The Effect of Environmental Regulations on Pollution Concentration: Evidence form Ontario's Coal Phase out*

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Abstract

Many countries, including Canada, have started replacing coal with cleaner energy sources for electricity generation. One of the first attempts to achieve this goal in North America was the shut down of coal-fired power plants in Canadian province of Ontario. In this paper, I use data from pollution monitoring networks to estimate the impact of Ontario's coal phase out on local air quality. I apply a difference-in-differences estimation strategy comparing the pollution concentration within 20 miles of power plants relative to 20-40 miles before and after the shut down. I find that applying this policy decrease O_3 and SO_2 levels by 6 and 19 percent, respectively. However, the results do not show a statistically significant effect on $PM_{2.5}$, NO_X, NO_2, and NO levels.

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1 Introduction

Policy makers, and researchers from different disciplines are interested in the effect of environmental regulations on air quality and pollution concentration. The reason for this attention is that understanding the impacts of the environmental regulations on pollution is crucial for designing more informed and efficient policies in different countries and jurisdictions in the future.

The impact of environmental regulations on air quality has been well documented in the literature with most of the studies being focused on the United States. For example, Chay and Greenstone (2005) study the effect of the Clean Air Act on the total suspended particulates (TSPs) and housing prices using the US county-level data, comparing nonattainment and attainment counties. In another study, Greenstone (2004) focuses on the effect of the same policy on SO_2 (sulfur dioxide) concentration and he found a minor effect on SO_2 level in 30 years following application of the policy. However, Currie and Walker (2019) found that the Clean Air Act significantly improved air quality.

Hanna and Oliva (2010) estimate the effect of inspections of manufacturing plants on air emissions. Their results show that an inspection reduces air emissions of a plant by 15 percent over the five years following the inspections. Greenstone and Hanna (2014) study the effect of environmental regulations in India on air and water pollution and infant mortality using two different policy settings, supreme court action plans and installing catalytic converters. They find that installing the converters decreases Particulate Matters (PM) and SO_2 levels significantly, while it has no effect on reducing Nitrogen dioxide (NO_2). However, the supreme court action plans policy has no statistically significant effect on reducing the pollutants levels under study.

A relatively new stream of environmental studies focuses on the effect of pollution on several outcome variables including infant and adult health, housing value, labour supply, productivity, education attainment, and so on.[1]

[1]See Chay and Greenstone (2003), Ransom and Pope (1995), Schlenker and Walker (2016), Chay and

Among these studies a growing literature explores the local effect of pollution on above-mentioned outcomes. Although these studies agree on the fact that pollution effects are highly localized, still there is little guidance in the literature on how far pollution from the emitting sources are transported.

For instance, Currie et al. (2015) use the data from pollution monitoring stations to show the relationship between regulated chemicals and distance from emitting industrial plants. They use the opening and closing of the plants as an experimental setting and show that operational status of the plants significantly affects air quality and housing value and infant health within 1 mile of the plants compared to 1-2 miles.

Levy et al. (2002) show that over 40 percent of $PM_{2.5}$ exposure occurs in 30 miles of power plants and less than 20 percent in 30-90 miles. Although they argue that there are differences between emissions from older and newer power plants, as older plants are sometimes exempt from emissions standard requirements in the US.

Clay et al. (2016) exploit the opening of coal-fired power plants in the US in the mid-20th century to study the costs and benefits of coal-fired electricity generation. Following Levy et al. (2002), they use distance of 30 miles as treatment group and 30-60 miles, and 30-90 miles, as the control groups. Alternatively, Casey et al. (2018) studied the impact of eight coal and oil power plants retirements on infant health in California among mothers residing within 5 km of the plants compared to 5-10 km.

The variation in using different distance categories in the literature comes from different institutional settings in different jurisdictions, the age of power plants, pollutants under study, local weather, local wind pattern, and so on.

The present study is among few studies that uses pollution data to find the air pollution travel distance around coal-fired power plants. Applying a similar approach developed by Currie et al. (2015), I use pollution monitoring network data from 2000-2016 in Ontario to characterize air emissions transport. I use coal-fired power plants shut down in Ontario

Greenstone (2005), Currie et al. (2015), Graff Zivin and Neidell (2012), Bartik et al. (2019), Currie and Walker (2019), Currie and Walker (2011) between 2005-2014 as an experimental setting.

The coal phase out in Ontario made the province the first coal-free jurisdiction in North America. In the process of coal phase out, the province applied a staged approach and replace coal-fired electricity generation by mainly natural gas and wind power. [2]

The paper proceeds as follows. Section 2 provides some background information on coal power generation and coal phase out in Ontario, Canada. Section 3 describes data sources and presents summary statistics. Section 4 introduces my empirical method and identification strategy. Section 5 presents the results and conducts several robustness tests. Section 6 concludes.

2 Historical Background

2.1 Coal Power Generation in Canada

Canada has long been a major coal producer, and coal mining has been a widely pursued employer in the country for many years. There are mostly two types of coal in Canada, metallurgical and thermal coal which are used in steel-making and electricity production, respectively. However, the main use of coal is electricity generation.

Power generation accounts for 80% of coal consumption in Canada, while coal has produced 9-10% of electricity in recent years. The electricity generation has been dominated by hydro power over the past decades, near to 60%, while there is a significant potential for solar and wind power. Nuclear and gas jointly made up near to 25% of power generation in 2017.

Ontario used to be one of the largest coal consumers in its electricity sector, producing 25% of the province electricity using coal. However, between 2005-2014 Ontario shut down all its coal power plants. Ontario coal phase out is the basis of the research design I use in

[2] Recently, the US started closing number of their coal-fired power plants in Pennsylvania which some of them replaced by natural gas. See Russell et al. (2017) and Burney (2020) for more details.

his paper. Canada's domestic coal consumption has dropped sharply afterwards, mainly as a result of a decline in coal-fired electricity generation, and the country increased its coal export over recent years. In 2018 for instance, Canada was a net exporter of coal, exporting 34 million tonnes and importing 7.6 million tonnes of coal.

Canada's coal production in 2018 was 62.3 million tonnes. Coal mining is regionally concentrated and is actively produced in British Columbia, 44%, Alberta, 41%, and Saskatchewan, 15%. After closure of Ontario's coal-fired power plants, the remaining coal power capacity is spread over five provinces, Alberta, Saskatchewan, Nova Scotia, New Brunswick and Manitoba. In 2019, Alberta had the largest share of coal-fired electricity generation capacity in Canada,[3] 65%, and is followed by Saskatchewan, 17%, Nova Scotia, 12%, New Brunswick, 5%. Among these five provinces, Manitoba has 105 MW coal capacity used for backup generation. More importantly, in November 2015 government of Alberta announced its Climate Leadership Plan which has the goal for decreasing emissions from coal-fired electricity generation to zero by 2030. Furthermore, in December 2018, government of Canada announced its final regulations to phase-out traditional coal-fired electricity generation by 2030.

