coal reserves should go unused between 2015 and 2050 to avoid exceeding the carbon budget (CT 2013, McGlade and Ekins 2015).

Coal power will see the greatest reductions first. In 2011, 46% of carbon dioxide emissions from fossil fuel combustion came from the burning of coal for power generation (IEA 2015a). Coal has a high emissions intensity relative to its energy output, significant negative environmental side effects such as air and water pollution, and is a stationary power generation source with available and affordable substitutes (Michielsen 2012, Sachs and Tubiana 2014). As opposed to other first-mover options for reducing emissions that, while necessary, may have unintended consequences (such as Jevon's Paradox in energy efficiency), there can be a high degree of precision in linking the closing of coal power plants with emissions reductions (Collier and Venables 2014), particularly with the expanding rate of technology development for both shale gas and renewables, substitutes who are realizing significant cost reductions (van der Ploeg 2016).

However, the world is not currently on a 2° C pathway. IEA modeling predicts an emissions plateau in the electricity sector by 2030, but does not precut the meaningful emissions reduction necessary to reach a 2° C world (IEA 2015b). Emissions from coal have risen 69% since 2000 and approximately 30% of current global energy consumption comes from coal (BP 2015). Coal demand growth has offset any emissions reductions from falling oil use and the growth of renewables, and this demand growth will continue with the growth of China, India, Indonesia, and South Africa. To wit, the capacity planned in China and India alone may, if run for forty years, exceed emissions beyond 2 °C (Arezki and Bogmans 2016, NCE 2014).

In the United States, coal power is on the decline. Since 2010, 185 coal-fired electricity generation facilities—402 steam generation units representing over 60GW—have fully or partially closed throughout the country. This has been credited to three main drivers: (1)

increasing competitiveness from natural gas and renewable substitutes, (2) strong environmental policy implemented through the Clean Air Act (such as the electricity industry's response to the EPA's Mercury and Air Toxics Standards) and the forthcoming Clean Power Plan (CPP) to capture the true costs of emissions (3) stagnant electricity demand from gains in energy efficiency (EIA 2016a, 2016b). Additional pressures come from grassroots organizations driven by local concern over health and climate.[2] While the drivers are well known, each closure has arisen from a unique combination of these influences, all of which have grown over time to compliment one and other (Pratson et al. 2013; Kohl, 2016, pers. comm., 13 July).

Climate Action and Coal: Moral and Economic Incentives

For global action on emissions reductions, nations including the United States will need to lead by example. Climate politics, as a collective action problem, requires a degree of moral pressure to build momentum towards action. In the closing of coal power, Collier and Venables (2014) propose the sequential closing of coal production to effectively harness moral pressure, framed on an aggregation of the three driving narratives for action on climate change—action from those who can pay (income), action from those who are emitting egregiously today (current emissions), and action from those who are primarily responsible overall (cumulative emissions). Separately, these narratives can compete with each other, but, when combined, a lead group for first action emerges of Australia, Germany, and the United States, followed by Russia, Poland, China, South Africa, Indonesia and India. While bilateral agreements such as the USA-China joint climate agreement may suggest other pathways toward reductions in coal-based emissions, analysis of the policy commitments again tends to argue that lead action is expected and necessary from the United States (Carafa 2015).

[2] Oftentimes, shutdown announcements solely blame regulations, when a suite of economic factors in fact drives closures.

Such leadership is now a financial reality as well: it is simply smart investing to not build more coal generation facilities. In 2015 only 3 megawatts (MW) of coal was added to the grid, in comparison to 8.186 GW of wind power and 5.952 GW of natural gas (FERC 2015). As the price of renewables continues to decrease, natural gas prices remain low in the short run, and energy efficiency investments offset growth in energy demand, it is clear that coal power plants will only continue on their trend of becoming increasingly uneconomic (Sanzillo 2015). Of the current pipeline of fossil fuel projects and overall coal industry value, over $28 billion is likely to become "stranded assets," and that number may balloon to over $400 billion across the fossil industry as price distortions and particularly high coal subsidies disappear (Caldecott et al. 2015, van der Ploeg 2016, Stefanski 2015).

As coal fades from the generation portfolios of utilities and investment portfolios of companies in the United States, there are consequences that require attention to ensure that communities that have provided the power for post war economic growth in the United States are not left as stranded as coal generation assets. To make informed decisions to support these communities, policymakers need to understand where specific attention is needed amongst the sometimes conflicting narratives of lost jobs, rising energy prices, and reduced tax revenue that accompany the retiring of coal power plants.

Research Questions, Aims, and Motivation

Yes, the United States is a country that should and will lead on decarbonizing their electricity sector, and yes, this will begin with a significant contraction of the coal industry. However, there are citizens employed in these sectors that stand to lose jobs and income from the shuttering of a shuddering industry. While Collier and Venables' first-mover moral imperative is true, few of the people suffering from the contracting economies in rural West Virginia or Kentucky have a direct, human connection to those

suffering from the increasing frequency and intensity of storms and flooding, driven by sea level rise and often with increasing likelihood due to climate change. Stories from half a world away (see Franta 2016) do not resonate with lost jobs, lost income, and declining communities, particularly when some policymakers in the United States stress that being a first mover in emissions reduction is a costly effort with little impact on lowering worldwide emissions (see Inhofe qtd in EPW 2015). Through the congressional hearings on the impacts of the Clean Power Plan (CPP)—the strongest legislation so far for achieving the emissions reduction targets put forth by the United States in its landmark agreement on emissions reduction with China and in its Intended Nationally Determined Contribution (INDC) for the Paris COP—it is clear that jobs, local incomes, and local communities take priority for many policymakers before climate change, echoing Smil's (2010) emphasis that, when considering climate change, one must always think locally and skeptically.

The fear of lost jobs resonates in the halls of Congress. Both the House Subcommittee Chairman on Energy and Power and the Senate Majority Leader conjure "a dim future where Americans will be paying more" and suffering "more job losses and higher electricity prices" with "deeply regressive regulations that would eliminate good jobs, punish the poor, and make it harder…to put food on the table" (Whitfield 2012, McConnell qtd in Page 2015). James Inhofe, chairman of the Senate Committee on Environment and Public Works and self-affirmed 'climate denier,' has bemoaned the strain on the grid and the rising electricity rates as a result of regulation, and some power producers have echoed similar concerns (Crawford 2016). The integration of policy on energy and the environment—and its potential for effective cooperative federalism—has been bumpy, with a surprising Supreme Court stay on the CPP (Engel 2015, Powell 2016). On a state-level, politics dominates the debate between energy, climate, and the environment, with some utilities and public commissioners in clear support of the ability to reconcile emission reductions and economic growth while others paint it as a pure trade-off (EPW 2015). This political disagreement has stalled efforts considered more

economically efficient, such as a carbon tax or the cap-and-trade system proposed by the Waxman-Markey legislation that failed to pass through Congress, and led to emission reduction policy driven by the regulation of power plant emissions through the US Environmental Protection Agency (EPA) and its enforcement of the Clean Air Act (C2ES 2009).

The uniformity of such fears, however, should also be viewed with skepticism, and may not be in the best interest of coal generation employees. If fossil fuel employees are taken care of, through either compensation or the stimulation of alternative employment opportunities, they will not necessarily oppose climate policy (Tvinnereim and Ivarsflaten 2016). That is, these people are not opposed to addressing and mitigating the effects climate change, they are simply keen to see that their communities are economically supported in the transition. Such research suggest that more entrenched establishment and industry positions against climate regulation are not properly addressing the needs of communities in adapting changing economic and political paradigms, and are in fact stranding them without the funding to pursue new opportunities (Byrd 2010). Capturing this ethos, Evans and Phelan (2016) argue that the "spontaneous consent" given by the masses to the "dominant fundamental group" of energy production for the progression of social life has eroded to the growth of alternative social identities that have gained permanent footholds in policy and communities and are becoming increasingly economic to realize.

The fears of coal industry workers are not without merit, and the perceptions generated from coal's decline have political consequences (Walsh 2016). Issues of equity and justice, both domestic and abroad, must be considered in the process of decarbonizing electricity, particularly for those whose livelihoods are affected by and dependent on a fossil fuel economy. This will ensure that decarbonization strategies do not follow patterns of "exploitation and dispossession"—such thinking is foundational to 'just transition' theory and its application for shared responsibility in supporting exposed

workers (Newell and Mulvaney 2012, Stevis and Felli 2015). Nevertheless, it is important to distinguish the difference between the noise of politicians and the reality of the current predicament of coal generation and the impacts of coal plant closure on employees and communities.

How can we better understand the impacts of coal power plant closures on jobs, changing electricity prices, and shifting tax bases? This thesis aims to address this multi-faceted, complex question by quantifying and examining the impacts of closures on communities through measures of employment, energy prices, and lost tax revenue, and hopes to delineate pathways forward for the just management of the transition away from coal power in the United States through economic opportunity and community support.

The dissertation will answer the following questions:

1. *What have the effects been of closing a large amount of coal power in the United States?*
2. *How has this closure impacted employment in local communities?*
3. *Have there been dramatic impacts on local electricity prices or the local tax revenue because of closures?*
4. *What other key factors must be considered when considering how to best support the transition of these communities?*

To address these questions, this research will first analyze the current impacts of coal closure on unemployment, electricity prices, and local tax bases. It will then identify trends to help identify particularly vulnerable communities and review efforts to date at helping on such community transition from a heavy reliance on the coal industry. Finally, this research aims to draw holistic conclusions on the trajectory of coal closure in the United States, address the implications for coal closure in other countries, and identify some areas of further research beyond the scope of this thesis but imperative for

understanding transitional justice and decarbonization pathways and the role good policy can plan in achieving them.

While not addressed extensively in this thesis, it is worth noting the clarity of literature on the negative local health impacts of coal power plants, a significant component of the Beyond Coal Campaign and grassroots efforts to close coal power. The scientific community has reached uniform consensus on the negative impacts of air pollution from coal power on the health of nearby communities. This includes the increased prevalence and hospitalizations from asthmas, as well as negative impacts on language, attention, and memory in infants (see, for example, ALA 2011, Burt et al. 2013, CATF 2010, EDF 2011, Grandjean et al. 1997, Lockwood 2012, Lockwood et al. 2009). Similar work captures the negative effects of localized water pollution (Broto et al. 2007, EPA 2015, Meij and Winkel 2007, Popovic and Djordjevic 2001, Sabbioni et al. 1984).

Plan of the Dissertation

This thesis will progress as follows: first, a review of the literature on closing coal in the United States—particularly how coal closures affect employment and prices—will lay the framework for the subsequent evidence and analysis. The following methodology section will discuss the two options—macro-level econometrics and individual case studies—available to better understand the relationships between employment, energy prices and closing coal, and will provide a justification for the methodology chosen. The Results section will discuss the findings of the analysis, and bring in preliminary analysis on electricity price and taxes to provide a macro picture of coal in the PJM interconnection's wholesale and capacity markets. To complement this analysis, a case study will be presented. The Discussion section will compare the econometric findings to previous results and the case study and then will consider the broader implications of this thesis' surprising results on current policies guiding coal closure in the United States and how it

may contribute to the dialogue around this process, including a suggestion of future research programs in the area. The Conclusion will synthesized the finding of the thesis, including a discussion regarding some of the limitations of the methodology, and future research will consider how to progress this body of knowledge forward.

