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The health impacts of weekday traffic: A health risk assessment of $PM_{2.5}$ emissions during congested periods

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ABSTRACT

Little work has accounted for congestion, using data that reflects driving patterns, traffic volume, and speed, to examine the association between traffic emissions and human health. In this study, we performed a health risk assessment of $PM_{2.5}$ emissions during congestion periods in the Greater Toronto and Hamilton Area (GTHA), Canada. Specifically, we used a micro-level approach that combines the Stochastic User Equilibrium Traffic Assignment Algorithm with a MOVES emission model to estimate emissions considering congestion conditions. Subsequently, we applied a concentration-response function to estimate $PM_{2.5}$-related mortality, and the associated health costs. Our results suggest that traffic congestion has a substantial impact on human health and the economy in the GTHA, especially at the most congested period (7:00 am). Considering daily mortality, our results showed an impact of 206 (boundary test 95%: 116; 297) and 119 (boundary test 95%: 67; 171) deaths per year (all-cause and cardiovascular mortality, respectively). The economic impact from daily mortality is approximately \$1.3 billion (boundary test 95%: 0.8; 1.9), and \$778 million (boundary test 95%: 478; 981), for all-cause and cardiovascular mortality, respectively. Our study can guide reliable projections of transportation and air pollution levels, improving the capability of the medical community to prepare for future trends.

1. Introduction

The effects of traffic congestion have long been a concern in most metropolitan areas. By increasing travel times, traffic congestion increases the costs of travel and reduces accessibility (Weber and Kwan, 2002). Exposure to such congestion has also been associated with other negative effects, including increases in driver stress and decreases in commuting satisfaction (Higgins et al., 2017; Wener and Evans, 2011), increases in feelings of time pressure and decreases in an individual's reported subjective wellbeing (Hilbrecht et al., 2014), and a slowing of metropolitan economic growth (Sweet, 2014).

From an environmental perspective, traffic congestion also results in increases in fuel consumption (Bigazzi and Clifton, 2015; Treiber et al., 2008) and air pollution emissions (Levy et al., 2010; Zhang et al., 2011). For air quality in particular, previous research has reported higher emissions during congested periods as vehicles spend more time idling and engaging in more frequent acceleration and deceleration events (Smit et al., 2008; Zhang et al., 2011).

From this, increased air pollution emissions are associated with adverse human health effects (Cohen et al., 2017). A large number of epidemiological studies have shown that traffic emissions are linked to morbidity and mortality. These outcomes occur over multiple pathways with varying end points, which include respiratory and cardiovascular diseases (Peng et al., 2009; Phung et al., 2016), cancer (Fajersztajn et al., 2013; Guo et al., 2016), low birth weight (Bell et al., 2008; Veras et al., 2010), and diseases of the central nervous system (Genc et al., 2012; Suglia et al., 2008). For example, in Ontario, Canada, exposure to particulate matter 2.5 μg or smaller in aerodynamic diameter ($PM_{2.5}$) is

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associated with the development of diabetes, with a 1.11 hazard ratio for a 10 μg/m^3 increase in $PM_{2.5}$ (Chen et al., 2013). In China, Guo et al. (2016) show that the relative risks of lung cancer incidence related to a 10 μg/m^3 increase in $PM_{2.5}$ is 1.074 (95% CI: 1.060; 1.089). Pope et al. (2009) found that improvements in $PM_{2.5}$ exposure during 1980s and 1990s led to an average increase in life expectancy of 4.9 months in United States. In Connecticut and Massachusetts in the United States, $PM_{2.5}$ emitted by road transportation is associated with 2.1% and 3.5% increases in cardiovascular and respiratory admissions, respectively (Bell et al., 2014). In New York City, all on-road mobile sources are estimated to contribute to about 320 deaths annually due to $PM_{2.5}$ exposures (Kheirbek et al., 2016).

$PM_{2.5}$ is a common air pollutant that has been associated with multiple adverse health outcomes. Numerous studies have shown that $PM_{2.5}$ is one of the major pollutants associated with traffic emissions. For example, motor-vehicle-related emissions are directly responsible for about 30% of ambient $PM_{2.5}$ in Toronto, Canada (Brook et al., 2007), 22% of $PM_{2.5}$ in Boston, U.S. (Masri et al., 2015), and 25% of $PM_{2.5}$ in five Chilean metropolitan regions (Kavouras et al., 2001). Worldwide, $PM_{2.5}$ is responsible for about 2.9 million deaths, according to the 2013 Global Burden of Disease Study (GBD, 2015). The World Health Organization (WHO) finds that $PM_{2.5}$ is responsible for an 8.6 month reduction in life expectancy for the average European population (WHO, 2013). In Canada, $PM_{2.5}$ was linked to 92,000 emergency department visits, and 21,000 early deaths in 2008 according to the Canadian Medical Association (CMA, 2008).