2.2 Coal Phase-out in Ontario

In 2005, Ontario had five coal-fired generating stations, Lakeview, Nanticoke, Lambton, Thunder bay, and Atikokan, responsible for generating of 12-28% of province electricity.[4] In 2003, Ontario's liberal government committed to eliminate all of its coal-fired generation by 2015.

Public health was an argument put forward in support of the coal phase out. In April 2005, a cost-benefit analysis was prepared for Ontario Ministry of Energy proposing different alternatives for Ontario's coal-fired electricity generation. The study identified three scenarios. First, producing all the replacement electricity through gas generation facilities

[3] Canada had a coal-fired electricity generating capacity of 9,834 MW in 2017.
[4] Ontario Ministry of Environment, 2001

constructed for this purpose alone. Second, producing all the replacement electricity through a combination of nuclear and gas facilities. Third, operating the coal-fired generation facilities together with installing new and best available emissions control technology. They compared the cost and benefit of each scenario with a base scenario, keeping the five coal-fired power plants as they are.

Based on this study an average annual of 660 premature deaths, 920 hospital admissions, 1090 emergency room visits, and 331000 minor illness cases could be avoided by switching from the baseline scenario to nuclear and gas scenario. In other words, implementing nuclear and gas scenario would save $2.6 billion in average annual health costs compared to the base scenario. This study drew public attention toward health risks caused by coal-fired power generation in the province. Many doctors and environmental activists started a campaign that led the government to issue a regulation requiring the closure of Lakeview Generating Station (GS) in April 2005.

Lakeview GS was originally built in 1962 in Lakeview area, east of Mississauga, Ontario, with 8 units. It was closed in April 2005, after 43 years of service, and the building was demolished in 2007. It was considered as the largest coal-fired GS in the world in 1960s. At the time of closure Lakeview had 275 employees with generation capacity of 2400 MW. The remaining coal capacity in the province was reduced in a staged approach from 2005-2014 to maintain system reliability and operational efficiency. To achieve this goal, a number of gas generators were built to replace much of the coal capacity, and it was supplemented with wind generation in meeting demand. However, price volatility and environmental impacts made gas undesirable for base load generation.[5] Therefore, gas and nuclear energy was used as the new supply mix at the beginning. Soon after, Ontario moved from a net importer of electricity to a net exporter.

The next GS to close was Atikokan, with one unit and generation capacity of 211 MW. It is located near a small town named Atikokan [6] in northwest of Ontario. The station stopped

[5]Still, gas generation has roughly half the emissions of thermal coal plants.

[6]The population of Atikokan was around 2700 people in 2014.

using coal as fuel in September 2012 and 90 jobs were lost as a result of the coal phase out. Atikokan is now North America's largest 100 percent conventional biomass-fuelled power plant. Nanticoke and Lambton, the two larger coal-fired power plants, were closed in the same year, 2013. Nanticoke GS began operation in 1972 with 8 units in southern Ontario. It was the largest coal-fired GS in North America before closure, and it could provide 3940 MW of power at full capacity. The 2 units of this power plant ceased operation in 2010, another 2 were shut down in 2011, and the plant was closed when the final 4 units of the plant were retired in December 2013. The number of employees at the time of closure was under 250 people. Nanticoke's chimneys were demolished after the closure and in April 2019, a 44 MW solar facility was built in the site. In the same year Lambton GS was also shut down with 4 units, generating capacity of 1980 MW and 250 employees. However, there is no plan of repurposing Lambton GS. Lambton GS was located in St. Clair Township, 26 kilometres south of Sarnia, southwestern Ontario.

The last piece of coal was burned in Thunder Bay GS in April 2014. Thunder Bay had been a coal burner for most of its operating life with 3 units and 306 MW of generating capacity. It was converted to a biomass for a short period of time and was used during the peak demand. However, the 56 years-old facility was closed again in July 2018, as it outlived its usefulness.

After coal phase out, Ontario electricity supply mix changed from 25% coal, 42% nuclear, 23% hydro and 11% gas in 2003 to 60% nuclear, 24% hydro, 9% gas and 6% non-hydro renewable, such as biomass, wind, and solar in 2014.

There are several reasons that made the political decision of coal phase-out feasible in Ontario. First, the province has no exploitable coal reserves, and coal was imported mainly from the United States or to a lesser extent from other provinces with large coal reserves such as Saskatchewan. Therefore, no coal reserves means that no job would be lost in coal production as a result of coal phase out. Although the numbers are not known, the job market impact of the coal phase out in Ontario does not seem to be considerable. It is true that a number of jobs were lost due to the coal phase out, however those jobs have been replaced with green jobs. It is evident that the renewable capacity in the province has been increased after coal-fired power plants closure and has created new jobs. For instance, wind capacity of the province has increased from 15 MW in 2005 to 4374 MW in 2015 and solar energy capacity has raised from 17 MW to 2119 MW in the same time period.[7] Besides, conversion of some power plants such as Atikokan to biomass has created new job in forestry and transportation.

Second, all coal-fired plants have government ownership, owned by Ontario Power Generation, and no negotiation with private firms was needed. Third, the life expectancy of coal-fired power plants is around 40 years, while most plants in Ontario were built in 1960 and 1970 which meant that all coal-fired plants in the province had reached their half-life or past it. Finally, electricity generation in Ontario has historically relied on hydro-power, mostly from Niagara Falls. Besides, the province has also excellent potential for producing wind, solar and biomass energy. The fact that Ontario is rich in biomass that can be burnt in the converted coal power plants or in new generating facilities offered interesting options for the phase out.[8]

3 Data Sources and Summary Statistics

3.1 Data Sources

This paper use an extensive data on ambient air pollution using a pollution monitoring network all over the province of Ontario. For the purpose of this study, I use data from two pollution monitoring programs. First, The National Air Pollution Surveillance (NAPS) program managed by Environment and Climate Change Canada (ECCC) which began in 1969 and is the main source of ambient pollution data in Canada. Each provincial, territorial,

[7] Canada Energy Regulator

[8] Adams et al. (2012)

and regional monitoring network is responsible to collect continuous air pollution data in their own jurisdiction and each monitoring station reports hourly measurement of pollution levels for each pollution type. Second, Ontario Ministry of Environment (OME) provincial program that collects hourly pollution concentration of seven major air pollutants.