Literature Review

Closing Coal

While dispersed, a growing body of literature is researching the decline of coal power on the electricity grid, and the relative merits of active or potential policy instruments. Most climate policies that will lead to large-scale coal emissions reduction, including carbon taxes, emissions trading, and renewable energy subsidies, are complemented by a low risk of the green paradox among coal suppliers (Michielsen 2012). Harstad (2012) argues for a coalition to buy foreign coal deposits and hold them: part of the growing literature on coalition-building for climate impact (such as in Nordhaus 2016). Yet the moral implications of this process may be hegemonic, regressive, and colonialist in a way that may undermine its plausibility, and would need significant reforms in international trade law as well if it was to be considered a viable option (Collier and Venables 2014).

The narrative pushing against emissions standards and increased emissions regulations is a simple one. The simplified economic story is as follows: emissions regulations will increase the costs of generating electricity; coal plants will need to choose between a costly retrofit or retirement because they can no longer compete economically with internalized externalities of pollution. With capacity offline, supply is reduced and prices go up, increasing costs to employers, particularly those in manufacturing and industry. With higher energy bills, employers will cut jobs, leading to unemployment. Higher energy bills for individuals will comparatively lead to reduced household spending in the

economy (Bivens 2015). The decommissioning of power plants would thus result in lost jobs (1) at the power plant, (2) upstream at the mines supplying coal to the power plant, and (3) in the communities supported by these industries along the supply chain. Particularly, this pathway would disproportionately harm those at the lower income brackets who have less ability to respond to price changes and thus must spend more of their after tax income on energy bills (for example see Trisko qtd. in EPW 2015). In summary, the four consistent arguments are: (1) lost jobs, (2) rising electricity prices, (3) a "strained" grid, and (4) abandoned communities that have contributed to the unprecedented growth of the United States economy in the late 20th century.[3] These will be key themes that this thesis will unpack.

Coal Power Generation, Employment, and Energy Prices

The literature reveals a complex relationship reduced coal power capacity, employment, energy prices. Studies across the electricity generation sector tell a story of overall job growth—growth driven by investments in available substitutes: energy efficiency and low cost natural gas, wind, and solar that decrease energy prices and stimulate employment (Knight et al. 2015, Clift 2015). Barker et al. (2016) found that closing inefficient coal power plants led to a 1% increase in net employment in the US to 2020 through substitution. Harer and Pratson (2015) similarly found that the net job losses in the US electricity sector between 2008-2012 were more than offset by rising employment in the natural gas, solar, and wind sectors; they also found a strong upswing over the period of their analysis in indirect jobs. They captured this by reviewing the literature to quantify the direct-jobs-per-sector, which favored of wind (3:1), natural gas (3.1:1) solar (~10:1) over coal (1.9:1).[4] Specific studies on reduced coal power through EPA CPP

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[3] The most thorough analysis of system failure due to lost coal capacity comes form Aylott et al. (2015), who find that generation failures more often come from online plants failing than from planned plant removals.

[4] It is worth noting that many of the job estimates in the literature come with caveats regarding the nuances in estimating them, particularly regarding indirect jobs (Lambert and Silva 2012).

regulation (Bivens 2015, IEc 2015, EPA 2015) project a net job growth, though contingent on natural gas prices and the development of renewables.

The literature on energy prices and closing coal is more opaque, and there are no clear conclusions in the literature about the impact of removing coal on prices. Many, like Bivens (2015), project the future impact of regulations. On the PJM interconnection, Aydin et al. (2013) argue that with coal retirement prices will increase by $9-11/MWh, though their analysis assumes an increase natural gas prices which have so far remained low and full natural gas replacement over increased energy efficiency, demand response, or renewable capacity, which also has not been the case. While the retroactive analysis of Cox et al. (2014) found that higher electricity prices did lead to both output reductions and lower labor demands in Germany, they did not solely contribute price increases to coal power plant closures. Bedeck and Wendling (2012) specifically argue that every 1% decrease in coal-generated electricity puts 24,000 to 26,000 jobs at risk, but they leave no argument for supply substitution and their paper appears to be heavily politicized.

Nevertheless, studies show that job growth within the electricity sector rarely overlapped into areas strongly impacted by coals contraction. Both Bivens (2015) and Harer and Pratson (2015) found a disproportionate exposure to job displacement within poorer counties and states that will need the most support in transitions.[5] There is clear evidence that the volume of coal power plant closures since the mid-2000s has led to job losses, estimated around be about 50,000 jobs: this was offset, according to Harer and Pratson, by the addition of 125,000 jobs in natural gas, solar, and wind generation.[6] Labor mobility within the energy sector as a whole suggests a small impact on employment is possible as well, as shown in the rapidly declining coal mining industry. Aragon et al. (2015) find rapid labor re-allocation with decreasing labor participation rates but not

[5] They additionally emphasize the lack of studies of job changes across the electricity generation supply chain.

[6] Though the DOE notes that the largest job losses in the electricity generation sector since 2010 were predominately driven by nuclear power station shutdowns (Martinson 2015).

unemployment rates in coal mining, a sector with similar demographics of high salaries comparative to education levels.

Like in coal mining, the narrative of coal power plant closures in the public domain is dominated by lost jobs, and not the opportunities for towns and communities to transition through a scenario where people may change jobs or retire, but unemployment does not grow. US government support of job transitions from previously important industries has been mixed. A study of defense sector workers in the wake of the Cold War through programs such as the Defense Reinvestment and Conversion Initiative found that most people ended up at jobs that paid them less and underutilized their skills (Powers and Markusen 1999). More recent programs, however, have fared better. The Department of Energy's Worker and Community Transition Program, designed to mitigate the impacts of nuclear decommissioning on communities with a significant reliance on nuclear plants, has had favorable results (Pollin and Calacci 2016). In the thirteen communities the program supported, it performed well in job creation and support for economic growth, though analysis of the program identified a the lack of basic regional development and industrial diversification as key barriers moving forward (Kirsehnberg et al. 2000). In 2004, the US government established the Tobacco Transition Payment Program to distribute $9.6 billion to help US tobacco farmers transition from an economic reliance on a product causing national health risk to a cleaner crop (Hertsgaard 2015). The similarities between the problems these programs address and the dynamics of the coal industry—closed generation facilitates away from a health risk that requires job creation, economic sustainability—are clear.

The PJM Interconnection

One area of the United States that has experienced a high volume of coal power generation closure has been across the PJM interconnection. PJM is the Regional

Transmission Organization (RTO) that coordinates in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia, in total serving over 61 million people with 171.648 GW of capacity (PJM 2016a). There are seven RTOs and ISOs (Independent Service Operators, who only operate in one state) operating bulk electric power systems in the United States (additionally are the California ISO, Electric Reliability Council of Texas, Southwest Power Pool, New York ISO, Midwest ISO, and ISO New England) which combined manage about 60% of power supplied to load-servicing entities in the United States—the remaining 40% is managed by either individual utilities or utility holding companies (EIA 2011). The benefit of focusing on one ISO such as PJM is that it provides consistent data on electricity pricing where prices will be affected in the same manner for every power plant that goes online —differently structured market mechanisms could lead to a more muddled results. Further, PJM operates both an electricity market for real time and day-ahead prices and a capacity market, where capacity requirements (including demand response and energy efficiency) are auctioned three years ahead to ensure stability of supply at a target level.

Almost half of the coal capacity retirements in the US between 2009 to 2013 came on the PJM interconnection (totaling 10 GW)—since 2003, 31.301 GW of primarily fossil fuel capacity has come offline, and a dominant amount of that since 2010, driven by coal power plant retirements (PJM 2016b). Looking forward, PJM has over 12 GW of coal power scheduled to come offline by 2020, mostly attributed to EPA's Mercury Air and Toxics Standards (MATS) as well as the Regional Haze plan but also likely dependent the large amount of low-cost natural gas connecting to the market (CoalAge 2014, Copeland 2012). The size of the PJM market, the large number of coal power taken offline recently, and the existence of a capacity market, a planning mechanism to ensure available capacity, make PJM an attractive sample space to investigate coal closure.

Thesis Statement and Explanation

This thesis seeks to identify the impacts of the closure of coal-fired power plants in the United States, specifically within in the PJM RTO, on unemployment rates and electricity prices. This framework captures many questions: Now that there has been a significant amount of coal capacity brought offline since 2010, what has happened in markets, starting with PJM's? Have counties been able to work with electricity companies and the federal government to protect and support workers through these closures as they either move within companies, retire, or find jobs elsewhere? Have interconnections such as PJM been able to handle the loss of coal generation without significantly detrimental price spikes –particularly sustained ones that impact low income individuals closer to the poverty line— or power failures?

Methodology

There are two different though complementary ways to approach and understand of the impacts of a coal power plant's closing on communities: through a statistical analysis of the macroeconomic effects of this across a wide range of places, or through the development and analysis of in-depth case studies in specific areas. While there has been a significant amount of macroeconomic analysis conducted around the impacts of specific regulations that close coal power (see, for example, Bedeck and Wendling 2012, Fell and Kaffine 2014, IEc 2015, Linn et al. 2014, Rahimani et al. 2016), much of it has focused on the impacts of future regulations, such as the Clean Power Plan (Bivens 2015) and much less analysis has looked at the retroactive impact of the closure of coal power plants and what those impacts have been.

There is a strong argument to focus on case studies, as many coal power plants are closed on an individual basis. To organizations such as the Sierra Club, closing coal is a one-plant-at-a-time process, as each unique local circumstance offers different community

strengths and holds different community interests regarding how a coal power plant should be closed (Shaw, 2016, pers. comm., 3 August). The bottom-heavy design of the Sierra Club's Beyond Coal Campaign (BCC) places much of the skills and capacity at the ground level, where local interests synergize with broader theory from the top. This would give value to a deep look into individual case studies where coal power plants have closed and towns have worked to find solutions around employment and lost tax revenue.

Such case studies would provide examples of how communities can sustain a power plant closure and transition forward; however, they would not serve to make the broader argument that this thesis is interested in engaging in—whether coal closures over large areas have had significant negative impacts on employment, prices, and tax revenues. Work to capture individual power plants is important to inform communities and politicians beyond brief newspaper reports of closings that signal lost jobs and lost ways of life—stories not uncommon in the political space, where one relatable instance can grab a headline and drive the overall narrative. They may show both the economic realities and opportunities to move beyond generation station closings.

There are limitations to case studies as well. While a richness of depth can be achieved with a case study, a similar analysis could show how efforts failed and a specific community was left behind. Here, an individual case study here would not specifically answer the research question with a mind to informing policy makers about the overall impacts *so far* of coal power plant closings across a larger economic space. Different counties, states, companies, and institutions, may follow different pathways to mitigate the effects of power plant closures on labor markets, and while it is important to capture and learn from such actions, it is equally important to understand if, combined, these actions are contributing to a blanket of support that has perhaps prevented any significant unemployment impacts from closed coal power plants. Understanding where such

coalitions have succeeded, but also where they have not, and why, will be an important future addition to research.

