Pollution Emissions Impact of Public Transit: Evidence from a Long Strike

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Abstract

The Government of Canada will spend $20.1 billion over the next ten years, through the Budget 2017, to improve public transit infrastructure in Canada. Previous literature shows that public transit can reduce traffic congestion and consequently improve commutes and reduce air pollution. Using panel data from the Ontario Ministry of the Environment and Climate Change, I conduct a triple difference-in-difference regression to observe the impact of the 51-day OC Transpo strike in Ottawa on air pollution. Similar to previous literature, at the time of the strike during rush hour, the ambient concentration of particulate matter ($PM_{2.5}$) increased by 2.02% of a standard deviation. In contrast, I find a decrease in the concentrations of nitric oxide (NO) and nitrogen oxides (NO_X) by 9.6% and 6.5% of a standard deviation, respectively. These results suggest that not all public transportation is good, and that inefficient or aging infrastructure may contravene with the intended positive environmental impact of public transit.

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1. INTRODUCTION

Public transit in major urban cities requires substantial continued public funding to improve and expand infrastructure to accommodate changes in ridership. The Canadian federal Budget 2016, through Public Transit Infrastructure, declared a $3.4 billion investment into public transit improvements across Canada. Following this, the Canadian Federal Budget 2017 announced the delivery of $20.1 billion in new funding to build, expand, and further improve Canada's public transit systems (Infrastructure Canada, 2018). In 2011, Federal, Provincial, and Municipal funding accounted for 14%, 68%, and 15% of total public transit capital investment (CUTA, 2013). The Canadian Government's public transit subsidies are believed to create positive externalities that benefit Canadians by improving commutes and air pollution. The impacts associated with public transit are well documented in current literature. On one side, literature suggests that public transit investments do not improve congestion and even reduce social welfare of citizens (Stopher 2004; Winston & Maheshri 2007). On the other side, literature strongly suggests that the benefits of public transit outweigh the costs of investment and subsidization.

The public transit system in Washington, DC was found to reduce on-road congestion by 184,000 person-hours each day (Nelson et al., 2007). In Los Angeles 2013, highway transit delays increased on average by 47% during a transit union strike (Anderson, 2014). It is estimated that the annualized operating financial benefit of public transit in Los Angeles is $1.2 billion to $4.1 billion through reduced on-road congestion (Anderson, 2014). Moreover, it was concluded that the increased supply of public transit in Quebec City resulted in a significant positive fiscal impact of $6 million and added-value for home owners of $35 million over twelve years (Dubé et al., 2010). In aggregate, the economic benefit and reduction of vehicle operating costs for Canadians provided by public transit on an annual basis are estimated at approximately $10 billion and $5 billion, respectively (CUTA, 2010).

In a Canadian context, understanding the benefits of public transit has become increasingly important. Since 1996, the Canadian federal government's public transit infrastructure investments increased the number of commuters taking public transit to get to work by 59.5% (Statistics Canada, 2017). In 2016, the number of working Canadians commuting to work living in urban metropolitan areas was 73.5% or 11.7 million people (Statistics Canada, 2017). Further, Canadian cities such as Vancouver, Toronto, and Ottawa have grown by 6.5%, 6.2%, and 5.5%, respectively (Statistics Canada, 2017). As metropolitan areas across Canada continue adapting to increasing population growth, understanding how public transit increases urban mobility and reduces pollution is crucial. Infrastructure Canada (2017) notes that:

> "Canadian cities have been growing at a rapid rate, but investment in public transit has not kept pace. This has led to more traffic congestion…The gridlock that results has a serious financial impact—costing Canada's economy billions of dollars in lost productivity each year—and is damaging to the environment."

Despite this, a relatively small body of economic literature examines the environmental impact(s) of public transportation. Nonetheless, providing efficient mass transit such as metro, light rail, and bus rapid transit (BRT) in urban developed cities is vital to improve economic, social, and environmental wellbeing of urban areas (UN Habitat, 2013).

It is understood that efficient public transit systems reduce the number of on-road vehicles by moving many people with fewer vehicles. In Taipei, the opening of an urban rail transit system reduced carbon-monoxide emissions, a pollutant primarily emitted by petrol vehicles, between 5% to 15% (Chen & Whalley, 2012). Most recently, a study focused on the impact of one-day public transit strikes in German cities observed significant increases of traffic volumes and travel times which were associated with significant increases of vehicle collisions, particle pollution, and admissions to hospitals for respiratory related illnesses among children (Bauernschuster et al., 2017). Henceforth, this paper will address the environmental impact of the 51-day OC Transpo strike in Ottawa between 2008 and 2009. Similar to previous literature focused on the environmental impact of public transit strikes, I find an increase in the concentration of ambient particulate matter during rush hour. However, opposing previous literature, I find a decrease in ambient nitric oxide concentration during the same period. These results suggest that public transit can contribute to ambient levels of pollution particularly when a transit system is out of date and inefficient as OC Transpo was in 2008 and 2009. With this, the environmental impact of public transit is relevant for all levels of Canadian government when determining the types of investment into and the necessity of public transit services – a service deemed essential for the first time in Canada in the City of Toronto as of 2011 (CBC News, 2011).

The organization of this paper is as follows. Section 2 will briefly discuss previous literature regarding externalities of strikes and specifically the impact of public transit strikes on pollution and the public. Section 3 reviews Ottawa's public transit service, OC Transpo, pertaining to its ridership, fleets of buses and trains, and alternative means of transportation specifically in 2008 and 2009. Section 4 describes the pollutants of interest concerning their formation, primary sources, and environmental and health impacts. Section 5 describes the sets of pollution data from the Ministry of the Environment and Climate Change (MOECC) used for the regression analyses and presents descriptive statistics. Section 6 outlines the preparation of data for analysis, methodology for the triple difference-in-difference, initial results, and checks for robustness. Section 7 concludes by comparing my results to previous literature and provides possible explanations for the differences observed regarding environmental impact of public transit strikes.