The data consist of hourly readings of six air pollutants, O_3, SO_2, $PM_{2.5}$, NO_X, NO_2, and NO from 55 pollution monitoring stations over the period of study, 2000-2016 in Ontario.[9] I use hourly pollution levels information to construct average daily pollution levels. Air pollution monitored includes, Ozone (O_3), Sulphur dioxide (SO_2), Carbon monoxide (CO), Nitrogen dioxide (NO_2), Nitric oxide (NO), Nitrogen oxides (NO_X), and Fine particulate matter ($PM_{2.5}$).

Ontario coal power plants information such as power plant's age, capacity, number of employees, geographical coordination, and average annual emissions come from National Pollutant Release Inventory (NPRI). NPRI is Canada's public inventory of releases, disposals and transfers which tracks pollutants from facilities, such as power plants and factories to air, water, and land all over Canada.

To link the coal-fired power plants and pollution monitoring stations, I use geographical coordination, latitude and longitude, of coal-fired power plants and pollution monitoring stations. Using ArcGIS geographical information system, I measure the distance of each power plants from pollution monitors and match each power plants with the nearby monitoring stations. Figure 1 depicts Ontario Forward Sortation Areas (FSAs)[10] and includes Ontario five coal-fired power plants, shown as red circles, and all monitoring stations around each of them which are shown by green circles. The black circles show 0-20 and 20-40 miles buffers around each power plant. One can see from the map that most of the monitoring stations are located in southern part of the province and close to the large metropolitan areas, where the three biggest coal-fired power plants are. As there is no monitoring station in 40 miles of Atikokan GS, this power plant was excluded from the analysis in this paper.

[9]Details of data preparation procedure are included in Appendix A.

[10]Forward sortation areas are geographical units with same first three characters of postal code.

3.2 Summary Statistics

Table 1 presents summary statistics from the dataset. Panel A of Table 1 reports characteristics of five coal-fired power plants that were shut down from 2005-2014. The first four columns show power plant's age, capacity, number of employees, and closure year, respectively. All coal-fired power plants are long lived plants, with age between 40-45 and Atikokan GS with age of 27. Nanticoke and Lakeview and Lambton GS are the biggest stations respectively and had the highest number of employees ranging from 620 to 253 employees. Lakeview GS was the first power plant that was shut down in 2005 and it took around seven years for the next power plant, Atikokan GS, to be closed completely and the other two power plants, Lambton and Nanticoke GS, were closed in 2013 and the last one, Thunder Bay GS, was shut down in 2014 and ended of coal-fired electricity generation in Ontario.

Column 4 describes each power plant's average annual Criteria Air Contaminants (CAC), including SO_2, $PM_{2.5}$, and NO_2,[11] releases to air in tonnes. As expected, the largest power plant, Nanticoke GS, has the highest emissions of all three pollutants.

Panel B reports the average pollution before and after closure together with the standard errors in parenthesis for each pollutant.Column one is average pollution monitored in 10 miles of the power plants before and after plants closure. Average pollution concentrations decrease for all pollutants, while there is a small increase in average O_3 level. Column 2 and 3 shows the same statistics in 20 miles and 20-40 miles of the plants, respectively. Except $PM_{2.5}$, average pollution level is lower after closure in 20 miles of the plants.

The average O_3, SO_2, $PM_{2.5}$ levels are historically lower in 20 miles of the plants. However, NO, NO_2, and NO_x concentration were always higher closer, in 20 miles, to the power plants relative to areas far from them, 20-40 miles.

The empirical analysis in this paper is based on comparing pollution level in areas closer to coal-fired power plants with areas far from them before and after power plants closure. The monitoring station in 20 miles of the power plants serve as the treatment group and the

[11] NPRI reports Nitrogen oxides by Nitrogen dioxide.

ones that are located between 20 and 40 miles of the plants form the control group. I also repeated the analysis for monitors located in 10 miles of the plants. I will discuss the reason for choosing the treatment and control groups in more details in the next section.

4 Methodology

4.1 Pollution travel distance

The basis of my difference-in-differences strategy is to compare pollution level for each pollutant near and far from the power plants before and after power plants closure. Areas near power plants are the most exposed to pollution from power plants and form the study's treatment group, while areas far from the plants serve as counterfactual, as they are less exposed to pollution from power plants, still they are otherwise similar to the treatment group. The empirical challenge in this context, however is to find the distance buffer for the treatment and control groups. While there is no disagreement that particle pollution from power plants or other emitting sources concentrate locally and diminish slowly with distance from the source , there is no conclusive answer on how far air pollutants emitted from power plants travel in pollution transport literature.

Therefore, I apply a method employed by Linden and Rockoff (2008) and Muehlenbachs et al. (2015) to determine the distance buffer for treatment and control groups in this study. I create two subsamples of pollution level, one for years before plants closure and another for years after plants shut down and restricted the samples to five years before and after closure. Then, I estimate a pollution level function for each pollutant using local polynomial regressions. The dependent variables in these regressions are the residuals of regressing pollution levels on plant-year fixed effect to capture time trend in the data.

Figure 2-7 show the results of the local polynomial regressions before and after coal-fired power plants shut down in 20 miles and between 20-40 miles of the power plants. By looking at Figure 2, we can see that O_3 level is quite steady in all distances from the power plants while it drops after closure in close proximity of the plants, up to around 20 miles, and then increases. There are similar patterns for SO_2 and $PM_{2.5}$ levels in Figure 2 and 3. Fig 4 shows that NO level has been increased both close and far from the plants after closure. However, NO_x and NO_2 level have been decreased for all distances to 40 miles of the plants in Fig 5 and 6.