For this thesis, I estimate fixed effects and propensity score matching models to study how coal closures affect one macroeconomic variable—the unemployment rate—in the PJM interconnection territory. This will be complemented by an analysis of PJM's electricity and capacity price trends and a comparative analysis of these results with a case study on one particular closed power station. Complementarity between macroeconomic analysis and case studies are beneficial to provide complementary analysis and balance the two narratives of trends in the electricity sector and individual lives.

Data

The data used in the analysis comes from multiple sources. For retired coal power plants, data was taken from the EIA list of retired coal power plants, which is sourced from EIA-860 survey data (covering up to 2014) and combined with the preliminary EIA 860A form for 2015 and an aggregation of the 2016 EIA-923 monthly reports (EIA 2016d, EIA 2016a, EIA 2016e). These forms exclude power plants with capacity less than 1 MW. This data was then compared to and complimented by the active list of power plants retired in use by and provided by the Sierra Club.[7] To identify power plants supplying the PJM interconnection, electricity generators that supplied electricity to PJM were cross-referenced with EIA utility owners with the PJM membership list, which captures companies that have signed an Operating Agreement with PJM. These members are broken down into "Generation Owners" who own or lease a capacity or energy-only resource that has cleared a capacity auction or "Other Suppliers" who engage in buying, selling, or transmitting electricity or capacity and does not qualify for "Generation

[7] Privately provided, available upon request.

Owner;" finally, some companies fall under "Affiliate Members" if they are a member of a family of companies all affiliated with PJM (PJM 2016d).

Generators less than 50 MW and those that came offline prior to 2010 were removed. Generators less than 50 MW were removed because they were primarily localized generators for large factories that either did not appear on the PJM interconnection or provided power to the connection very infrequently. Additionally, none of the smaller units were part of larger plants that had other, significantly sized units retired. As this study was concentrated on the PJM interconnection, the final step was to cross referenced this list with the PJM official decommissioning list, so as to eliminate plants that were not active and were decommissioned—for example, the JK Smith Power Plant in Kentucky and the Perryman Steam Plant from Maryland were included in the EIA database, but they were in fact cancelled projects that never produced electricity and never employed any permanent employees.

Additional data sources, including control variables used in propensity score matching and capacity and wholesale electricity pricing data, are cited when addressed. Figure 1 below captures the summary statistics for variables. See Table 2 in Appendix for a list of variables, descriptions, stata names, and sources.

Variable	Obs	Mean	Std. Dev.	Min	Max
lf	4596	52406.75	131692.9	286	2671615
population	4596	105234.2	257875.5	2138	5248704
construction	3427	184524.6	512016.6	1019	9898613
farmearnings	3715	24260.85	37966.46	-13012	561032
gasoilextr~n	14361	1166.474	22861.97	0	1456472
manufactur~g	3472	380651.1	933386.9	455	1.65e+07
TotalMWLost	508	82.98327	230.6119	0	1710
MWOffline	4599	.0104371	.1016384	0	1
uer	4596	8.211314	2.482409	2.8	23.5
pci	3830	35864.17	8500.765	17613	87662
povr	13588	17.02666	6.464919	2.9	55.1

Figure 1: Summary Statistics for Variables

Fixed Effects

Fixed Effects regressions help as an initial step to understand whether there is a correlation between two variables and to justify further analysis. For this thesis, that question is whether or not employment variation can be explained to some extent by coal plant closures. For two variables studied here, the loss of coal generation megawatts was compared to changing unemployment rates in the years after megawatts were taken offline. The regression being run is:

Where represents the dependent variable (the unemployment rate) observed for an individual *i* (the specific county) at time *t* (the year), is the time-variant regressor matrix, is the unobserved time-invariant individual effect (the removal of MW capacity, and is the error term, which captures the deviations of the dependent variable observations from this function. Fixed effects regressions are used to exploit within-group (in this case,

within-county) variation over time, with an underlying assumption that unobservable factors, which may affect either unemployment or coal unit closures, are time-invariant.

Previous studies that modeled employment changes were reviewed for the determination of control variables. For this study, the selected covariates included county demographics that help determine labor demand including per capita income, population, labor force size, and poverty rate (Deller et al. 2001). Also captured were labor force demographics including farm earnings (as a proxy for the size of the farm labor force) and the construction and manufacturing sector, both which capture the number of establishments primarily engaged in these relative activities (Brown 2014).

Harer and Pratson (2015) as well as Fell and Kaffine (2014), argued that, because of labor force substitution in the electricity generation sector, it is important to include controls to serve as proxies for the size of the natural gas sector (where most jobs go) and the electricity sector overall (to capture the growth of renewables as well) which has significant labor mobility. Holladay and LaRiviere (2014) and Linn et al. (2014) found that low natural gas prices have had an influence on the output of coal power plants, and to capture this natural gas extraction is captured as well—while this metric captures both oil and gas extraction, these numbers are dominated by gas extraction within the states being analyzed. As natural gas prices fall, extraction of natural gas will increase, and labor in natural gas development will be more closely tied to the amount extracted than the price. Data was compiled from the US Census data on small area income and poverty estimates (annual poverty rate) and the Bureau of Labor Statistics Quarterly Census of Employment and Wages (for employment in electricity sector generation, natural gas generation, wind generation, and fossil fuel generation, as well as data on farm income, manufacturing, construction, and oil and gas extrication).

To properly identify control years, the power plant database was collapsed by year for all megawatts offline to create only one unique event of mw-removed per year per county.

Between this process and applying the earlier constraints, the sizable database of power plants was reduced to 45 unique observable "MW-removed-from-county" events. As a fixed effects model only observes changes within respective counties over only five years, any correlation in such a small sample size would be most useful for justify further research, and not for drawing any significant conclusions. Reducing observations, while ensuring that they are correct and of sizable influence, does mean that there is a risk of having less certain results because of unobserved time-invariant cofounders is much more likely with a smaller sample size (Imai and Kim 2016).

In defining the treatment *MWOffline*, untreated counties were defined as a county with an active coal power plant that did not close, starting from the PJM 2010 EIA 411 data. After data cleaning, this form was merged with the existing dataset: this was done to remove power plants from cities in Virginia (which are considered separate counties, unlike in any other state), some repeated data that grossly over-reported the amount of megawatts from a plant, or adding power plants that should have existed on the 411 form and did not. This process did keep one set of data away—added capacity in coal since 2010. While further study would benefit from including this information, it was not publically accessible in a workable format on the PJM page. Similarly, in places where PJM reported a power plant closure between 2010 and 2015, but that plant did not match with the 2016 retired plant sheet also produced by PJM, I assumed that this power plant was the only one active in that county, if there were no other mentions of the county in the dataset.

Propensity Score Matching

While it is useful to assess the impacts within counties where power plants have closed, a more significant correlation may be found in the comparison between counties where coal generation has been closed to similar counties where coal has not closed. While the

Fixed Effects regression looks at the entire data set, a Propensity Score Matching test creates the illusion that there was a treated group (where MW of capacity were taken offline) and an untreated group (where there was MW of coal capacity but there were not taken offline). In essence, the idea is to sample from a large group of counties that have not had a treatment to the group to produce a control group with a similar distribution of covariates to the treatment group (Rosenbaum and Rubin 1983). By doing this, PSM creates a better counterfactual—actual counties, than a Fixed Effects model. Propensity Score Matching (PSM) is often used in labor market studies and is particularly useful when there is not random assignment and when a treatment or event is relatively rare, making many control samples incomparable (Caliendo and Kopeining 2005). In this analysis, both are true: while growing in commonality, there were still few year-MW retired observations, and they were deliberately planned closures, not random. For this study, the treatment will be a closure of megawatts at a coal power plant and the matching will be across two sets of counties: all counties, and counties that have installed coal capacity that does not close. This was done with a simple valuation of "1" for a closure of a greater than 50 MW unit (though they scale to over 1GW) and "0" if no power was closed during the time period in a county where there was installed capacity. While not all are supportive of the method proposed by Rosenbaum and Rubin (1983), particularly concerning the scaling of variables or restrictiveness of a caliper,[8] PSM remains actively used across many disciplines (King and Neilson 2016, Sianesi 2012).

Matching requires having a robust set of covariates, as the omission of important variables can greatly increase the bias of the produced estimates (Heckman, Ichimura, and Todd 1997). Nevertheless, it is also important to avoid adding too many parameters, as they may increase variance or worsen a support problem (Bryson, Dorsett, and Purdon 2002). Thus, a balance must be struck, though Rubin and Thomas (1996) emphasis the

[8] A caliper is a measure of closeness between a treatment observation and a matched propensity score—the maximum permitted difference between matched subjects. For further discussion, see Lunt (2013).

benefits of favoring inclusion to omission, and only omitting if there is agreement of a variable as either not a proper covariate or wholly unrelated.

There are two dominant techniques for selecting comparable counties, both of which are explored in this thesis. The *nearest-neighbor* method with more than one neighbor matches controls to a certain number of closest counties, and can be done with or without replacement, or whether or not an untreated observation can match with more than one treatment observation: including replacement increases the quality of matching but creates a risk because it may reduce the number of distinct counties without closed coal used in comparison with those who have lost coal capacity. Replacement will thus increase the estimator's variance but potentially reduce bias (Caliendo and Kopeining 2005, Smith and Todd 2005). Similarly, matching additional neighbors similarly may reduce matching quality (and increase bias) but allows for more information to be used to construct our counterfactual, thus decreasing variance (Smith 1997). Results were tested across multiple neighbors, although testing was done with only replacement.[9]

The other useful technique for this study is *caliper*. While nearest neighbor runs a risk of creating bad (but nearest) matches if the neighbor is far, a caliper implements a tolerance level on the distance of the propensity score, avoiding bad matches (decreasing bias) but similarly with the potential to allow for fewer matches (and increased variance); Smith and Todd (2005) also note that researchers often do not know the appropriate caliper rate to apply (Caliendo and Kopeining 2005). Results were tested across multiple calipers.

Results

[9] This was due to the limitations of the statistical program *teffects*, which only runs PSMs with replacement (see STATA 2016).

This section summarizes the results from the fixed effects and propensity score matching regressions. It will then proceed to an analysis of price changes across the PJM capacity and wholesale electricity markets. It will close with close with the consideration of a case study on the retired Huntley Power Plant in western New York.

Overview of Regression Analysis Results

The propensity score matching produced a statistically significant (at 1%) negative correlation of = ~-1 between the removal of coal MW capacity in a county and the county's unemployment rate; that is, counties with coal capacity brought offline saw a *decrease* in the unemployment rate relative to the controls. Combining this with the Fixed Effects result makes a strong argument that there is little evidence of a positive association between plant closure and unemployment to date on the PJM interconnection.

Fixed Effects

The fixed effects analysis looked at the counties with coal capacity and what the impact a loss of coal capacity would have on unemployment, using the controls described in the Appendix. Regressions were run both with only the events where coal capacity was taken offline and with all events in coal counties (or when the coal capacity taken offline was zero). For the former, the coefficient was -.122 (through not statistically significant); for the latter, the coefficient was -.0013 (statistically significant to 1%). The magnitude of these results suggest that impact of coal closures on unemployment rates is close to zero and statistically significant. Both regression results are available in the Appendix as FE1 & FE2.