2. LITERATURE REVIEW

2.1 Necessity of services, strikes, and impact

On January 28, 2009, the Minister of Labour, Hon. Rona Ambrose, confirmed that she approached the Liberal Party to enforce back to work legislation after 49 days of unsuccessful negotiation attempts with the Amalgamated Transit Union (ATU) local 279 (Reevely, 2009). At the time, public transit was not considered an essential service nor is it currently considered an essential service in the province of Ontario with the exception of Toronto. However, during the

OC Transpo strike the necessity of Ottawa's public transit services became apparent due to the substantial adverse impact on citizens mobility during that time.

The right to strike is subjected to restrictions for services deemed essential. Essential services are defined by the ILO as services which "the interruption of which would endanger the life, personal safety or health of the whole or part of the population" (ILO, 1983b, para. 214). Over time, the ILO recognized the evolution of non-essential services to that of essential services given that "a non-essential service may become essential if a strike lasts beyond a certain time or extends beyond a certain scope, thus endangering the life, personal safety or health of the whole or part of the population" (ILO, 1996d, para. 541). Leading into the 1990's the academic consensus concerning the impact of strikes were the financial implications for parties directly involved. Beyond that, it was believed that the cost to non-involved third parties was negligible (Kaufmann, 1992).

Recent literature has found significant evidence supporting that the impact of strikes goes beyond the financial implications for primary parties. It has been observed that nurses' strikes in hospitals can increase mortality and readmission rates of patients, suggesting that strikes increase the number of deaths amongst patients (Gruber & Kleiner, 2012). In the Canadian and Belgium schooling system, educators' strikes negatively impacted students academic achievements (Belot and Webbink, 2010; Baker, 2013). In the industrial sectors, union strikes at tire factories have been found to impact the quality of production increasing the number of fatal accidents (Krueger & Mas, 2004). Further, temporary reductions in energy production as a result of an oil refinery strikes in France led to positive outcomes for newborn children in surrounding areas (Lavaine & Neidell, 2017). Following these results, it is reasonable to assume that public transit strikes or even the ability of public transit unions to strike may produce externalities otherwise unconsidered. Thus, it becomes logical to explore beyond the financial impacts of transit strikes and consider their impacts on the health and safety of the environment and the public.

2.2 Public transit strikes impact on pollution and public

It is reasonable that essential services should include those provided by military, police, firefighters, or hospitals but why not public transportation? It is believed that transportation workers pose a primarily economic threat rather than a threat to public health and safety and therefore should have the ability to strike (Swearengen, 2010). Contrastingly, more recent literature finds significant non-financial impacts of public transit strikes on air pollution and public health and safety (Bauernschuster et al., 2015).

Public transit strikes significantly increase travel times due to congestion. This notion is supported with significant evidence from urban metropolitan cities in Germany, United States, and the Netherlands (Bauernschuster et al. 2015; Anderson, 2014; Alder & Ommeren, 2016). Externalities associated with public transit strikes extend beyond longer daily commutes. Vehicles are most fuel and emission efficient when functioning at consistent midrange speeds (Davis & Diesel, 2007). The consistent acceleration and deceleration of vehicles in congested traffic does not allow vehicles to reach optimal functional efficiency and consequently emit higher quantities of air pollution. Supporting the link between public transit, traffic congestion and pollution, empirical evidence finds that high-levels of traffic congestion can increase ambient pollutants in urban areas (Currie & Walker, 2011; Knittel et al., 2016).

Currently, the body of literature observing the impact of public transit strikes on the environment is relatively scarce. The most complete and comprehensive study quantifying the impact of public transit strikes on public and the environment was conducted by Bauernschuster et al. (2017). Using panel data from 2002 to 2011, they observe the impact of 71 one-day public transit strikes across 5 major cities in Germany. In their study they determine that public transit strikes increase traffic volume which is associated with a 14% increase in vehicle crashes and a 20% increase in accident-related injuries. More important for this study, the higher traffic volumes during peak hours caused by transit strikes are associated with a 14% increase particulate matter which is a main traffic-related pollutant. Further, they observed an 11%

increase in infant hospital admissions for respiratory related illness and disease. Motivated by these findings, this paper explores the environmental implications of transit strikes to answer the question: How did the 2008-2009 OC Transpo strike in Ottawa impact ambient air pollution?

3. REVIEW OF OC TRANSPO SERVICES

3.1 OC Transpo

OC Transpo is the urban transit system for the city of Ottawa, the sixth-largest city in Canada with a population of almost 1,377,000 inhabitants (Statistics Canada, 2018). With 95.6 million annual riders or approximately 340,000 daily trips with OC Transpo in 2007, the transit system is clearly an important component of the urban commute strategy (City of Ottawa, 2008). This system came to a halt on December 10th, 2008 when the ATU local 279 went on strike. This strike lasted 51 days until the federal government threatened to impose back-to-work legislation. The city of Ottawa and ATU came to an agreement on January 29, 2009 officially ending the strike. The O-Train Trillium Line began servicing customers on February 2, 2009 followed by bus lines on February 9, 2009 thus resuming services to pre-strike capacity.

3.2 OC Transpo: Services

OC Transpo's public transit system consists of two main services: buses travelling on fixed routes in mixed traffic and a rapid transit system. The former operates 126 bus routes on normal streets amongst traffic in the city of Ottawa. The latter is segmented into two independent rapid-transit systems: Transitway consisting of bus rapid transit (BRT) and O-Train light rail transit (LRT). The Transitway roads are unique in that they are designed specifically for the BRT service and rarely intersect with regular road traffic. Transitway's use is restricted to that of the 10 BRT lines allowing the OC Transpo BRT system to operate at consistent speeds with minimal interruptions. The Transitway carries approximately 230,000 passengers through weekdays of which approximately 10,000 passengers are accounted for during peak hours one-way volume. The O-Train, which does not intersect with regular road traffic, operates a single service line, Trillium, running north-south through Ottawa and carrying 10,000+ daily riders (OC Transpo, 2015).