4.2 Empirical Strategy

This section describes the econometric approach for assessing whether closing coal-fired power plants in Ontario impacted the air pollution concentration in the plants' neighborhood. To do so, I fitted the following econometric model:

$$Y_{ipt} = \beta_0 + \beta_1[PPClosed]_{pt} + \beta_2[Near]_{ip} + \beta_3[PPClosed]_{pt} \times [Near]_{ip} + \tau_{dp} + \mu_{pt} + \epsilon_{ipt} \quad (1)$$

Where $\mathrm{Y_{ipt}}$ is one of the six measures of pollution listed above recorded by monitoring station i at year t close to plant p. $\mathrm{[PPClosed]_{pt}}$ is an indicator which takes the value of 1 if plant p is closed at time t and 0 otherwise. $\mathrm{[Near]_{ip}}$ is an indicator of being in proximity of power plants and takes the value of 1 if monitor i is located in 20 miles of the power plants and 0 if a monitor is located in 20-40 miles. Therefore, there are two types of observations associated with each plant in a given year: one for treatment group, 0-20 miles, and another one for control group, 20-40 miles. $[PPClosed]_{\mathrm{pt}} \times [Near]_{\mathrm{ip}}$ denotes the interaction term. The model also includes Neighborhood-Plant fixed effects τ_{dp} that control for time-invariant factors that affect pollution level near each plant and Plant-Year fixed effects which include the time-varying pollution determinants that are specific to each plant.

The parameter of interest is β_3 , the coefficient of interaction term, $[PPClosed]_{\mathrm{pt}} \times [Near]_{\mathrm{ip}}$ which captures the effect of power plants shut down on average pollution level in areas near the power plants compared with areas far from them.

5 Results

Figure 8-13 presents the event study graphs which shows the impact of coal-fired power plants shut down on O_3, SO_2, $PM_{2.5}$, NO_x, NO_2 and NO concentration, respectively. They are driven from estimation of the coefficient of $[PPClosed]_{\text{pt}} \times [Near]_{\text{ip}}$ in equation (1), that can vary with event time, and 95 percent confidence interval. The year of closure is shown by zero and pollution concentration is normalized to zero in the years prior to power plants closure which is noted as a horizontal line in the graphs. The years range from seven years before closure to ten years after that.

The graph is useful for two reasons: It shows the validity of the empirical design, difference in difference strategy, and assess whether the chosen treatment and control groups had parallel trend before adaptation of the policy. Second, they visually show the effect of the policy on pollution concentration for years after the policy change. The plotted coefficients show the time path of each pollutant level in 0-20 miles of the power plants compared to 20-40 miles away from them, conditional on plant by year and plant by neighborhood fixed effects. The graphs show the validity of common trend in years before the policy adaptation.

Table 2 presents the results of the estimation of Equation (1) for O_3, SO_2, and $PM_{2.5}$, reporting the coefficient and standard error of the interaction term $[PPClosed]_{\text{pt}} \times [Near]_{\text{ip}}$. The regressions are specified in different ways. First, I include year fixed effects and distance fixed effects separately. Second, I included plant-neighborhood fixed effect to control for unobservable time-invariant factors affecting pollution level near each power plant. Third, I controlled for time-varying factors specific to each power plant by including plant-year fixed effect. Lastly, I controlled for both neighborhood-plant and plant-year fixed effect. The treatment group is monitors located 0-20 miles of the power plants and the control group is the monitoring station in 20-40 miles of the plants.

The results of these regressions are summarized in column 1-4. The results show that plants shut down decrease inO_3, SO_2, and $PM_{2.5}$ level by about 3-9, 28-56, and 1-13 percent, respectively in 20 miles of the plants compare to 20-40 miles of them. However, the decline is not significant for $PM_{2.5}$. I also estimate the regressions using monitors in 0-10 miles as another treatment group, keeping the control group the same, to find out if the effect fades away by distance. The plants closure have no significant impact on O_3 and $PM_{2.5}$ concentration in 10 miles of the plants while SO_2 level decrease by about 46 percent which is slightly larger than the estimate of the similar regression in 20 miles of the plants.

For robustness check, I tried two different specifications. First, I restrict the observations to five years before and after plants closure including both plant year and neighborhood plant fixed effects. Column 6 reports estimates of these short run specifications. It is evident from the table that plant shut down decrease the O_3, SO_2 and, $PM_{2.5}$ level roughly by 6, 36, and 3 percent in the short run, respectively while $PM_{2.5}$ level is not been affected significantly.

Second, there are number of monitoring stations which are present in the sample either before or after closure of closest power plant. To address this issue, I created a balanced sample including the monitors that record a specific pollution concentration both before and after closure of matched power plant. In the other word, a monitoring station are included in the sample if it records one of the six pollutants for at least one year before and after shutting down of nearest power plant. Column 7 presents the results of the specification using the balanced sample. The results seem very similar to the short run effect reported in column 6 while the magnitude of the effect is smaller for SO_2 which shows a decline of about 19 percent.

Table 3 presents the same estimation results for other three pollutants NO_x, NO_2, and NO. Surprisingly, the results show an increase in the pollution concentration after power plants closure in 20 and 10 miles of the power plants. Focusing on the last two columns, NO_x, NO_2, and NO concentration increase in the short run in 90 and 95 percent confidence interval. Although, the estimation using the balanced sample do not show any significant increase except in the case of NO concentration which we see around 16 percent increase.

6 Conclusion

This paper study the effect of an environmental regulation, Ontario's coal phase out, on air pollution concentration using average daily pollution data from pollution monitoring networks in the province. The policy was the first attempt to end coal use in electricity generation in North America and lead to the shut down of one of the biggest coal-fired power plants in the world. I find that the policy was in part responsible for improving air quality by reducing O_3 and SO_2 level close to power plants, while it has no statistically significant effect on $PM_{2.5}$, NO, NO_2, and NO_X level.

The results of this study is noteworthy and has implications for other Canadian Jurisdictions, such as Alberta, that plan to shut down coal by 2030. Besides, it is among the few studies that estimated the air pollution travel distance.

To better evaluate the effect of Ontario's coal phase out, one need to study the health effect of the policy. Because health concerns are one of the main reasons in prompting most environmental regulations, at the early stage. Therefore, I investigate the effect of improvement of air quality, in the neighbourhood of the power plants, on infant and adult health using outcome variables, such as low birth-weight and prematurely incidence, infant mortality, adult and children death due to respiratory and cardiovascular diseases. Besides, there is very limited information on the local migration pattern triggered by environmental regulations, in the literature. Hence, I am currently working on the effect of this policy on local migration and income to find out if the policy has any heterogeneous effect on different income groups.