Propensity Score Matching

After testing for balancing, a nearest-neighbor matching test was done, which uses the distances between covariate patterns to define the closest match. This analysis returned a coefficient estimate of -1.2 (statistically significant to 5%), suggesting a small negative effect on the unemployment rate from a removal of coal capacity in a county. Exact matching for counties was not possible due to a very large number of observations without exact matches. When the propensity score matching was run—generally viewed as preferable to nearest-neighbor matching because there is no need for a bias adjustment as matching is done on one continuous covariate, a similar result was found. Table 1 shows a series of propensity score matching results. Initial results with all controls were significant (ex. 1, 2, 3), but including *per capita income (pci)* as a control biased matching, as public data for 2015 was not available, significantly reducing the number of treated observations.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
PSM	1.201**	.688*	.963*	.890**	1.095**	.737**	.0772	.794**	.834**
	(.505)	(.285)	(.469)	(.281)	(.340)	(.273)	(.493)	(.289)	(.256)
Controls	x	x	x	x	x	x	x	x	x
PCI	x	x	x	x			x		
Manufacturing	x	x	x	x	x	x	x		
Construction	x	x	x	x	x	x			
Farm Income	x	x	x		x	x	x	x	x
NN	1	1	2	1	1	2	1	1	2
Caliper	-	-	-	-	0.35	-	-	-	-
Number of Observations	1,424	3,270	1,424	3,270	3,270	3,270	3,472	3,427	3,474
Controls exclusive of those below. * p<0.05; ** p<0.01									

Table 1: Main Estimates: Coal Closure on Unemployment

Running propensity score matching across all covariates except *pci* produced a statistically significant coefficient of -1.1, consistent with the previous nearest-neighbor

matching (ex. 4-ex. 6). Removing the additional least balanced covariates across matching tests (*farmincome* & *manufacturing*) provided a consistent result (ex. 4, 8-9).[10]

Tests were done across nearest neighbor values and calipers—though it is worth noting that some matches were far off enough that the PSM test could not be run at calipers less that ~.35. Ex.8 is included in the stable to show the impact of removing an important control for unemployment, *construction*.

Taking both the results from the fixed effects regression and the propensity score matching, while it may be debatable whether or not the effect is zero or negative, it is likely not a positive effect. These results suggest that there is not a positive relationship between unemployment and coal closure in the PJM territory over the time period studied here. If anything, the estimation results consistently indicate that here may be a small negative relationship, which is robust across fixed effect and PSM specifications. Further analysis would be insightful particularly regarding what is driving it—there are numerous potential explanations for these findings. For instance, it is possible that people are exiting the labor force altogether through retirement, or alternatively, they are quickly finding new jobs.

In many ways, these results are consistent with much of the qualitative review across the PJM interconnection of employment conducted. Of the 141 coal generating units closed since 2010, very few reported actual jobs lost; instead, almost all of them in press releases and news reports suggest that most employees transfer to other power plants within the company or retire with retirement packages, in some cases such as at the FirstEnergy Armstrong Power Station in Pennsylvania, with packages offered to those age fifty-five and above (Weaver 2012). See Table 1 in the Appendix for a full list of the power plants in PJM with public reports on job losses.

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[10] Full Stata regression outputs are available in the Appendix.

Most electricity companies have taken care of their employees. The prevailing narrative is that while some employees are indeed laid off, most at this point are able to be transferred within the company or, where appropriate, offered a retirement package. It has been the case so far that companies have been proactive in planning for retirements, including through support for retraining programs and by holding positions open at other power plants in anticipation of transfers (Martinson 2015). This is not surprising: utility companies have permanence in regions, and would not benefit in the long run from a poor reputation surrounding the support they provide their employees after a plant closure.

Electricity Prices

In assessing the impact of coal exit on electricity prices, it is evident that, due to a combination of low natural gas prices and an effective capacity market, there have been no long-term negative impacts on the cost of power for consumers. While some may argue that prices could have decreased more, their rate of decrease has more or less perfectly mirrored natural gas prices across the PJM interconnection.

This thesis will conduct a brief quantitative review and qualitative assessment and present initial conclusions. This will progress though a discussion of the role of electricity price suppression for analyzing the removal of capacity, the structure of the PJM electricity markets, and what the history of prices on the PJM interconnection and the what PJM's recent capacity market auctions suggest about how the removal of coal units is affecting electricity prices across the PJM interconnection.

Electricity Price Suppression

A pure analysis of the literature on whether electricity prices rise or fall with coal power plant closures requires a close consideration of the interactions between price effects of coal megawatts coming offline. If capacity is brought offline after it has been effectively priced out of electricity markets while being replaced by less expensive electricity supply, then there is a possibility that the expensive power plants were blocking cheaper capacity additions that were spurred by the coal plants' closing.

One important effect to consider is price suppression. Electricity price suppression occurs when low marginal cost resources (such as solar or wind, which have very little operating costs) displace electricity sources with higher marginal costs, such as coal. In doing this, the energy portion of the wholesale price of electricity, which may also include transmission costs, energy credits, capacity payments, emissions allowances, generation bid production guarantees, and ancillary services, is suppressed. As shown by Felder (2011), this effect tends to be larger during peak hours, and the consumer surplus created by this suppression effect is dependent on many factors, including price elasticity of demand, the demand rebound response due to the initial price reduction, and fluctuations in fuels costs and available supply. With capacity markets and other mechanisms in place to predictively incentivize investments, price suppression effects may further shrink.

Trends in the PJM electricity and capacity markets

Because ratepayers face the same bills, and thus poor people spend a large fraction of their after-tax income on electricity bills, electricity prices are most often regressive (Boardman 1991, Rentschler 2016). A major concern of politicians, economists, and researchers is ensuring that low cost electricity is delivered, especially to people in low-income communities. In the PJM market, costs of electricity are mostly captured in two markets: an electricity market and the capacity market. The electricity market is operated as a both a real time and day-ahead spot market where electricity is bought and sold for immediate delivery using locational marginal pricing; while it may have a uniform price,

more often than not local marginal pricing is higher in certain locations because of congestion.

The capacity market is a mechanism designed to prevent electricity supply shocks.[11] That is, having a capacity market should PJM's capacity market, the Reliability Pricing Model (RPM), is designed to ensure enough supply so that the frequency of having more demand than supply is no more than one in ten years. A capacity market identifies gaps in future capacity across the interconnection based on demand projections and auctions this capacity so as to incentivize the development of new generation, improved transmission, or even demand response or energy efficiency in those areas (Copeland 2012). The RPM operates on a three-year forward requirement, which provides a time window for new firms to plan to enter the market and also gives existing firms the time to make decisions about upgrading or retiring units. The RPM was implemented because the electricity market was failing to produce sufficient returns to encourage enough investment to meet PJM's desired reliability criteria, a common occurrence in liberalized energy markets (Boring 2013).

From 2008-2014, the spot electricity prices on the PJM interconnection closely mirrored the fluctuations of natural gas prices (see Figure 1), driven by the fact that natural gas often fueled the marginal unit on the PJM market which determines the price at that moment (Brown 2013).

[11] For a thorough analysis of capacity markets, see Cramton et al. 2013.

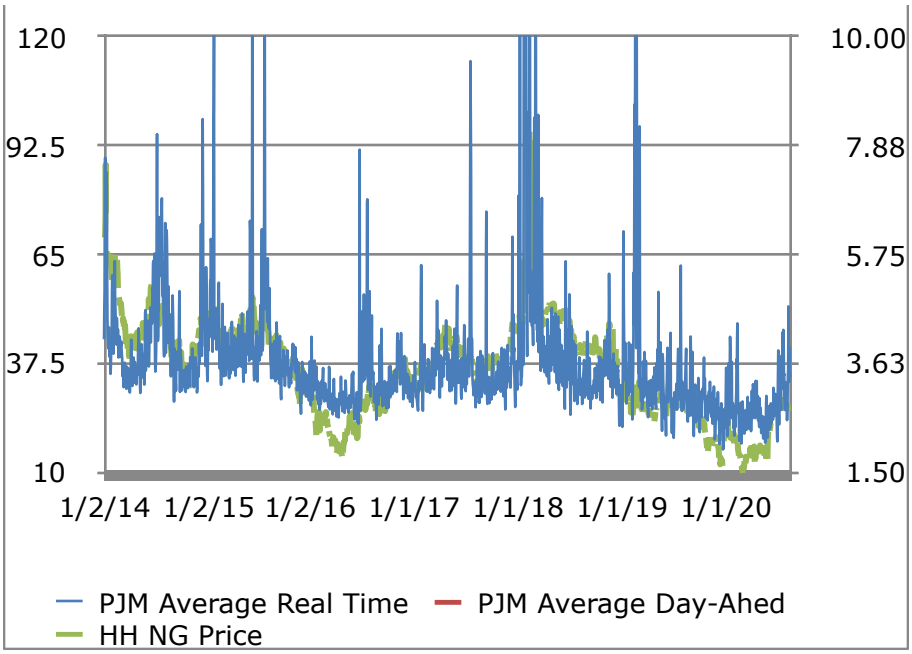

Figure 2: PJM Average Real Time Prices ($/MWh) and Hen Hub Natural Gas Spot Price (Dollars per Million Btc)

Source: EIA,PJM Datafinder

While at some points the price of gas has dropped below the price of electricity, investment to capture this has led to large amounts of gas coming online in the PJM interconnection, and prices then recovered to relative consistency again. The large spikes in prices came from the polar vortex energy systems in January 2014; however, this was due to both the unavailability of gas (36% of plants offline) and coal (17%) and reliability was primarily thanks to installed wind capacity (Paulos 2014). For example, since 2014, prices have follow the average trends shown in Figure 2.