Given the number of daily riders on and the exclusive structure of Ottawa's rapid transit system, it is reasonable to believe that it reduces on-road congestion and subsequently reduces pollution emissions associated with vehicle traffic. To better understand which pollution emissions are associated with either diesel or petrol fueled vehicles, section 4 will discuss the formation and sources of common traffic-related pollutants. Before this, I will identify the types of on-road and railed vehicles used by OC Transpo to understand how the 2008/09 strike could impact various air pollutants.

3.3 OC Transpo: Bus and O-Train fleets

Leading into the 2008/09 transit strike, OC Transpo operated a fleet of 230 buses and 9 train cars in total. Of the 230 buses in operation at the time, 53 were New Flyer D60LFs and the remaining 177 busses were Orion VII Hybrids (OC Transpo, 2018). The New Flyer D60LFs were diesel fueled and the larger of the two busses. They were used on higher-capacity routes, measuring 60ft in length, and featured an mid-point extension joint at the centre of the bus (New Flyer, n.d.). The Orion VII Hybrids, were diesel-electric fueled allowing the buses to have a 25% reduction in fuel-consumption and decreased emissions compared to standard diesel buses (Toronto Transit, 2017). The Trillium line was serviced by three 3-unit Bombardier Talent BR643 diesel LRT trains. As it will be demonstrated in section 6, OC Transpo's reliance on an older diesel transit fleet had specific pollution implications during the strike.

3.4 OC Transpo: Transit Strike Alternative Transportation

During the strike period, commuters only had limited options to make their daily commute. Their first option was to use their own cars to go to work. Parking likely became an issue, since parking lots did not have the capacity to harbor this new traffic. A second option was to walk or bicycle to work. With average temperatures of -20 during the second week of January and a total snowfall of 76.8 cm in January (Government of Canada, 2018), this option would not sound very tempting for most people. A third option was home-office. The Canadian federal government, the major employer in Ottawa, introduced a policy enabling tele-working in 1999. Managers have the discretion to allow or not their employees to work from home. One can imagine that managers would have been inclined to show some flexibility during the period of the strike. Finally, commuters could have decided to carpool. While requiring a certain level of organization, carpooling maximizes use of the cars already in traffic and reduces the burden on parking lots.

These different strategies have different implications on pollution. If commuters choose to walk, to take advantage of teleworking or to car share, the strike may not have much of an environmental impact on the city. In fact, there could be a reduction in pollution, because the OC Transpo with their relatively older diesel engines could be important polluters themselves. Research on school busses has shown that they have important health consequences on children riding them, on schools they are serving, and on the neighbourhoods through which they are driving (Beatty & Shimshack, 2011). Similar research exists for public transit busses (Bauernschuster et al., 2017). Instead, if commuters decide to drive with their own cars, each full bus will be replaced by 40 to 60 single cars thus causing an increase in traffic congestion and ultimately air pollution.

4. AIR POLLUTANTS

In this section, I will describe the four commonly monitored air pollutants linked to traffic congestion as per the World Health Organization (2006) and the Government of Canada (2016) which include: nitrogen oxides (NO_X, specifically NO_2 and NO), particulate matter ($PM_{2.5}$), and ozone (O_3). For each pollutant, I will discuss properties and formation, primary sources, and short- to long-term environmental and health implications as indicated in current literature.

4.1 Types of air pollutants

(i) Nitrogen Oxide NO_X (NO, NO_2)

Of the seven nitrogen oxides produced by the chemical bonding of nitrogen and oxygen nitric oxide (NO) and nitrogen dioxide (NO_2) are emitted in the highest quantities. NO_X primary formation occurs during fuel combustion which accounts for 99% of technology-related NO_X (Annamalai, K., & Puri, I. K.,2007). The reaction of nitrogen and oxygen produces NO_x gases through three chemical reactions: nitrogen in fuel combines with oxygen in the combustion air; fuel hydrocarbons from crude oil break down and react with atmospheric nitrogen; high temperature combustion (form engines) force ambient nitrogen to synthesise with ambient oxygen (US EPA, 1999). The primary nitrogen oxide produced from combustion emissions is nitric oxide (NO) (Nylund et al. 2004). NO represents approximately 95% of the total NO_X gasses produced by combustion (Yaverbaum, 1979). NO is rapidly oxidized by ozone to form NO_2, a more toxic pollutant. The lifespan of NO_2 ranges from 100 to 200 years whereas other NO_X gases lifespans range from minutes to days. NO_2 has the potential to react in the atmosphere to form smog, ground-level ozone (O_3) and acid rain (Government of Canada, 2018).

During engine combustion, the internal temperature has a positive relationship with the quantity of NO_X emissions (Schifter et al., 2014). A diesel combustion engine emits approximately 10 times more NO_X than an equivalent petrol car (Franco et al., 2014). Diesel engines operate at higher temperature and pressure with more oxygen content than petrol engines which increases NO_X emissions (Omersa., n.d.). The proportion of NO_2 emitted from a diesel vehicle is estimated at 60% compared to petroleum vehicles which range from 0-30% (Air-Quality UK, n.d.). These figures are dependent on the vehicle size and emission reduction technologies in use. Diesel vehicles emit more NO_X with a higher concentration of NO_2 than their petrol alternative and therefore are the primary contributors of toxic NO_2 pollutant (Air-Quality UK, n.d.). In Ontario, transportation including both public and private accounts for 69% of NO_X emissions in the province (Government of Ontario, 2012). In cities like Ottawa with a reliance on public diesel-fuelled transport it is reasonable to assume that there will be higher concentrations of NO_2 due to increased use of diesel public transit.

Long- and short-term health implications associated with exposure to NO_X gasses depend on the duration of exposure and the concentrations of NO_X gasses. Numerous epidemiological studies have found it difficult to determine the precise impact of NO_2 on health (WHO, 2006). This is due to the contributing effects of other correlated atmospheric pollutants. Elevated levels of NO_2 can cause lung irritation and promote lower resistance to respiratory infections. Specifically, people with asthma and bronchitis experience increased sensitivity. Further, there is an observed positive short-term relationship between elevated NO_2 levels and increased respiratory hospital admissions and emergency visits (EPA, 2008). “These associations were noted to be consistent amongst children and older adults (more than 65 years of age) for all respiratory diagnoses, and among children and all age groups for asthma admissions” (WHO, 2013, p.82). Further literature supports single-pollutant associations for emergency visits and hospital emissions for asthma (Colais et al., 2009; Giovannini et al., 2010) and respiratory illness (Faustini et al., 2013; Giovannini et al., 2010).