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7 Tables

Table 1: Summary Statistics

	Age	Number of Employees	Capacity	Closure year	Average annual emissions (tonnes)		
	(1)	(2)	(3)	(4)	(5)		
					SO2	PM2.5	NO2
Panel A: Power plants characteristics							
Atikokan Generating Station	27	90	211	2012	3109	5.71	1051
Lakeview Generating Station	43	253	2400	2005	15,922	80	5238
Lambton Generating Station	43	310	1980	2013	17103	535	6615
Nanticoke Generating Station	40	620	3940	2013	46378	725	17500
Thunder Bay Generating Station	45	140	306	2014	2953	53	1513

	0<d≤10 (1)		0<d≤20 (2)		20<d≤40 (3)	
	Before	After	Before	After	Before	After
Panel B: Average pollution level by distance						
O3 level (ppb)	22.21	22.73	24.56	24.32	25.94	26.96
	(9.92)	(10.6)	(10.76)	(10.91)	(11)	(11.17)
SO2 level (ppb)	2.86	2.39	3.16	2.69	3.8	3.34
	(2.41)	(1.73)	(3.57)	(3.16)	(3.9)	(2.28)
PM2.5 level (Mg/m3)	7.38	7.18	7.03	8.15	8.03	8.63
	(5.54)	(4.23)	(6.2)	(6.75)	(6.37)	(5.5)
NO level (ppb)	14.38	11.14	10.42	8.55	7.01	3.75
	(15.72)	(12.97)	(13.02)	(10.54)	(10.41)	(5.87)
NO2 level (ppb)	19.31	16.43	16.86	15.26	12.47	9.82
	(11.37)	(9.6)	(10.65)	(8.74)	(8.51)	(6.1)
NOx level (ppb)	31.24	26.54	25.57	23.02	18.43	13.22
	(22.37)	(19.77)	(19.75)	(17.04)	(16.32)	(10.69)

Notes: This table shows the characteristics of five coal-fired power plants in Ontario and average pollution concentration before and after power plants closure. Panel A column 1-5 report plants' age, number of employees, capacity, closure year, and average emissions in tonnes for each power plant. Panel B column 1-3 reports the average pollution level before and after plants closure in 10, 20, and 20-40 miles of the plants, respectively. ppb and MG/m^3 stand for parts per billion and milligram per cubic meter.
Standard errors are in parentheses

Table 2: The Effect Of Power Plants Closure On Air Quality

	0-20 Miles				0-10 Miles	+/-5 years	Balanced sample
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Estimated effect on O3							
Near x After	-0.093**	-0.037	-0.074**	-0.044	-0.038	-0.065**	-0.069**
	(0.036)	(0.035)	(0.029)	(0.032)	(0.049)	(0.03)	(0.033)
Observations	212305	212305	212305	212305	140826	131361	144549
Panel B: Estimated effect on SO2							
Near x After	-0.483***	-0.289**	-0.562***	-0.403***	-0.461***	-0.363***	-0.193***
	(0.137)	(0.13)	(0.121)	(0.111)	(0.103)	(0.116)	(0.102)
Observations	76383	76383	76383	76383	51341	52303	56777
Panel C: Estimated effect on PM2.5							
Near x After	-0.131	-0.078	-0.109	-0.019	-0.07	-0.036	-0.035
	(0.125)	(0.067)	(0.092)	(0.061)	(0.071)	(0.064)	(0.068)
Observations	82661	82661	82661	82661	70788	50780	63775
Year FE	Yes	No	No	No	No	No	No
Distant FE	Yes	No	No	No	No	No	No
Plant-year FE	No	No	Yes	Yes	Yes	Yes	Yes
Distance-year FE	No	Yes	No	Yes	Yes	Yes	Yes

Notes: This table shows the estimation results from equation (1). The dependent variable is one of the pollutants (in log), O_3, SO_2, and $PM_{2.5}$. Column 1-4 reports the estimation coefficients and it shows that how pollution concentration react to the policy in 20 miles of the plants relative to 20-40 miles. In column 5, the treatment group is changed to 10 miles of the plants keeping the counterfactual the same. In column 6, the sample is restricted to five years before and after plants closure. Column 7 reports the results from a balanced sample where only monitors that are in the sample before and after nearest power plant's shut down are kept. Robust standard errors are clustered by Forward Sortation Areas (FSAs).
Standard errors in parentheses ="* p<0.10 ** p<0.05 *** p<0.01"

Table 3: The Effect Of Power Plants Closure On Air Quality, Continued

	0-20 Miles				0-10 Miles	+/-5 years	Balanced sample
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Estimated effect on NOx							
Near x After	0.152	0.060	0.137**	0.058	0.019	0.083*	0.073
	(0.092)	(0.065)	(0.066)	(0.051)	(0.064)	(0.043)	(0.045)
Observations	188458	188458	188458	188458	161817	111346	163514
Panel B: Estimated effect on NO2							
Near x After	0.140*	0.047	0.113*	0.049	0.005	0.066*	0.060
	(0.078)	(0.057)	(0.064)	(0.046)	(0.055)	(0.039)	(0.037)
Observations	190741	190741	190741	190741	163826	113554	165497
Panel C: Estimated effect on NO							
Near x After	0.250*	0.176*	0.231**	0.157*	0.129	0.190**	0.167**
	(0.138)	(0.097)	(0.099)	(0.083)	(0.107)	(0.079)	(0.079)
Observations	177792	177792	177792	177792	151254	106159	153771
Year FE	Yes	No	No	No	No	No	No
Distant FE	Yes	No	No	No	No	No	No
Plant-year FE	No	No	Yes	Yes	Yes	Yes	Yes
Distance-year FE	No	Yes	No	Yes	Yes	Yes	Yes

Notes: This table shows the estimation results from equation (1). The dependent variable is one of the pollutants (in log), NO_x, NO_2, and NO. Column 1-4 reports the estimation coefficients and it shows that how pollution concentration react to the policy in 20 miles of the plants relative to 20-40 miles. In column 5, the treatment group is changed to 10 miles of the plants keeping the counterfactual the same. In column 6, the sample is restricted to five years before and after plants closure. Column 7 reports the results from a balanced sample where only monitors that are in the sample before and after nearest power plant's shut down are kept. Robust standard errors are clustered by Forward Sortation Areas (FSAs).
Standard errors in parentheses =" * p<0.10 ** p<0.05 *** p<0.01"