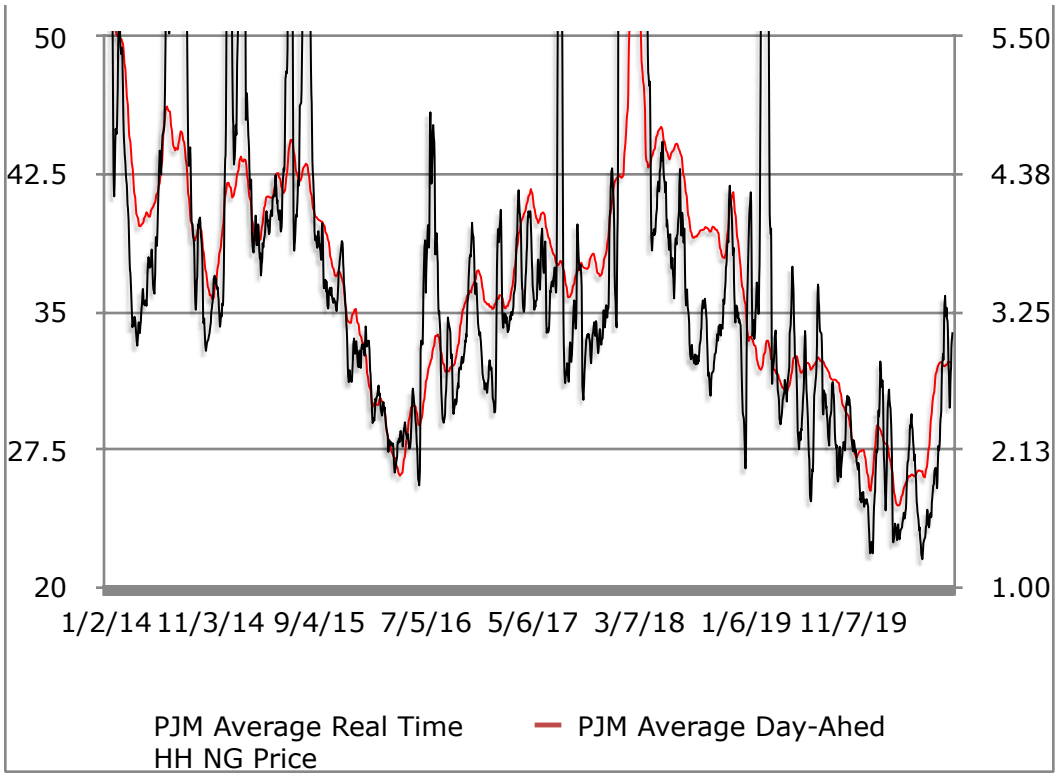

Figure 3: PJM 15-d Average Real Time Prices ($/MWh) and Hen Hub Natural Gas 15-d Spot Price (Dollars per Million Btc)

Source: EIA, PJM Datafinder

While there are significant coal resources coming off-line, suppressed demand, especially energy efficiency, has been complimented by increased natural gas investment to continue to allow gas prices to remain on the margin (as inefficient coal plants move above it).

In the capacity market, there is more gas, energy efficiency, and demand response as generation upgrades have fallen and demand response has stabilized. The significant uprate capacity additions are driven by gas-fired combusting turbine and combined cycle generation units (while a large number of MW of coal uprates happened in 2016/2017, there has been significant drop off since then) (PJM 2015, PJM 2016c). These trends are reflected in Table 2 below. Analysts note that one load delivery area with significantly higher prices in the capacity auction, ComEd in northern Illinois where the capacity auction price was nearly double the general RTO price ($202.77 vs $100.00) was not due

to coal power plant closures, but instead due to the economics of a pair of nuclear power plants (Paterno qtd in Lundin 2016, Newell et al. 2015)).

BRA Delivery Year	New Generation	Generation Updates	Imports	Demand Response	Energy Efficiency
2019/2020	5373.6	155.6	3875.9	10348	1515.1
2018/2019	2954.3	587.6	4687.9	11084.4	1246.5
2017/2018	5927.4	339.9	4525.5	10974.8	1338.9
2016/2017	4281.6	1181.3	7482.7	12408.1	1117.3
2015/2016	4898.9	447.4	3935.3	14832.8	922.5

Table 2: Megawatts of Unforced Capacity Procured by Type from PJM Capacity Auctions

Source: PJM 2016c

RTO rules implemented in 2014 to manage future cost spikes experiences during the aforementioned polar vortex sharply penalize capacity bids that are not able to guarantee power at any time during the year. The renewables industry has complained that this regulation is particularly anticompetitive for renewables and demand response, both of which were actually key power providers during the natural gas and coal shutdown (see AEMA 2014, RGC 2014). PJM disagreed with these objections (Pyper 2014); so far, the effects are unclear. While the most recent auction saw the largest solar bid so far, but both the solar and wind bids paled in comparison to natural gas, and neither renewable source cleared much capacity in the payment tier of the new performance rules (PJM 2016c). While coal is coming offline, the PJM grid is not on a fast path to decarbonization from fossil fuel generation assets.

Coal's removal so far has caused few problems on the PJM grid, and its continuation will not negatively affect prices or reliability. Luken et al. (2016) find that PJM could decrease their reserve margins by approximately the amount of coal capacity scheduled

for retirement (11 GW) and maintain adequate reliability levels, though it would be more exposed to the reliability risks of other power sources, including nuclear power shutdowns, gas generator reliability issues in the winter, and supply disruptions along natural gas pipelines. Others like Walawalker et al. (2008) and Sioshansi et al. (2009) have emphasized the opportunity for significant strong social welfare benefits on the PJM interconnection by focusing investment on progressive solutions such as energy storage and demand response, and Rahimani et al. (2016) noted that higher electricity prices from coal retirements could be offset by either transmission upgrades or wind penetration at high geographic diversity.

It is unclear from the data reviewed if a specific coal plant closure has had a sustained negative price effect for ratepayers. This will require additional analysis of the local marginal pricing in specific nodes of the PJM interconnection. So far, the current trend of low natural gas prices will overall keep ratepayer prices low, as PJM works to smooth high price spikes in time of extreme cold. Some options would include a similar macro-level analysis as conducted with unemployment, using electricity market modeling; alternatively, a case study analysis similar to that of Sanzillo (2016b) which looks at regional wholesale power prices, the change in retail power prices, compares available capacity to current peak demand periods, and notes the source of power from electricity imports to the region.

Case Study: Huntley Power Plant

It is useful to consider these results within the context of a case study. While not on the PJM interconnection, perhaps the most detailed work done in this space has been by the Institute for Energy Economics and Financial Analysis (IEEFA) around the Huntley Power Plant in western New York, which employed seventy-nine workers and paid over

$6 million in taxes to the area, including significant funding for its school districts.[12] After noticing a precipitous drop in pre-tax earnings at the power plant starting in 2005 driven by slowing demand from the recession, low natural gas prices, coals waning competitiveness, and increased energy efficiency, IEEFA began a campaign to inform the community and prepare it for what the institute saw as the writing on the wall for the financially viability and thus sustenance of the power plant (Kunkel et al. 2014) and capture the full tax implications across the community (Raimondo 2014).[13]

IEEFA's work highlighted the possibilities for organized communities to take ownership of their transition away from dependency on a coal generation station. When the plant's retirement was announced by the utility NRG in March 2015, IEEFA helped the community to implement a transition strategy, which required collaboration across the worker's unions, teachers union, and state legislators to direct state funding to support the school district, retrain workers, and help rejuvenate the local economy (Sanzillo 2015). IEEFA continued to analyze the impacts of the closure and showed that the plant's closing did not increase electricity rates in western New York. Further, there was no increase in coal fired power imports into the region that correlated with the decreasing use of Huntley in the years preceding its closure, or after it (Sanzillo 2016b). With IEEFA, a community of stakeholders built a roadmap for an economic transition that included school funding, worker protection, job creation, town redevelopment, the creation of a sustainable tax base, protection for electricity ratepayers, and improving the environment and public health (Newberry 2016). By harmonizing efforts across the local teachers association, labor federation, community members, and the AFL-CIO, the town was able to lobby for a bill in the New York state budget that will give state funding to support Tonawanda and similar communities facing coal power plant retirement.

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[12] A concern pressed by IEEFA.

[13] Similar research has been carried out for other plants as well (see Schlissel 2016a & 2016b).

Discussion

Combining the significant results of the economic analysis of employment—that closing coal units has not led to increased unemployment—and electricity prices—which have not seen any significant growth in the capacity or wholesale market as coal power has come offline—it becomes clear the closure of coal power on the PJM interconnection has overall not had lasting negative impacts.

PJM

With proper planning, companies have been able to manage transitions of employees and capacity markets have been able to manage transitions of power. For example, American Electric Power held positions open at other power plants in anticipation of needing to transfer employees from retired units, which is complemented by a number of employees who chose to retire themselves (Buschbaum 2016). While the closures of power plants require significant local, state, and national attention to support communities that have helped power much of the United States' growth and correlated increases in living standards, both statistical and qualitative analysis suggests that the closure of coal power generation units does not have a significant impact on the unemployment trends in the county where that unit resides.

While this thesis does not analyze the impacts of closure over a span of years, such analysis would likely not alter results. As power plants slowly contribute less and less to the grid, as in the case of Huntley, employment reductions may take place gradually over a number of years, and there is an argument to be made that this would shift or distribute the employment impacts. The closure of one unit in a power plant (as most have several) may have a similar impact. Of the closures studied here, early unit retirements led to a

high incidence of labor redistribution to other units within the company.[14] A longer time window over which employment would be reduced at a plant would in theory allow for employees to see the writing on the wall and plan better for impending layoffs or retirement, which would reduce the likelihood of a negative impacts on employment as they would be more prepared to reenter or leave the labor force.

Huntley

These results are complimented by the Huntley case. Huntley clearly shows that: (1) with active community engagement, transitions can be better managed and (2) coal power stations do play a role in supporting local economies through tax payments, and this requires particular attention. To study Huntley, Raimondo (2014) contacted the county budget office to obtain tax revenues from the power plant, although Raimondo is quick to note that through PILOT (payment in lieu of taxes) programs, the power plant has often paid significantly reduced tax rates (and at times zero property taxes). An assessment of the tax payments of coal power plants and how tax revenues of local governments have changed is an extensive research project on its own. Preliminary analysis across the PJM grid found significant concern about the large amounts of tax revenue lost, such as $1.1 million from the Kanawa Plant (Murphy 2014) or almost $7 million dollars reported to be lost from the closing of the Chesapeake Energy Center in Dominion, VA (Schapiro 2011). Other power plants are reported to pay less, such as the $500,000 for a coal plant in Hatfield's Ferry, VA, but there a reported $353,902 supported the local school district (Niedbala and Shrum, 2013).

While there are gaps in IEEFA's analysis,[15] it shows the potential for institutions to work with communities throughout the closing of a coal power plant. Future research of much

[14] A more distributed decrease in labor would also be difficult to measure in the small time window in which the analysis was conducted.

[15] Particularly Raimondo's sparse tax analysis.

greater depth, but following the path laid by Raimondo, should aim to determine both the amount of taxes paid by closing coal plants, what the taxes funded, and how counties managed this loss of revenue stream—which, in many cases, had already dwindled far from heyday profit levels—in both the short and long run. For example, the $1.1 million lost from Kanawa was offset by a transmission line upgrade that yielded more than $3 million in revenue that following year (Murphy 2014). Examples of investment planning at Kanawa will likely play a greater role in offsetting employment impacts as well, though there may not be direct labor substitution.

Implications

Combining the results from PJM and Huntley, there is a clear conclusion: so far, unemployment has not increased from coal power plant closures. In fact, it has marginally shrunk more in counties where coal plants have closed. This is an encouraging piece of news: the work by companies and governments to retrain, reemploy, or help workers retire has weathered the impacts of major employers in specific regions departing. As noted in the methodology section, a merging of a macro-level analysis across an interconnection with the richness of specific case studies captures a holistic picture of the transition away from coal that tells us that, while different organizations may take leadership in guiding workers and communities in a transition, the benefits of an electricity sector transition away from coal are not overshadowed by significant costs in terms of employment or prices.

On the PJM interconnection, it is clear that new generation is not being built exactly where old generation has been retired. While some, such as Louie and Pearce (2016), have argued that retraining programs toward the climate progressive end of the electricity generation workforce is economically feasible and would allow employees to maintain similar standards of living, most employees either retire or take other positions within the

company.[16] With an average age in the coal power generation industry of over 50 years old, there have been many retirements as well, and likely a large amount of worker attrition on its own in the coming decades (Buchsbaum 2016). It is also likely that many works have avoided retirement as fallout from the economic shocks caused by the 2008 financial collapse, which saw a nearly 30% decline in household wealth (Pollin and Callaci 2016).