(ii) Particulate Matter ($PM_{2.5}$)

Particulate matter (PM) consists of a mixture of microscopic solid particles and liquid droplets suspended in the air. The major components of PMs are acids such as nitrates and sulphates; organic and inorganic chemicals; dust; pollen; metals; soot; and/or smoke (GreenFacts Scientific Board, n.d.). Particulate matter is separated into two groups of measurement which include coarse fractions containing larger particles ranging from 2.5 to 10 (PM_{10} – $PM_{2.5}$) and fine fractions containing particles less than or equal to 2.5_{um} ($PM_{2.5}$). Any particulate matter smaller than 2.5_{um} in diameter is labelled ultrafine. Particulate matter found in the air is emitted directly or formed indirectly. Direct or primary emission occurs when fuel is burnt or naturally when dust is carried by the wind. Indirect or secondary emission occurs when previously emitted pollutants in the air combine to form particulate matter (GreenFacts Scientific Board, n.d.). For this study, I am more concerned about directly emitted PM formed by combustion, which produces large quantities of fine particles 10_{um} in diameter or smaller (Cooper et al., 2012).

In general, diesel combustion engines emit higher quantities of primary particulate matter compared to petrol engines with a catalyst (Air-Quality UK, n.d.). This is a result of soot formation produced from partial combustion of diesel fuel in cooler parts of the cylinder where fuel burn is comparably less than in petrol engines (OmnaGen, n.d.). Compared to diesel engines, particle emissions for petrol vehicles have a higher dependence on operational factors including speed, engine load, and ambient temperature (Air-Quality UK, n.d.). Petrol vehicles have been found to emit the same number of PMs in some operational modes for example when the ambient temperature is -7 degrees or less (Eriksson & De Serves, 2008).

Exposure to fine particulate matter over short (a day) and long periods (more than a year) are associated with adverse health implications. Fine particulate matter with a diameter of less than 2.5_{um} have considerably greater health implications than coarse particles. $PM_{2.5}$ are observed to have the greatest adverse impact on human health observed in urban environments. The human body is unable protect itself from exposure to fine and ultrafine particles. Through respiration, these particles enter the heart and lungs leading to serious health implications, including respiratory diseases and lung conditions (EPA, 2012a). Previous literature demonstrates that short-term exposure to fine particulate matter is positively associated with hospital admissions. Furthermore, positive associations between daily emissions of particulate matter and daily emergency room visits and diagnoses for respiratory illness have been observed (EPA, 2009; Bauernshuster et al., 2017). People with persisting health conditions such as asthma, cardiovascular or lung disease, as well as children are more sensitive to the impacts of particulate matter on health. Children's continuing respiratory development, smaller lung size, and higher activity levels make them more susceptible illness induced by particulate matter (Beatty & Shimshack, 2014).

(iii) Ground-Level Ozone (O_3)

Ozone (O_3) is found within the earths troposphere extending from the earths surface to 12-20 kilometres above sea level. Ground-level ozone (GLO) is a secondary pollutant formed through the reactions of two primary pollutants in the presence of sunlight and stagnant air (Government of Canada, 2016). In ambient air, GLO is formed by a photochemical reaction between sunlight and nitrogen dioxides catalysed by volatile organic compounds (VOCs, photochemically reactive hydrocarbons). Ambient concentrations of ozone are partial to intensity of solar radiation, concentrations of NO_X and VOCs, as well as the ratio of NO_X and VOCs. In Ontario, the highest levels of observed O_3 occur from May to September and between noon and early evening when the sun is positioned more overhead where more solar radiation reaches earths surface (Government of Ontario, n.d.). At nighttime, the concentration of ambient O_3 is depressed in the presence of large emissions of NO (e.g. automobiles, industrial) through a NO_X titration process (Sillman, n.d.). O_3 is removed as it reacts with NO to form NO_2 and O_2 (oxygen). Further, without sunlight residual O_3 reacts with NO_2 to produce NO_3 and O_2 (Ball, 2014). For this reason, peak O_3 concentrations are found mid-day (in summer months) and is the principal ingredient of smog, a pollutant associated with photochemical reactions.

O_3 precursors (NO_X and VOCs) are derived from both natural and anthropogenic sources. Naturally occurring VOCs are emitted from trees and plants, which in some locations may account for two thirds of ambient VOCs in some locations (US EPA, 1986). A few specific anaerobic biological processes are found to contribute up to 90% of naturally occurring NO_X emissions (Godish, 1991). Anthropogenically sourced ground-level O_3 is driven primarily by motor vehicles through NO_X emissions (World Bank Group, 1999). Given that diesel engines emit more NO_X on average, it follows that these engines produce more O_3 precursors than petrol engines. In contrast, petrol engines emit a significantly higher number of VOCs than diesel because of the volatility of petrol fuel (Government of B.C., n.d.).

GLO found above the earths surface is much less concentrated than that found elsewhere in the troposphere but has a greater impact on human health. Most notably, ambient O_3 is found to have adverse impacts on the reparatory system. As a primary component to smog, O_3 can be attributed to acute symptoms including choking, coughing, and stinging eyes (US EPA, 2012a). Further, attributes short-term exposure is associated with chest discomfort, thoracic pain, headache and decrements in children's' pulmonary functions at elevated hourly levels of O_3 (WHO, 1987). There is no conclusive evidence suggesting that certain groups of individuals demonstrate higher sensitivity to heightened ground-level O_3 levels. Long-term ozone exposure is associated with aggravated asthma and possibly a cause of asthma. Elevated long-term exposure is also believed to be linked to permanent lung damage (US EPA, 2017).