8 Figures

8.1 Map

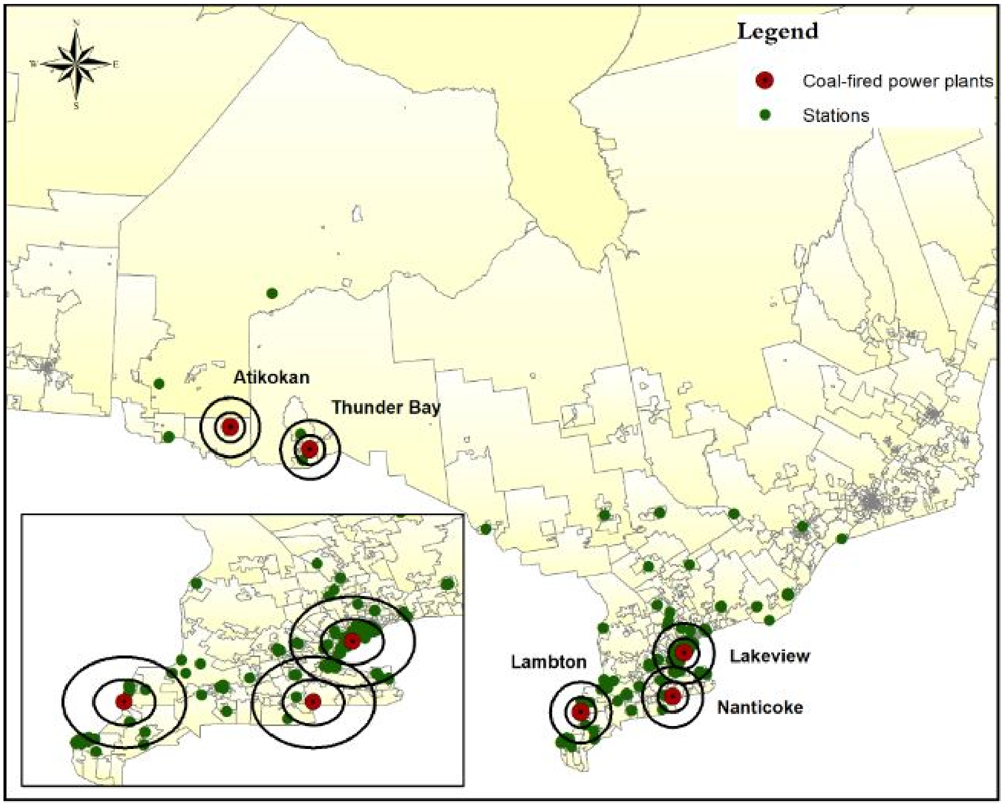

Figure 1: Map of Ontario coal-fired power plants and monitoring stations in forward sortation areas

8.2 Local Polynomial Graphs

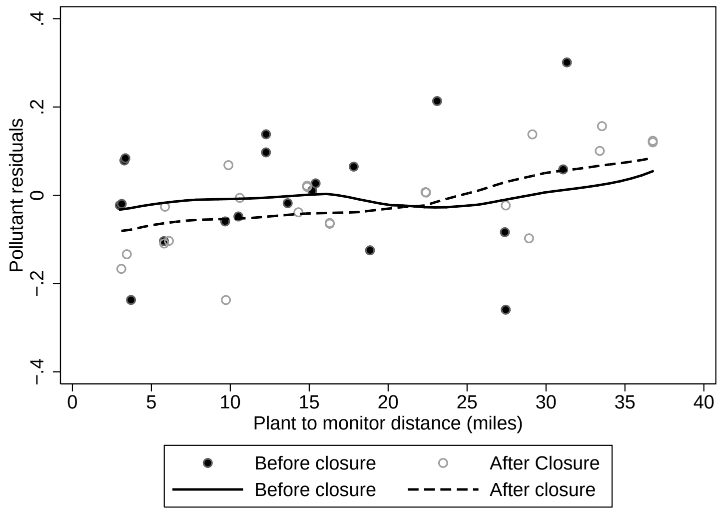

Figure 2: Average pollution by distance from power plants before/after closure, O3

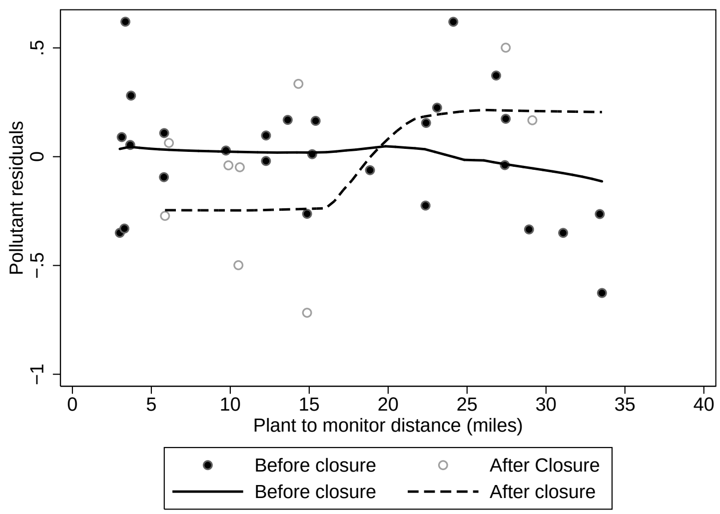

Figure 3: Average pollution by distance from power plants before/after closure, SO2

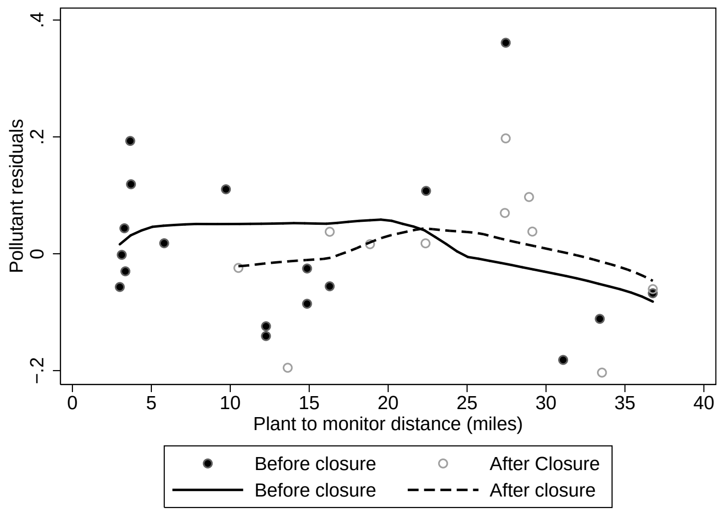

Figure 4: Average pollution by distance from power plants before/after closure, PM2.5