For some, the fear of lost jobs and lost wages is justified. Within the PJM interconnection, West Virginia and Kentucky lost significant jobs in the coal sector, though in mining more than coal generation (Harer and Pratson 2015). At the same time, this is nothing new: the number of coal mining jobs has been falling for decades. Mountaintop mining jobs are now less than 1% of jobs in the Appalachian region (Perks 2015).[17] At the same time, over 27% of West Virginia's personal income arises from federal or state transfer payments, and one in five are on food stamps (Tumulty 2013, Parker 2012). 60% of households take home an average of less than $1,900 a month and spend over 15% of their after-tax income on electricity (Capito qtd in EPW 2015). Much of the labor identity in the Appalachian region is driven by coal's history of high wages and the corresponding economic growth of a natural resource boom. While this particular economy has long been shrinking, the reality of closed power plants and bankrupt mining companies is a recent and significant shock to the identity of the region (Walsh 2016).

Such demographics create the risk that workers in certain industries and their communities will be unceremoniously left behind, or nevertheless perceive that country's are leaving them behind. Similar work to Perks (2015) was conducted by Australian Bureau of Statistics, which found that in some areas peoples believe of the size of the coal industry's contribution the local economy was more than triple (Richardson and Denniss 2011). As captured by Sanzillo (2015), Evans and Phelan (2015) emphasize that

[16] See Table 1 in appendix.

[17] Although they do account for a higher percentage of wages.

marginalized communities must be engaged with and supported to keep them from aligning themselves with an industry that will eventually leave them due to greater economic factors.

Proper foresight, analysis, and community action makes a difference. With research to identify and address the funding gaps, local governments can begin to develop post-coal funding plans while short-term investments by energy companies—such as renewable power developments, energy efficiency investment projects, and transmission line upgrades—can provide a short-term funding buffer across a wide diversity of geographic space.

New policies are addressing this gap. Federal programs such as the proposed Secure Coal Community Schools program or Power Plus grants for economic projects to support communities struggling with the decline of the coal industry will also serve a role. With, for example, only 52,300 coal mining jobs remaining in the United States, providing support for these and coal generation families should not require unattainable federal investment, particularly considering the relative social cost of carbon they are generating per capita (BLS 2016). Where possible, cost efficiencies may be realized by training and transitioning younger power professionals to the clean technology, as opposed to the current turnover to mostly natural gas plants (Pollin and Callaci 2016). Other programs for funding include the EPA's Brownfields program, the Department of Labor's Dislocated Workers National Reserve, and the Appalachia Regional Commission (Buschbaum 2016). In more prosperous states like New York, the Huntley challenge is not daunting to all: "ten million dollars a year to keep the schools open, that nothing" relative to New Yorks $5 billion budget surplus claims Sanzillo, a former comptroller of New York State, "if you give yourself two or three years to make these transitions, nobody has to get hurt" (qtd in Hertsgaard 2015).

Future Research

Of the three areas under study in this thesis, the least amount of literature exists on the impacts of coal closure on local tax bases. More work is needed to understand the opportunities to address state and local funding gaps. It is most likely that the most significant negative impact on local communities would come from the loss of a potentially significant tax base, particularly in smaller communities and in states without large economies to redistribute budget surpluses. More case studies could further promote a positive narrative around just transitions. If work similar to IEEFA's empowerment of the community in Tonawanda proliferated across the PJM interconnection, the likelihood of a clearly defined answer to this thesis' question, supported by a growing body of case studies, would surely increase.

Further research in the economic and price analysis would also be useful. This would include building the employment analysis across multiple ISOs and interconnections, as well as deepening its quality with additional information, such as more controls, perhaps a longer time frame, and data tweaks such as controlling for the relative amount of megawatts close or including added capacity in coal since 2010. Research would also benefit from understanding the lead and lag effects of employment as power plants being to contribute less and less to the grid, a strong signal for impending retirement as was noticeable at Huntley. More work on how to smooth the spikes in winter-time electricity prices would smooth any regressive price impacts; while with limited data points and without extensive analysis, it would be preemptive to assign any significant causality between coal power closure and price spikes. Finally, it is important to track the growth of these impacts, which may shift as more capacity comes off line. The power plants that have been shut down so far are overwhelmingly old, and because they are the least economical to operate, the trends so far in their closing may shift moving forward, although this will likely be dependent on the proactive behavior of utilities, communities, and governments.

When plants close, workers do change their lives. Employees who have worked most of their lives at one job all of a sudden need to move around, and it is important to make this transition less scary and less painful. In this essence, a better understanding of where these workers go, and what the psychological impact of that transition on them, would be helpful. As Tvinnereim and Ivarsflaten (2016) showed, coal generation is more about jobs than against the environment. Breaking down the climate-coal binary into one that provides opportunities for alienated workers is an important first step, and much of this could be driven by a greater understanding of how employees view the options facing them, and how those options are presented.

Given its technological advantages, it would be optimal for the Untied States to be a lead country investing in carbon capture and storage—a necessary part of a solution for economically reaching a 2-degree target and for reaching a 1.5-degree target whatsoever. However, unlike previous attempts, the fossil fuel industries would need to be willing to invest significantly more, unlike previous iterations—further whether this technology is developed for coal or for gas (or even smelting) in the United States. This will be a challenge, as the industry's naive "clean coal" campaign proved fruitless and the heralded Kemper County Energy Facility and FutureGen proven to be more of a boondoggle to taxpayers than a home run (IPCC 2014, Samuelson 2015, Buchanan 2015). For coal, market forces in the United States will likely retard any development carbon capture and sequestration in the near future, and though there may now be an opportunity for natural gas investment, such investments have yet to appear. Further research and thought is needed to design how this regime would function, particularly to discourage any new coal capacity and enable rapid and efficient technology transfer to countries that will need it, such as India and China.

Finally, continued research on the shrinking coal industry to minimize social harm while moving to a low carbon future is essential. One very useful project, building on the work

here and inspired by Bledsoe (2016, pers. comm., 15 June), would be to survey the different policy instruments being used in the United States that are impacting the landscape and economics of coal use in the United States. Some, such as the growth of renewables, the Clean Power Plan, and recent BLM policies have been identified already here, but others would include the growing divestment movement among funds and shifting investments away from coal in national banks, legal challenges to coal export terminals, and, of course, low natural gas prices. As made clear by the large number of closures, challenges to new power plants, and bankruptcies of coal mining companies, there is a shrinking pool of finance used by companies in liberalized electricity markets to invest in clean coal technologies, and currently it is not power companies that are contribution to decarbonization through carbon capture. A future study would then assess the relative impact of such instruments on communities and identify both leakages in policies to squeeze and characteristics of more exposed communities.

Limitations

Data

Coal retirement data accessible from the EIA website was not perfectly consistent with other public (such as PJM's decommissioned plants report) and private databases (for example, provided by the Sierra Club) of coal power plant closures. There are many likely explanations, including different definitions of decommissioning, such as how some listed power plants that were never actually built, but instead planned and cancelled, as decommissioned. Confirming some of this data required extensive follow-up with supporting documents, and where difference was unable to be resolved, the plant was dropped, thus decreasing the number of control observations.

Similar data concerns arose over important control variables based on the literature review regarding employment in the electricity generation sector. Data collected from the US Bureau of Labor Statistics (BLS) website were wholly inconsistent with much of the data on coal power plant closures. For example, in many counties where there were significant coal MW online (pre-retirement), the BLS employment statistics for fossil fuel generation employment reported no fossil fuel jobs (for example, in Sussex County, Delaware, where between 2010 and 2015 343 MW of coal power came offline, but no jobs in fossil fuel employment were listed in the BLS data). Due to many instances of this, additional theoretically useful control data from this database, including employment in the wind, natural gas, and overall electricity generation sector, were dropped. While a proxy natural gas employment was used through the gas & oil extraction, future research could employ additional controls that would serve similar proxy roles and text the robustness of the results with interchanging proxy control variables, or follow up with providers of public data to better understand the data inconsistencies.

Balancing & Bootstrapping

Testing for balancing was perhaps the most difficult element in the propensity score matching procedure, as literature fluctuated on the emphasis on how balanced propensity scores are needed for significance of results, particularly as performance tends to vary based on the growing range of combinations of propensity score estimation and applications. Based on Grotta and Bellocco (2014) or Austin (2011), the analysis met the satisfactory balancing, while more robust analysis guided by Starks and Garrido 2014) emphasized that improperly balanced covariates that fall beyond Rubin's (2011) range of acceptable extremity. Rubin would argue that the regression adjustment is not trustworthy, as the differences between covariate distribution is substantial; this is particular to his second condition, that the ratio of variances of the propensity score exceeded $\frac{1}{2} < X < 2$. While the literature suggested the controls ultimately used, the wide range of balancing is not entirely surprising, between the few control instances and issues

of data availability. Nevertheless, it is important to review this because the amount of bias invoked given the high standardized bias in the selected covariates may ultimately signify that the results gained are not to be given significant weight (Harder et al. 2011).

Future analysis could benefit from including a greater number of covariates or different measures for covariates to test across the propensity score balancing, as well as a better understanding and experience working through the many options of balancing tests such as guided by Starks and Garrido (2014). Additionally, once the decision for this project to solely focus on unemployment was made, it would have been beneficial to collect data across the entire United States, to increase the number of treatment observations (counties with MW of coal coming offline) and possible county matches, though additional controls would need to be added to account for the different interconnection areas beyond PJM (as suggested in Bryson et al. 2002).

Additional analysis through bootstrapping would have also proven useful to reduce standard errors. Some (Smith 2000, Heckman et al. 2008) emphasize that the estimated variance of a treatment effect should additionally capture (1) the variance from the estimation of the propensity score, (2) the imputation of the common support, and (3) the order of matching done for the treated group.

Conclusion

Coal will continue to close down in the United States: an imperative, as keeping warming below 2°C will require keeping over 80% of coal reserves in the ground (McGlade and Ekins 2015). Such a momentous task must have an iterative solution that builds low-carbon transitions off of community development and support.

From a combination of two regression analyses on a unique data set and qualitative and quantitative assessments of electricity prices in PJM and a case study in New York, this

thesis shows that sector-level concerns about unemployment and rising electricity prices are overstated. While appropriate attention needs to be given to exposed towns, macro-level concerns about unemployment are unjustified. Transitions away from coal are possible with the proper engagement across governments, citizens, institutions, and electricity companies. This thesis aims to answer part of a key question about closing coal plants—what happens to the workers next— though it does so on a level that intends to assuage the general concerns of policymakers. At the moment, the lights are on, unemployment is falling, and power prices are still going down on an interconnection with markets designed to preempt any significant capacity reductions.