5. AIR POLLUTION DATA & DESCRIPTIVE STATISTICS

5.1 Data Set

In Ontario, “The Ministry of the Environment and Climate Change (MOECC) works to protect and improve air quality through legislation, targeted programs, and partnerships with other jurisdictions. The MOECC has a network of 38 ambient (outside) air monitoring stations across the province that collect real-time air pollution data” (Government of Ontario, n.d.). Hourly data is collected for O_3, $PM_{2.5}$, NO_X (NO_2 and NO), CO, SO_2, and total reduced sulfur compounds (TRS) which are all publicly available online through the MOECC. For the purpose of this study, I use hourly pollution data from 19 environmental stations across Ontario. A map showing all Ontario environmental station locations can be seen in 9-1. Appendix A.

5.2 Descriptive Statistics

Table 1.1 shows descriptive statistics of pollutants for all 19 environmental stations in Ontario. In Table 1.1, the number of observations for PM, NO, NO_2, NO_x, and O_3 for all of Ontario is around 300,000, but the total for SO_2 is only slightly more than 165,000. The large standard deviation associated with each pollutant relative to their means suggest large fluctuations in pollution measurement data. The relatively high maximum values indicate that the distribution of such pollutants is highly skewed to the right (see 9-2. Appendix B – Kdensity Graphs). These observations are indicative of extreme outliers that may impact the regression analysis which is addressed in section 6.4.

Table 1.1: Descriptive Statistics Ontario

Pollutant	N	Mean	Standard deviation	Min	Max
PM	326706	6.37	5.97	0	102
NO	290343	5.37	12.74	0	377
NO_2	290341	12.72	9.71	0	81
NOx	290342	18.09	19.90	0	445
O_3	330077	25.02	14.11	0	94
SO_2	165474	2.30	4.32	0	136

6. METHODOLOGY & RESULTS

6.1 Missing Values

Each environmental stations' hourly pollution data contained missing or invalid data. Air Quality Ontario gives missing data a value of "-999" and invalid data a value of .9999. To prepare the data for the triple difference-in-difference regression it is necessary to remove all missing data. Simply replacing missing or invalid data with "." allows a regression analysis to be successfully performed on the data set. Of the 19 environmental stations analysed in this study, a total of 13 do not contain data recorded for carbon monoxide. For this reason, carbon monoxide will not be assessed in the regression analysis as the results would not truthfully represent the impact of the strike. Further, a total of 10 environmental stations do not contain recorded data for sulfur dioxide. Previous literature utilizes sulfur dioxide as a placebo as it is not a major traffic related pollutant (Bauernschuster et al., 2017). For this reason, SO_2 is included in the regression analysis keeping in mind that over half of the environmental stations do not contain SO_2 data.

6.2 Triple Difference-in-Difference

To determine whether the 2008/09 OC Transpo strike had an environmental impact on the city of Ottawa, I conduct this triple difference-in-difference regression for four common vehicle pollutants (NO, NO_2, $PM_{2.5}$, O_3,) and use SO_2 as a placebo:

$$\begin{aligned}
\text{Pollutant}_{idh} &= \beta_0 + \beta_1\text{Strike * Rush hour}_{dh} + \beta_2\text{Ottawa * Rush hour}_{id} \\
&+ \beta_3\text{Ottawa* Strike time * Rush hour}_{idh} + \beta_4\text{Time lag} \\
&+ \beta_5\text{Quadratic time trend}_{dh} + \beta_6\text{Holidays dummies}_{d} + \beta_7\text{Day of the week dummies}_{d} + \beta_8\text{Hour} \\
&\text{of the day*Weekday dummies}_{dh} + \beta_9\text{Hour of the day*Weekend dummies}_{dh} + \beta_{10}\text{Month} \\
&\text{dummy}_{d} + \beta_{11}\text{Station dummies}_{i} + U_{idh}
\end{aligned}$$

(Equation 1.1)

Whereby "i" stands for the environmental station, "d", for the day and "h", for the hour. The standard errors are clustered at the station level to address correlated shocks at a given station.

Clustering standard errors at the highest aggregation level, station level, follows previous literature whereby standard errors could be biased as a result of serial correlation (Bertrand et al., 2004; Bauernschuster et al., 2017). Further, I address serial correlation by including a lag dependent variable which was not included in the literature previously cited.

The coefficient of interest is β_3 which captures any difference in the level of pollution during the rush-hour[1] during the strike in Ottawa. If pollution was greater in all of Ontario during rush-hours during the strike, the coefficient β_1 will be positive and statistically significant. If pollution during rush-hour in Ottawa is generally greater than elsewhere in Ontario, the coefficient β_2 will be positive and significant. The dummies “Hour of the day*Weekday dummies” will control for any intra-day variation in pollution during work days and capture any impact of rush hours on pollution. Finally, the station dummies address heterogeneity across different stations and control for pollution specific to Ottawa across the period.

The remaining control variables enable us to capture other relevant variation in pollution. The time lag captures the idea that pollution emitted in the past still has an impact on the present pollution. In other words, if there is a high percentage of NO_X in the air at 06h00 at the Ottawa Central station, there will most likely be a higher percentage of NO_X in the air at 07h00 at the Ottawa Central station. I followed the data and included only one lag. Other lags are usually statistically significant, but their magnitude is very small. The quadratic time trend reflects the fact that pollution may have a positive trend throughout the period. Finally, I include month dummies to control for variation in pollution due to seasonality which impacts the amounts of sunlight in a given month and consequently the concentrations of photochemical dependent pollutants like O_3.

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1. Rush hour is defined as the time between 7 AM and 9AM and between 5PM and 7PM on weekdays.