Considering this information, Zhang and Batterman (2013) argue that rather than time wasted, the public health impacts of traffic-related air pollution are the main economic externalities of congestion. However, while there is a wealth of previous research that has investigated the association between traffic emissions and human health, little work has employed measures of traffic congestion, including travel patterns, traffic volumes, and travel speeds, to directly account for the effects of congestion on air pollution. To our knowledge, Levy et al. (2010) and Zhang and Batterman (2013) were the only researchers that estimated health impacts based on traffic congestion, and their efforts were focused on the United States.

Considering that (i) traffic congestion is a growing problem in many metropolitan areas worldwide; (ii) the literature shows strong evidence of the causal association of traffic emissions with morbidity and mortality, especially between $PM_{2.5}$ emitted by vehicles and mortality, and; (iii) there is a significant geographical gap of the research on attributable health risk in congestion periods; we argue that further investigation of the public health implications of traffic congestion is required.

Such work stands to enhance our understanding about the full costs of congestion, and how health risks differ by vehicle mix, fleet emissions characteristics, road infrastructure, population density, and atmospheric conditions. In response, in this present study we perform a health risk assessment of $PM_{2.5}$ emissions during congested periods in the Greater Toronto and Hamilton Area in Ontario, Canada. Specifically, we utilize a micro-level approach to estimate emissions based on estimated travel conditions. Next, we apply a concentration-response function to estimate $PM_{2.5}$-related mortality and estimate the associated health costs.

2. Background

2.1. Study area

The study was carried out in the Greater Toronto and Hamilton Area (GTHA), which is located in southern Ontario and the largest urban region in Canada. The GTHA encompasses six health regions, including Hamilton, Halton, Peel, Toronto, York, and Durham (Fig. 1). Health regions are administrative areas defined by provincial ministries of health according to provincial legislation.

The population in the GTHA is estimated to be over 7 million in 2016, representing 17% of the Canadian population (SC, 2016). Traffic has been considered a critical concern in the GTHA for air pollution exposure (Adams et al., 2012; Adams and Kanaroglou, 2016). During 2009, within the province of Ontario, Vehicle Kilometers Traveled (VKT) were about 130 billion, while within our study area (GTHA) VKT were approximately 55 billion (Natural Resources Canada, 2009). The indicator VKT is an aggregate measure of road usage expressed as the vehicle count on a given road link multiplied by length of the link. This indicator does not evaluate congestion. Details of how we incorporated congestion in our study are presented in Section 3.1.

2.2. Traffic congestion in the GTHA

Measures of the intensity of traffic congestion in the GTHA vary. Statistics Canada does not collect information on levels of congestion, but has started tracking commute durations as part of the 2011 National Household Survey. Here, it was estimated that the Toronto region has the highest commute times in Canada, with an average commute to work of 32.8 min compared to a national average of 25.4 min. Data from the 2016 Census show that average commute times have increased to 34 min in Toronto compared to the national average of 26.2 min. Other data sources use proprietary methods to generate congestion indices, and generally offer a similar story. The 2016 TomTom Traffic Index for example places Toronto second behind Vancouver among Canadian cities for congestion with an estimated 30% increase in travel times on the road network compared to free flow conditions. The City of Hamilton is the least congested of the 12 cities in the TomTom data with a congestion index of 18%. Inrix, Inc. also calculates rates of traffic congestion for Canadian cities, and here, Toronto ranks second behind Montréal with an estimated 45.6 driver hours spent in congestion in 2016 measured against free flow travel conditions. In this data, Hamilton ranks ninth out of the 20 cities studied with 16.3 h lost due to congestion. In terms of the geography of traffic congestion in the GTHA, previous research has used data on observed travel speeds (Sweet et al., 2015). This research examined differences in the spatial distribution of the extent and intensity of congestion and found that the highest levels of congestion are focused around Toronto's downtown core and suburban areas proximate to major highways.

3. Data and methods

This study was performed in five stages. In the first and second stages, we utilize traffic modeling techniques to infer traffic congestion and estimate vehicle emissions from daily travel in the GTHA. Next, we employ air pollution dispersion modeling to estimate exposure to congestion-related air pollutants. Fourth, we estimate a health risk using health assessment (concentration-response function), and the economic valuation associated with health impacts. Finally, in the fifth phase we performed a sensitivity analysis to assess the robustness of our results.

3.1. Traffic modeling

The first phase of the present research estimates link-level traffic conditions in the GHTA. To accomplish this, we employ the Stochastic User Equilibrium (SUE) traffic assignment algorithm to simulate how travelers choose their paths between origins and destinations in the region on the road network. The particular origin and destination pairs for a given trip are defined a priori from a trip matrix derived from the 2011 Transportation Tomorrow Survey, a travel survey of > 150,000 households in the GTHA (Data Management Group, 2013). The trip matrix represents motorized passenger trips that occurred on a typical weekday throughout pre-defined, mutually exclusive traffic analysis zones in the study area. Note that this matrix does not include commercial vehicle movements or transit trips.

The SUE algorithm estimates congested travel times for each link using the volume-delay function proposed by the US Bureau of Public Roads (1964). This function utilizes link design capacity (flows,