Policy instruments are making significant headway. Programs such as the Power Plus Plan and the Secure Coal Community Schools program fall within a broader regime of policy instruments in the United States to change the landscape of coal (WH 2016, Clinton 2016). The Bureau of Land Management (BLM) has issued a comprehensive review of federal coal leasing program to better support taxpayers and reflect environmental impacts, and, with this review, has instituted a hold on new coal lease issuance, spurred by a federal court ruling that found that the BLM did not consider the climate change impacts of coal leases (BLM 2016). While a small hold on the supply of coal, 70% or more of coal mined by the largest mining companies in the US is from federal lands, and changes to pricing may remove what is perceived to be a significant subsidy, as most coal is bid for at the minimum bid possible in auctions—and a number that hasn't risen, even with inflation, since 1982 (GAO 2013) and proposals for bottom-up carbon pricing at the extraction site have been rising (see Krupnick et al. 2015).

Supporting communities will require a combination of public and private efforts. So far, private generation companies have effectively supported their employees though transition programs and retirement packages that have not drawn ire. This may not be

case across the coal industry, given the proceedings of recent bankruptcy cases.[18] The coal industry's rousing of public anger against federal regulatory agencies will continue to hurt workers as well: as argued by former West Virginia Senator Robert Byrd, "to deny the mounting science of climate change is to stick our heads in the sand and say 'deal me out'…[it] would be much smarter to stay at the table…the greatest threats to the future of coal [are]…from rigid mindsets" (2010). Whether through market mechanisms or policy instruments, companies that invest and support communities exposed from coal closures should be rewarded for their moral behavior.

The ultimate goal of climate—and economic or energy—policy is to minimize social harm, though oftentimes at potentially competing scales between the coal power plant worker in Kentucky and the woman in Bangladesh threatened by sea level rise or the farmer in Kenya who's crops are becoming threated by the increased likelihood of droughts. While framing the literature in the scientific consequences is important in considering the macro-level consequences of policies and inform policymakers, the story is different in the areas feeling "under attack" from climate policies that ultimately lead to a decrease in coal-fired power generation. Constituents view a party that represented organized labor as one that is now leaving them behind, and this should not be a sacrifice (Burns 2015). So far, it has been the case that organized communities and some more proactive power organizations have been able to weather the storm of coal closures in certain areas, though more attention and strategic local governance and coalition building will be necessary in the years to come.

[18] Where many are attempting to forego responsibilities for clean up, for paying local taxes, or for supporting their employees' health benefits (Gallucci 2016, Sanzillo and Schlissel 2016, Marienau 2016).

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Appendix

FE Regression Outputs

FE1

```
. xtreg uer MWOffline pci povr manufacturing gasoilextraction farmearnings construction population lf

Random-effects GLS regression                   Number of obs      =      3270
Group variable: fips                            Number of groups   =       690

R-sq:  within  = 0.4014                         Obs per group: min =         1
       between = 0.2470                                        avg =       4.7
       overall = 0.2196                                        max =         5

                                                Wald chi2(9)       =   1020.79
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000
```

uer	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
MWOffline	-.1228091	.3372717	-0.36	0.716	-.7838494	.5382313
pci	-.0001884	7.96e-06	-23.67	0.000	-.000204	-.0001728
povr	.02746	.011199	2.45	0.014	.0055104	.0494096
manufacturing	-2.81e-07	1.41e-07	-2.00	0.046	-5.57e-07	-5.27e-09
gasoilextraction	-1.71e-06	9.52e-07	-1.79	0.073	-3.57e-06	1.60e-07
farmearnings	-8.92e-06	1.20e-06	-7.43	0.000	-.0000113	-6.56e-06
construction	-8.78e-07	2.91e-07	-3.02	0.003	-1.45e-06	-3.09e-07
population	8.47e-06	1.55e-06	5.47	0.000	5.44e-06	.0000115
lf	-9.44e-06	2.87e-06	-3.29	0.001	-.0000151	-3.82e-06
_cons	15.0849	.3927638	38.41	0.000	14.31509	15.8547
sigma_u	1.2018218					
sigma_e	1.2281448					
rho	.4891686	(fraction of variance due to u_i)				

FE2

```
. xtreg uer TotalMWLost pci povr manufacturing gasoilextraction farmearnings construction population lf

Random-effects GLS regression                   Number of obs      =       358
Group variable: fips                            Number of groups   =        79

R-sq:  within  = 0.4873                         Obs per group: min =         2
       between = 0.1195                                        avg =       4.5
       overall = 0.1502                                        max =         5

                                                Wald chi2(9)       =    182.48
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000
```

uer	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
TotalMWLost	-.0013528	.0004129	-3.28	0.001	-.0021621	-.0005435
pci	-.0002208	.0000222	-9.96	0.000	-.0002643	-.0001773
povr	-.0424879	.0383857	-1.11	0.268	-.1177226	.0327467
manufacturing	-7.30e-08	2.73e-07	-0.27	0.789	-6.09e-07	4.63e-07
gasoilextraction	1.35e-08	8.59e-07	0.02	0.987	-1.67e-06	1.70e-06
farmearnings	-6.22e-06	3.27e-06	-1.91	0.057	-.0000126	1.79e-07
construction	-1.92e-06	4.91e-07	-3.91	0.000	-2.88e-06	-9.57e-07
population	1.50e-06	2.85e-06	0.52	0.600	-4.09e-06	7.09e-06
lf	5.06e-06	4.84e-06	1.04	0.296	-4.43e-06	.0000146
_cons	17.84006	1.14329	15.60	0.000	15.59925	20.08087
sigma_u	1.5851898					
sigma_e	.91855954					
rho	.74862745	(fraction of variance due to u_i)				

PSM Regression Outputs:

No.1 (NN Match)

```
. teffects nnmatch (uer pci lf population povr construction farmearnings gasoilextraction ma
> (MWOffline),  nn (1)

Treatment-effects estimation                   Number of obs      =      1424
Estimator      : nearest-neighbor matching     Matches: requested =         1
Outcome model  : matching                                     min =         1
Distance metric: Mahalanobis                                  max =         1
```

uer	Coef.	AI Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
MWOffline (1 vs 0)	-1.201545	.5056252	-2.38	0.017	-2.192552	-.2105377

No. 2

```
. teffects psmatch (uer) (MWOffline pci lf population povr construction farmearnings gasoilextraction man
> ufacturing )

Treatment-effects estimation                   Number of obs      =      3270
Estimator      : propensity-score matching     Matches: requested =         1
Outcome model  : matching                                     min =         1
Treatment model: logit                                        max =         1
```

uer	Coef.	AI Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
MWOffline (1 vs 0)	-.6881345	.2853296	-2.41	0.016	-1.24737	-.1288987

No. 3

```
. teffects nnmatch (uer pci lf population povr construction farmearnings gasoilextraction ma
> (MWOffline),  nn (2)

Treatment-effects estimation                   Number of obs      =      1424
Estimator      : nearest-neighbor matching     Matches: requested =         2
Outcome model  : matching                                     min =         2
Distance metric: Mahalanobis                                  max =         2
```

uer	Coef.	AI Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
MWOffline (1 vs 0)	-.963132	.4695527	-2.05	0.040	-1.883438	-.0428255

No. 4

```
. teffects psmatch (uer) (MWOffline population lf pci povr manufacturing gasoilextraction construction)

Treatment-effects estimation                   Number of obs      =      3270
Estimator      : propensity-score matching     Matches: requested =         1
Outcome model  : matching                                     min =         1
Treatment model: logit                                        max =         1
```

uer	Coef.	AI Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
MWOffline (1 vs 0)	-.8900306	.2814846	-3.16	0.002	-1.44173	-.3383309

No. 5

```
. teffects psmatch (uer) (MWOffline lf population povr construction farmearnings gasoilextraction manufac
> turing )

Treatment-effects estimation                   Number of obs      =      3270
Estimator      : propensity-score matching     Matches: requested =         1
Outcome model  : matching                                     min =         1
Treatment model: logit                                        max =         1
------------------------------------------------------------------------------
             |               AI Robust
         uer |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ATE          |
   MWOffline |
   (1 vs 0)  |  -1.095443   .3401334    -3.22   0.001    -1.762093   -.4287942
------------------------------------------------------------------------------
```

No. 6

```
. teffects psmatch (uer) (MWOffline lf population povr construction farmearnings gasoilextraction manufac
> turing ), nn(2)

Treatment-effects estimation                   Number of obs      =      3270
Estimator      : propensity-score matching     Matches: requested =         2
Outcome model  : matching                                     min =         2
Treatment model: logit                                        max =         2
------------------------------------------------------------------------------
             |               AI Robust
         uer |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ATE          |
   MWOffline |
   (1 vs 0)  |  -.7369571   .2732041    -2.70   0.007    -1.272427   -.2014869
------------------------------------------------------------------------------
```

No. 7

```
. teffects psmatch (uer) (MWOffline population lf  povr manufacturing gasoilextraction farmearnings
> )

Treatment-effects estimation                   Number of obs      =      3472
Estimator      : propensity-score matching     Matches: requested =         1
Outcome model  : matching                                     min =         1
Treatment model: logit                                        max =         1
------------------------------------------------------------------------------
             |               AI Robust
         uer |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ATE          |
   MWOffline |
   (1 vs 0)  |  -.0772178   .4931035    -0.16   0.876    -1.043683    .8892473
------------------------------------------------------------------------------
```

No. 8

```
. teffects psmatch (uer) (MWOffline population lf  povr construction gasoilextraction farmearnings)

Treatment-effects estimation                   Number of obs      =      3427
Estimator      : propensity-score matching     Matches: requested =         1
Outcome model  : matching                                     min =         1
Treatment model: logit                                        max =         1
```

uer	Coef.	AI Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
MWOffline (1 vs 0)	-.7938721	.2896687	-2.74	0.006	-1.361612	-.2261318

No. 9

```
. teffects psmatch (uer) (MWOffline population lf  povr construction gasoilextraction farmearnings)
> , nn(2)

Treatment-effects estimation                   Number of obs      =      3427
Estimator      : propensity-score matching     Matches: requested =         2
Outcome model  : matching                                     min =         2
Treatment model: logit                                        max =         2
```

uer	Coef.	AI Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
MWOffline (1 vs 0)	-.8344762	.2565228	-3.25	0.001	-1.337252	-.3317008

Table 1: Jobs Impacted by Individual Power Plant Closures

Utility Name	Plant Name	Retirement Year	Jobs Impacted	Transfers Offered or Applied	Retirements	Retraining/ Severance
FirstEnergy Generation Corp	FirstEnergy R E Burger	2010	79	All	-	-
Duke Energy Carolinas, LLC	James E. Rogers Energy Complex	2011	N/A	X	-	-
Duke Energy Carolinas, LLC	Buck	2011	31	X	-	X
Duke Energy Progress - (NC)	W H Weatherspoon	2011	51	>50%	X	X
Exelon Power	Cromby Generating Station	2011	84	X	X	X