6.3 Results

Table 2.1 shows the impact of the strike on pollution during rush hour in Ottawa. There was an increase in the concentration of particulate matter (column 1), which represents 2.02% of a standard deviation. Interestingly, the strike led to a decrease in NO and NO_X, gasses emitted primarily by diesel engines, of 1.226 (9.6% of a s.e.) and 1.300 (6.5% of a s.e.), respectively. Following the significant decrease in NO and NO_x gasses at the highest level, it is surprising that the decrease in the concentration of NO_2 remains insignificant at all levels. A logical explanation for this phenomenon could be due to the fact that NO requires an abundance of O_3 for it to react and form NO_2. In Ontario, the ambient concentration of O_3 is highest from May to September when the weather is hot and sunny from noon to early evening.

Table 2.1: Impact of Strike on Common Pollutants

	(1) PM	(2) NO	(3) NO2	(4) NOX	(5) O3	(6) SO2
Strike*Rush hour	0.191***	1.373***	1.355**	2.815***	-1.439***	-0.322***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.007)
Ottawa*Rush hour	-0.0600**	-0.0897	0.163	0.143	-0.266	-0.102*
	(0.020)	(0.651)	(0.221)	(0.637)	(0.002)	(0.094)
Ottawa*Strike*Rush hour	0.130***	-1.226***	-0.0804	-1.300***	0.226*	0.171
	(0.006)	(0.001)	(0.500)	(0.003)	(0.066)	(0.142)
First lag	0.906***	0.847***	0.895***	0.877***	0.926***	0.792***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Time trend	-0.000467***	-0.000439	-0.000876***	-0.00142***	0.000791***	-0.000432
	(0.000)	(0.115)	(0.000)	(0.001)	(0.000)	(0.220)
Time trend squared	0.000000239***	0.000000323	0.000000750***	0.00000120**	-0.00000138***	3.97e-08
	(0.000)	(0.388)	(0.003)	(0.026)	(0.000)	(0.916)
Holiday_dummy	-0.149***	-0.848***	-0.921***	-1.756***	0.710***	-0.327**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.012)
DoW Dummy	X	X	X	X	X	X
HoD * Weekday	X	X	X	X	X	X
HoD * Weekend	X	X	X	X	X	X
Month dummy	X	X	X	X	X	X
Station dummy	X	X	X	X	X	X
Constant	0.678***	1.116***	1.514***	2.809***	0.656***	0.591**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.019)
N	324985	289727	289725	289727	329584	141397
r^2	0.831	0.738	0.843	0.800	0.914	0.645

p-values in parentheses

$*p<0.10$, $**p<0.05$, $***p<0.01$

Note: SO2 observation for January 21, 2009 at 07h00 was dropped as it is considered to be as an extreme outlier by MOECC

Therefore, the insignificant difference of NO_2 concentrations during the strike may be explained by typically low levels of O_3 during the winter months. One can notice an increase in O_3, but it is not statistically significant at the usual level. Again, this is not surprising given that ambient ozone is produced through a photochemical reaction between sunlight and NO_X gasses. Thus, concentrations of ozone are partial to the intensity of solar radiation which is characteristically low during December and January. Similar to that of previous literature, I find that the strike led to a statistically insignificant increase of 0.171 for SO_2[2].

6.4 Robustness

Due to factors other than the OC Transpo strike there exists probable threats to the significance of the coefficient of interest. As a result, air pollution measurements could be superficially high and not reflect the true impact of the public transit strike in Ottawa. In addition to the controls explained in section 6.2, atmospheric activity, fires, construction, and other polluting activities can produce otherwise unusual pollution recordings. In Table 1.1, the maximum value for each pollutant is substantially greater than the associated mean of each pollutant and beyond the bounds of each standard error. Therefore, it is possible that outliers in the data may be artificially influencing the impact of the OC Transpo strike on pollution. To test for the influence of outliers, I regress the natural logarithm of the dependent variables using equation 1.1.

Through regressing the natural logarithm of each dependent variable, I can observe coefficient sensitivity to outliers. By using the natural logs of the dependent variables, the extreme values are pulled inwards resulting in a narrowed distribution. Thus, by taking the natural log of the dependent variables I reduce the impact of extreme values. To avoid the loss of

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[2] On January 21, 2009 at 07h00 the Ottawa Downtown environmental station recorded a SO_2 value of 71µg/m^3. Initially, SO_2 was significant at the 95% level. After consulting with an analyst from MOECC, it was confirmed that such a measurement was not likely to be a result of the transit strike and more likely to be a result of a fire proximate to the environmental station. This value was therefore dropped for the purpose of this regression resulting in a statistically insignificant change of SO_2.

pollutant measurements equal to zero when regressing their natural logarithms, it is necessary to appropriately generate each pollutant's log variable. To do this, I conduct the following simple transformation:

$$gen\ lnPollutant_i = ln\ (Pollutant_i + 1)$$

By generating the natural logarithm plus a nominal value of one, I avoid any data loss. Table 2.2 shows the results of the logarithmic regression. Observing the values for the coefficient of interest, in the third row, the results remain mostly stable relative the initial regression. The respective log coefficients for PM and NO remain significant and retain their signs at the highest level. O_3 remains positive and becomes significant at the highest level as well. The log coefficient for NO_2 becomes significant and positive at the 95% level of confidence causing $lnNO_x$ (an amalgamation of nitrogen oxide gasses) to become insignificant. The value of $lnNO_2$ suggests that the negative statistically insignificant coefficient for NO_2 obtained in the initial regression could be driven by outliers in the rest of Ontario during the period of the strike in Ottawa. The log coefficient for SO_2, regressed for all SO_2 data points, remains statistically insignificant at all levels and positive which is crucial for the falsification test.