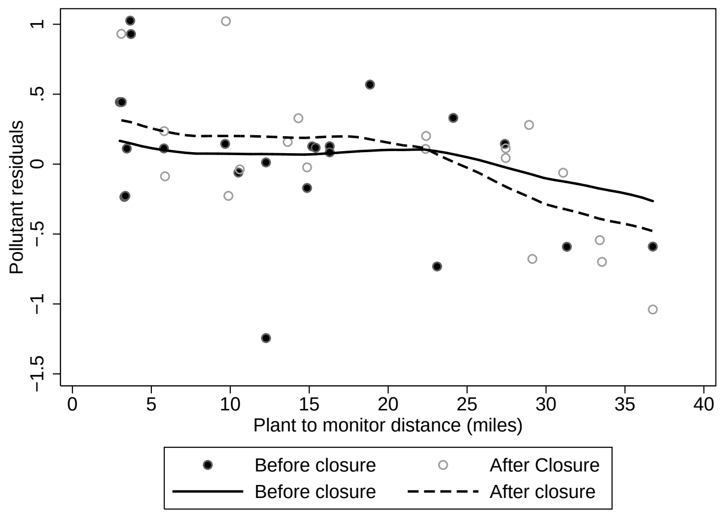

Figure 5: Average pollution by distance from power plants before/after closure, NO

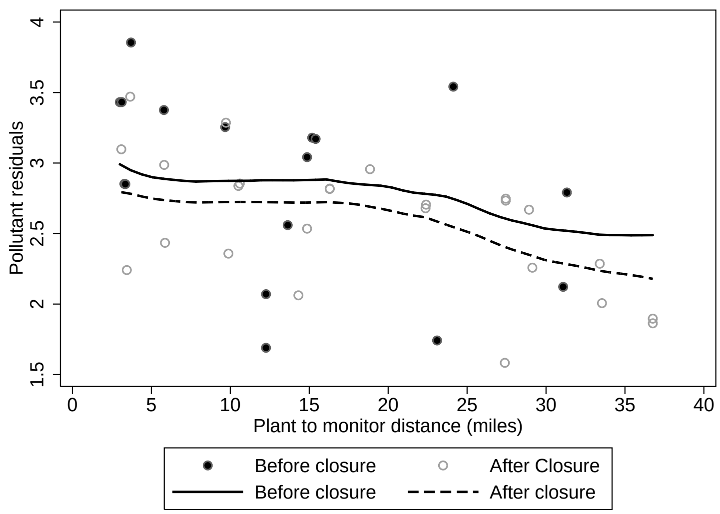

Figure 6: Average pollution by distance from power plants before/after closure, NOx

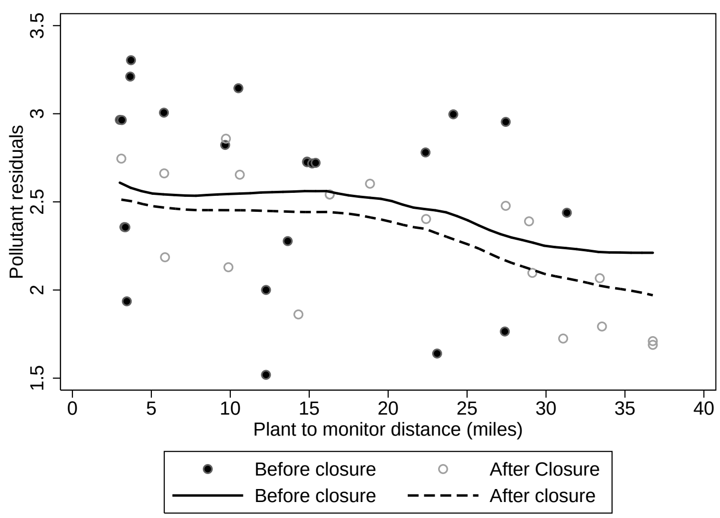

Figure 7: Average pollution by distance from power plants before/after closure, NO2