Utility Name	Plant Name	Retirement Year	Jobs Impacted	Transfers Offered or Applied	Retirements	Retraining/ Severance
FirstEnergy Generation Corp	FirstEnergy R E Burger	2010	79	All	-	-
Duke Energy Carolinas, LLC	James E. Rogers Energy Complex	2011	N/A	X	-	-
Duke Energy Carolinas, LLC	Buck	2011	31	X	-	X
Duke Energy Progress - (NC)	W H Weatherspoon	2011	51	>50%	X	X
Exelon Power	Eddystone Generating Station	2011	137	X	X	X
Duke Energy Progress - (NC)	Cape Fear	2012	113	57	27	7
Duke Energy Carolinas, LLC	Dan River	2012	N/A	X	-	-
Duke Energy Progress - (NC)	HF Lee Plant	2012	N/A	X	X	-
FirstEnergy Generation Corp	FirstEnergy Bay Shore	2012	80	X	X	-
Duke Energy Ohio Inc	Walter C Beckjord	2012	N/A	All	-	-
Appalachian Power Co	Philip Sporn	2012	N/A	X	-	-
Midwest Generations EME LLC	Fisk Street	2012	115	95	15	15
Midwest Generations EME LLC	Crawford	2012	See Fisk	See Fisk	See Fisk	See Fisk
AEP Generation Resources Inc	Conesville	2012	22	X	X	N/A
Duke Energy Progress - (NC)	H B Robinson	2012	See Cape Fear	22	See Cape Fear	10
Monongahela Power Co	FirstEnergy Albright	2012	30	X	N/A	N/A
Monongahela Power Co	FirstEnergy Rivesville	2012	30	X	N/A	N/A
Monongahela Power Co	FirstEnergy Willow Island	2012	35	X	N/A	N/A
Allegheny Energy Supply Co LLC	FirstEnergy R Paul Smith Power Station	2012	40	X	X	X
NRG Power Midwest LP	Niles Power Plant	2012	40	N/A	N/A	N/A
Allegheny Energy Supply Co LLC	FirstEnergy Armstrong Power Station	2012	60	X	X	X

Utility Name	Plant Name	Retirement Year	Jobs Impacted	Transfers Offered or Applied	Retirements	Retraining/ Severance
FirstEnergy Generation Corp	FirstEnergy R E Burger	2010	79	All	-	-
Duke Energy Carolinas, LLC	James E. Rogers Energy Complex	2011	N/A	X	-	-
Duke Energy Carolinas, LLC	Buck	2011	31	X	-	X
Duke Energy Progress - (NC)	W H Weatherspoon	2011	51	>50%	X	X
Exelon Power	Eddystone Generating Station	2012	110	X	N/A	X
Duke Energy Ohio Inc	Walter C Beckjord	2013	n/a	X	-	-
Duke Energy Carolinas, LLC	Buck	2013	31	X	-	X
Duke Energy Carolinas, LLC	Riverbend	2013	34	X	-	X
NRG REMA LLC	Titus	2013	45	X	X	-
NRG REMA LLC	Portland (PA)	2013	80	X	-	X
Allegheny Energy Supply Co LLC	Hatfields Ferry Power Station	2013	174	N/A	N/A	X
Allegheny Energy Supply Co LLC	FirstEnergy Mitchell Power Station	2013	206	N/A	N/A	X
RC Cape May Holdings LLC	B L England	2014	0	X	-	-
Duke Energy Ohio Inc	Walter C Beckjord	2014	N/A	X	-	-
Duke Energy Carolinas, LLC	W S Lee	2014	N/A	X	-	N/A
NRG Power Midwest LP	Elrama Power Plant	2014	50	N/A	N/A	N/A
Louisville Gas & Electric Co	Cane Run	2015	N/A	X	-	-
East Kentucky Power Coop, Inc	Dale	2015	N/A	X	-	-
Appalachian Power Co	Clinch River	2015	N/A	X	-	-
Appalachian Power Co	Glen Lyn	2015	31	X	X	3
Kentucky Power Co	Big Sandy	2015	71	X	N/A	N/A
AES Beaver Valley	AES Beaver Valley Partners Beaver Valley	2015	35	X	-	X
Kentucky Utilities Co	Green River	2015	36	X	X	X

Utility Name	Plant Name	Retirement Year	Jobs Impacted	Transfers Offered or Applied	Retirements	Retraining/ Severance
FirstEnergy Generation Corp	FirstEnergy R E Burger	2010	79	All	-	-
Duke Energy Carolinas, LLC	James E. Rogers Energy Complex	2011	N/A	X	-	-
Duke Energy Carolinas, LLC	Buck	2011	31	X	-	X
Duke Energy Progress - (NC)	W H Weatherspoon	2011	51	>50%	X	X
FirstEnergy Generation Corp	FirstEnergy Lake Shore	2015	42	X	-	-
Hoosier Energy R E C, Inc	Frank E Ratts	2015	46	X	X	X
Dayton Power & Light Co	O H Hutchings	2015	50	50	-	-
AEP Generation Resources Inc	Kammer	2015	55	X	X	-
FirstEnergy Generation Corp	FirstEnergy Ashtabula	2015	57	X	-	-
Appalachian Power Co	Philip Sporn	2015	70	X	X	-
Indiana Michigan Power Co	Tanners Creek	2015	115	X	X	-
FirstEnergy Generation Corp	FirstEnergy Eastlake	2015	120	X	-	-
Virginia Electric & Power Co	Chesapeake	2015	145	N/A	N/A	N/A
AEP Generation Resources Inc	Picway	2015	N/A	X	-	-
East Kentucky Power Coop, Inc	Dale	2016	N/A	X	-	-
Constellation Power Source Gen	Perryman	2016	N/A	X	-	-
Constellation Power Source Gen	Riverside (MD)	2016	N/A	X	-	-
NRG Power Midwest LP	Avon Lake	2016	76	X	-	X
City of Logansport - (IN)	Logansport	2016	30	X	-	X
Consumers Energy Co	J C Weadock	2016	49	X	X	-
Wabash Valley Power Assn, Inc	Wabash Valley Power IGCC	2016	50	X	-	X
Consumers Energy Co	B C Cobb	2016	65	X	-	-
Consumers Energy Co	J R Whiting	2016	71	X	X	-

Utility Name	Plant Name	Retirement Year	Jobs Impacted	Transfers Offered or Applied	Retirements	Retraining/ Severance
FirstEnergy Generation Corp	FirstEnergy R E Burger	2010	79	All	-	-
Duke Energy Carolinas, LLC	James E. Rogers Energy Complex	2011	N/A	X	-	-
Duke Energy Carolinas, LLC	Buck	2011	31	X	-	X
Duke Energy Progress - (NC)	W H Weatherspoon	2011	51	>50%	X	X
RC Cape May Holdings LLC	B L England	2016	75	X	-	-
Total			**63**	**56-61**	**22-32**	**24-34**

Key: N/A: Information not Available; X: employees but no exact number provided; exact numbers provided where possible; " - " : value of zero. sources of primary research available upon request: compiled mainly from news outlets and company press releases.

Table 2: Variables for Regression Analysis

Variable	Stata Name	Source	Description
Construction	construction	Bureau of Labor Statistics Quarterly Census of Employment and Wages	The Construction (NAICS) sector comprises establishments primarily engaged in the construction of buildings or engineering projects (e.g., highways and utility systems). Establishments primarily engaged in the preparation of sites for new construction and establishments primarily engaged in subdividing land for sale as building sites also are included in this sector. Construction work done may include new work, additions, alterations, or maintenance and repairs. Activities of these establishments generally are managed at a fixed place of business, but they usually perform construction activities at multiple project sites. Production responsibilities in this sector are usually specified in (1) contracts with the owners of construction projects (prime contracts) or (2) contracts with other construction establishments (subcontracts)

Farm Earnings	farmearnings	Bureau of Labor Statistics Quarterly Census of Employment and Wages	Farm labor and proprietors' income is comprised of the net income of sole proprietors, partners, and hired laborers arising directly from the current production of agricultural commodities, either livestock or crops. It includes net farm proprietors' income and the wages and salaries, pay-in-kind, and other labor income of hired farm laborers; but specifically excludes the income of farm corporations
Gas & Oil Extraction	gasoilextraction	Bureau of Labor Statistics Quarterly Census of Employment and Wages	Industries in the Oil and Gas Extraction NAICS subsector operate and/or develop oil and gas field properties. Such activities may include exploration for crude petroleum and natural gas; drilling, completing, and equipping wells; operating separators, emulsion breakers, desilting equipment, and field gathering lines for crude petroleum and natural gas; and all other activities in the preparation of oil and gas up to the point of shipment from the producing property. This subsector includes the production of crude petroleum, the mining and extraction of oil from oil shale and oil sands, and the production of natural gas, sulfur recovery from natural gas, and recovery of hydrocarbon liquids
Labor Force	lf	Bureau of Labor Statistics Local Area Unemployment Statistics (LAUS) Program	This group comprises all persons classified as employed or unemployed.

Manufacturing	manufacturing	Bureau of Labor Statistics Quarterly Census of Employment and Wages	The Manufacturing NAICS sector comprises establishments engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products. The assembling of component parts of manufactured products is considered manufacturing, except in cases where the activity is appropriately classified in Sector 23, Construction. Establishments in the Manufacturing sector are often described as plants, factories, or mills and characteristically use power-driven machines and materials-handling equipment. However, establishments that transform materials or substances into new products by hand or in the worker's home and those engaged in selling to the general public products made on the same premises from which they are sold, such as bakeries, candy stores, and custom tailors, may also be included in this sector. Manufacturing establishments may process materials or may contract with other establishments to process their materials for them. Both types of establishments are included in manufacturing
Megawatts of Coal Capacity Remaining	TotalMWLost	Form EIA-860 detailed data	Captures the total MW lost since 2010.
Megawatts of Coal Offline	MWOffline	Form EIA-860 detailed data	Captures whether or not MW of coal power were brought offline in counties where there was installed coal capacity

Per Capita Income	pci	Bureau of Labor Statistics Local Area Unemployment Statistics (LAUS) Program	The personal income of a given area divided by the resident population of the area. Personal income consists of the income that persons receive in return for their provision of labor, land, and capital used in current production as well as other income, such as personal current transfer receipts. In the state and local personal income accounts the personal income of an area represents the income received by or on behalf of the persons residing in that area. It is calculated as the sum of wages and salaries, supplements to wages and salaries, proprietors' income with inventory valuation (IVA) and capital consumption adjustments (CCAdj), rental income of persons with capital consumption adjustment (CCAdj), personal dividend income, personal interest income, and personal current transfer receipts, less contributions for government social insurance plus the adjustment for residence
Population	population	Bureau of Labor Statistics Local Area Unemployment Statistics (LAUS) Program	Included are persons 16 years of age and older residing in the 50 States and the District of Columbia who are not inmates of institutions (for example, penal and mental facilities, homes for the aged), and who are not on active duty in the Armed Forces. Employed persons are: All persons who, during the reference week, (a) did any work at all (at least 1 hour) as paid employees, worked in their own business, profession, or on their own farm, or worked 15 hours or more as unpaid workers in an enterprise operated by a member of the family, and (b) all those who were not working but who had jobs or businesses from which they were temporarily absent because of vacation, illness, bad weather, childcare problems, maternity or paternity leave, labor-management dispute, job training, or other family or personal reasons, whether or not they were paid for the time off or were seeking other jobs.
Poverty Rate	povr	United States Census Bureau Small Area Income and Poverty Estimates (SAIPE) Program	total number of people in poverty over total population, estimate for all ages.

Unemployment Rate	uer	Bureau of Labor Statistics Local Area Unemployment Statistics (LAUS) Program	The unemployment rate represents the number unemployed as a percent of the labor force.