Table 2.2: Impact of Strike on Common Pollutants (logs)

	(1) lnPM	(2) lnNO	(3) lnNO2	(4) lnNOX	(5) lnO3	(6) lnSO2
Strike*Rush hour	0.0326***	0.0458***	0.0540***	0.0574***	-0.111***	-0.0394***
	(0.000)	(0.010)	(0.000)	(0.000)	(0.000)	(0.006)
Ottawa*Rush hour	0.000984	0.0592***	0.0391***	0.0564***	-0.0240**	-0.0136
	(0.822)	(0.005)	(0.000)	(0.000)	(0.022)	(0.111)
Ottawa*Strike*Rush hour	0.0426***	-0.0658***	0.0325**	0.0164	0.0376***	0.0169
	(0.000)	(0.001)	(0.048)	(0.337)	(0.000)	(0.342)
First lag	0.845***	0.859***	0.903***	0.902***	0.898***	0.859***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Time trend	X	X	X	X	X	X
Time trend squared	X	X	X	X	X	X
Holiday_dummy	X	X	X	X	X	X
DoW Dummy	X	X	X	X	X	X
HoD * Weekday	X	X	X	X	X	X
HoD * Weekend	X	X	X	X	X	X
Month dummy	X	X	X	X	X	X
Station dummy	X	X	X	X	X	X
Constant	0.272***	0.153***	0.237***	0.258***	0.238***	0.135***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
N	324985	289727	289725	289727	329584	165218
r^2	0.730	0.801	0.860	0.857	0.869	0.766

p-values in parentheses

$*p<0.10$, $**p<0.05$, $***p<0.01$

Note: All observations included

The falsification test used in previous literature regresses the placebo pollutant, SO_2, to determine the threat of unobserved time-varying factors correlated with the OC Transpo strike. SO_2 is no longer considered to be a major vehicle exhaust pollutant. Nonetheless, SO_2 emissions are dependent on various environmental conditions. Column 7 of Table 2.1 indicates that during the time of the strike in Ottawa there was an insignificant increase of 0.171 in SO_2. Supporting this result, the coefficient of SO_2 obtained from the logarithmic regression, which includes the previously dropped SO_2 value suggest that the significance of the SO_2 coefficient is driven by outliers unrelated to the OC Transpo strike. Following this logic, SO_2 is shown to be statistically unaffected by the strike. This result follows previous literature supporting the robustness of the observed impact of the strike on PM and NO.

7. CONCLUSION

The objective of this paper was to determine the environmental impact from a long public transit strike using hourly pollution emission data from 19 environmental stations across Ontario between January 1, 2008 and December 31, 2009. Using a triple difference-in-difference method, the initial results indicate that the 51-day-long OC Transpo strike in Ottawa increased ambient concentrations of $PM_{2.5}$ by 2.02% of a standard error and decreased concentrations of NO and NO_x by 9.6% and 6.5% of a standard error, respectively. After assessing the coefficients sensitivity to outliers and utilizing a falsification test, I observe that the significant differences during the strike time in Ottawa for PM, NO, and to a lesser extent NO_x and O_3, are robust. The statistical insignificance of the initial regression and logarithmic regression coefficients for SO_2 allow me to make this conclusion whereby the results truly reflect the impact of the strike.

Previous literature indicates that public transit strikes increase ambient levels of NO_2 and $PM_{2.5}$. These results are accompanied by statistically insignificant changes in the ambient levels of SO_2. Supporting previous literature, I observe a positive and statistically significant change in the ambient levels of $PM_{2.5}$ and no statistically significant change of SO_2 during the OC Transpo strike. As discussed in section 3(ii), petrol engine $PM_{2.5}$ emissions are more operationally dependent than their diesel counterpart. Consequently, factors such as operational load, speed, and ambient temperatures impact $PM_{2.5}$ emission rates for petrol engines. During the strike, approximately 10,000 people who used OC Transpo services during rush hour needed to find an alternative commute. These individuals would have likely resorted to automobiles increasing on-road traffic congestion particularly during rush hours. Without traffic data this is difficult to confirm. However, the increase in $PM_{2.5}$ is supported by literature that shows public transit strikes increase traffic congestion and consequently increases ambient measurements of $PM_{2.5}$ (Anderson, 2014; Bauernschuster et al., 2017).

Contrasting the findings of Bauernschuster et al. (2017), I observe a statistically significant negative change in NO and an inconclusive change in NO_2 resulting from the OC Transpo strike in Ottawa. The decrease in NO and NO_X could be due in part to the age of Ottawa's public transit fleet in 2008 and 2009. The average age of OC Tranpo's fleet was 7.1 years and 6.7 years in 2008 and 2009 (OC Transpo, 2010). Pollution emissions from buses can be affected by vehicle and engine specifications, age, and fuel blend (OC Transpo, 2010). Following this logic, the decrease of NO and NO_X emissions from inefficient buses could have been greater than any emissions increase from commuters who utilized alternative transportation means during the strike.

These results suggest that public transit has the potential to decrease pollution emissions by reducing congestion, but the magnitude of this impact is partial to the emissions efficiency of the public transit system infrastructure. Considering the emission inefficiencies of older public transit systems is crucial when municipal, provincial, or federal levels of government allocate funding towards investment in public transit infrastructure. Therefore, I show that not all public transit necessarily creates the desired positive environmental impact whereby outdated or inefficient public transit infrastructure may in fact create unintended negative environmental impacts.

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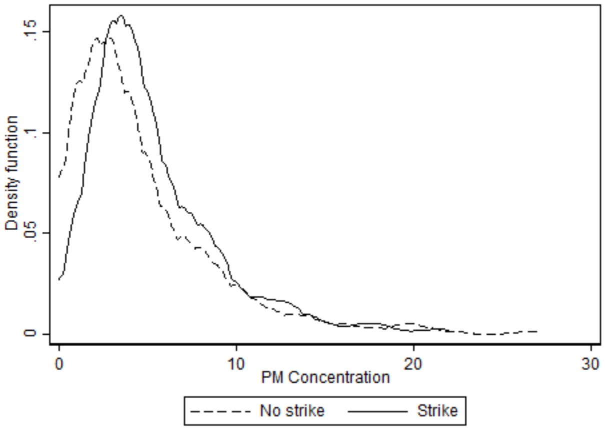
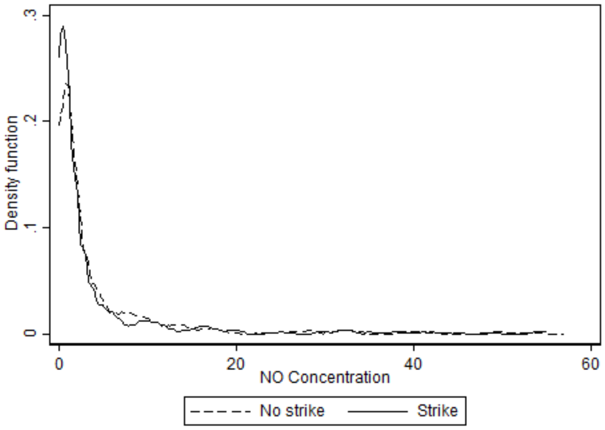
9. APPENDICES