8.3 Common Trend Assumption

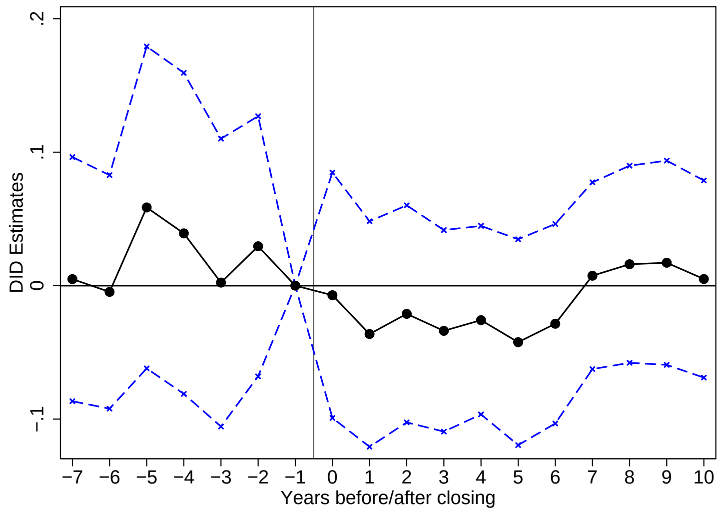

Figure 8: Even Study: The Effect of Coal Plants Closure on Pollution Level, O3

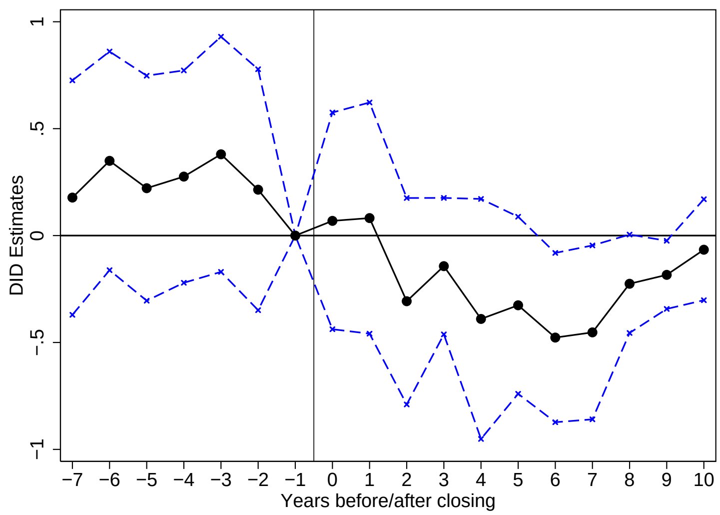

Figure 9: Even Study: The Effect of Coal Plants Closure on Pollution Level, SO2

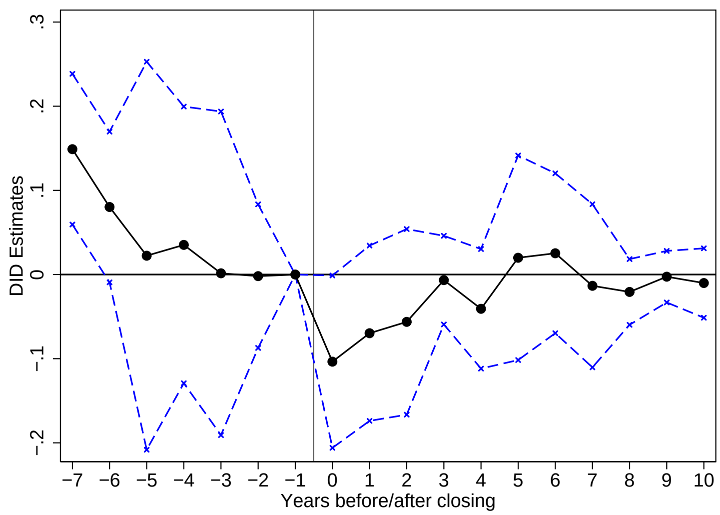

Figure 10: Even Study: The Effect of Coal Plants Closure on Pollution Level, PM2.5

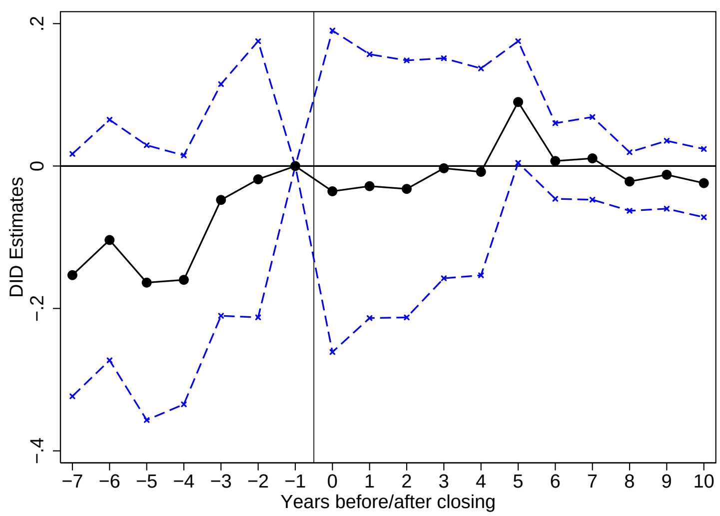

Figure 11: Even Study: The Effect of Coal Plants Closure on Pollution Level, NOx

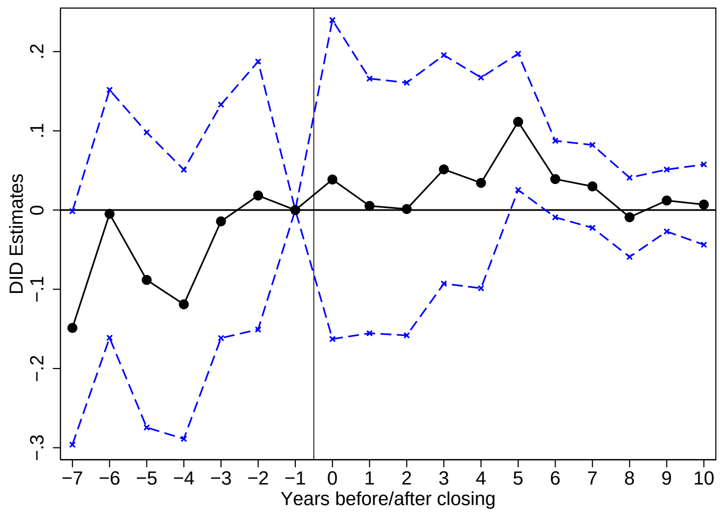

Figure 12: Even Study: The Effect of Coal Plants Closure on Pollution Level, NO2

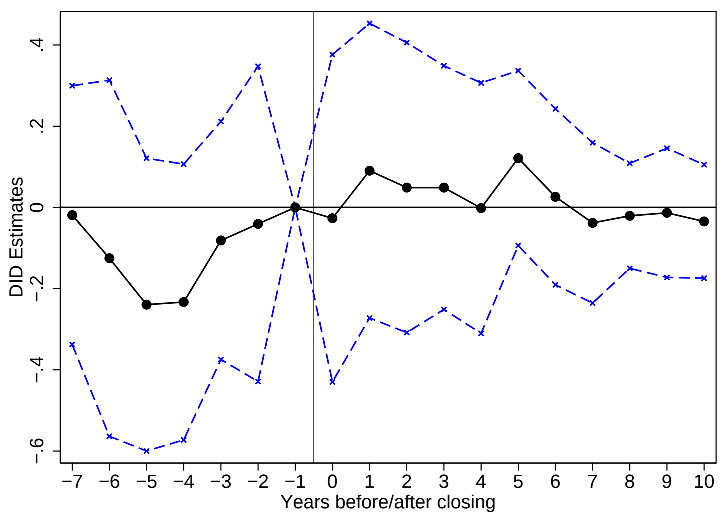

Figure 13: Even Study: The Effect of Coal Plants Closure on Pollution Level, NO

Appendix A. Data preparation

The raw dataset includes hourly air pollution level from 2000-2017 for 109 provincial and national air pollution monitoring stations. Information on national monitors is publicly available through NAPS network information . It includes hourly reading from 68 monitors in the province of Ontario for each year and pollution type. Then, I merged the data with hourly readings from 41 provincial monitors available at OME historical air quality pollutant data which is stored separately for each monitor, year, and pollutant. I downloaded each file and compile them in a single data file, using R software, before merging with NAPS dataset. I use hourly data to find average daily air pollution level.

The next stage is to restrict the dataset to monitors that were located in 40 miles of coal-fired power plants. To do so, I use ArcGIS to find the distance of each monitor from closest coal-fired power plant using latitude and longitude of power plants and monitors. This reduced the number of monitoring stations to 55 in the dataset I use for this paper. Many of these monitors track specific pollutants and some of them record all pollutants. However, many of them just operate for a subset of the sample and years. This is the reason for excluding CO from the analysis as there are very few monitors which record CO level close to power plants before and after the power plants closure.

One analytical concern is that some monitoring station track some specific pollutants during the years before (after) closing the nearest power plant and they do not record them after (before) the closure of that specific power plant. For instance, some monitors are in the sample for years before closure and are not present in the sample for all years after closure for a specific pollutant. To address this issue, I construct a balanced subsample including monitoring stations that are operation for at least one year before and after closure of the nearest power plant.