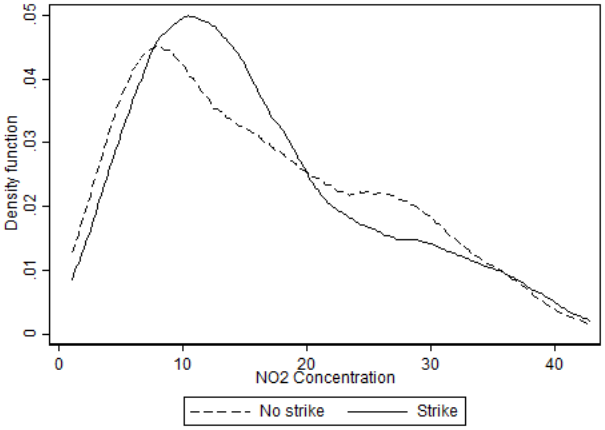
9-1. Appendix A – Ontario Environmental Stations Map

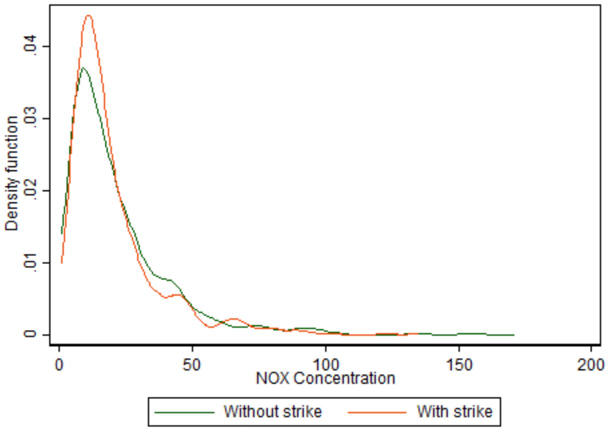
Legend		
Number	**Station**	**Station #**
1	Burlington	44008
2	Brampton	46089
3	Guelph	28028
4	Hamilton Downtown	29000
5	Hamilton Mountain	29114
6	Hamilton West	29118
7	London	15025
8	Mississauga	46108
9	Newmarket	48006
10	Oakville	44017
11	Oshawa	45026
12	Ottawa Central	51002
13	Ottawa Downtown	51001
14	Toronto Downtown	31103
15	Toronto East	33003
16	Toronto North	34020
17	Toronto West	35125
18	Windsor Downtown	12008
19	Windsor West	12016

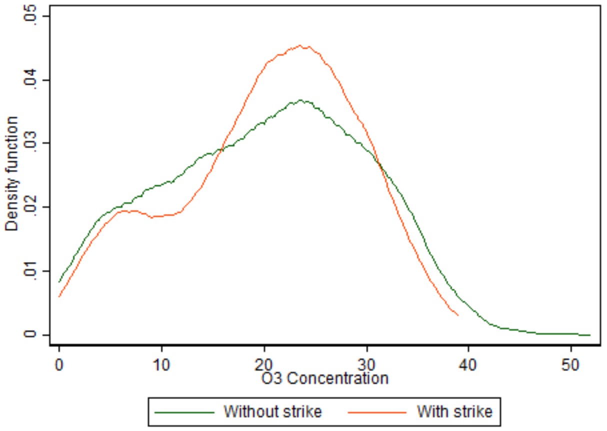
9-2. Appendix B – Kdensity Graphs

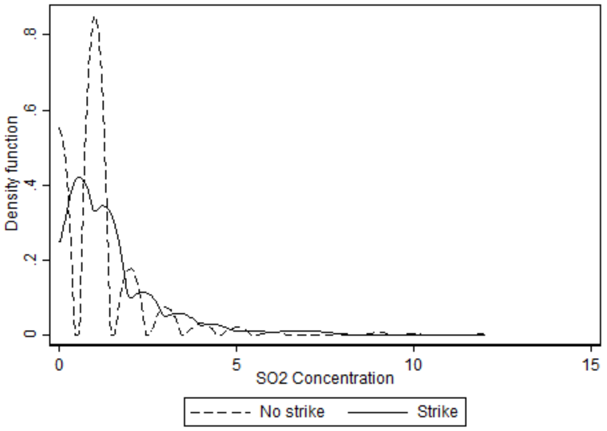







Density function
0
.01
.02
.03
.04
0
50
100
150
200
NOX Concentration
Without strike
With strike


Density function
0
.01
.02
.03
.04
.05
0
10
20
30
40
50
O3 Concentration
Without strike
With strike


Density function
0
.2
.4
.6
.8
0
5
10
15
SO2 Concentration
No strike
Strike

9-3. Appendix C – Descriptive Statistics

Table 1.2: Descriptive Statistics Ottawa

Pollutant	N	Mean	Standard deviation	Min	Max
PM	34559	4.84	4.81	0	79
NO	34416	2.40	7.34	0	137
NO_2	34415	8.68	8.38	0	69
NOx	34416	11.04	13.92	0	188
O_3	34738	24.69	12.86	0	85
SO_2	26162	0.90	1.23	0	71

Table 1.3: Descriptive Statistics Rest of Ontario

Pollutant	N	Mean	Standard deviation	Min	Max
PM	292147	6.55	6.07	0	102
NO	255927	5.77	13.25	0	377
NO_2	255926	13.26	9.75	0	81
NOx	255926	19.03	20.39	0	445
O_3	295339	25.06	14.24	0	94
SO_2	139312	2.56	4.63	0	136