Studies in
Environmental Policy

FRASER
INSTITUTE

January 2012

Canadian Environmental Indicators—Air Quality

by Joel Wood

Key conclusions

- Air quality in most of Canada has improved greatly since the 1970s and continues to improve.
- To control air pollution, Canada has a stringent, yet flexible, regulatory system that involves all levels of government.
- Concentrations of carbon monoxide have decreased significantly everywhere in Canada since monitoring began in 1974.
- Concentrations of nitrogen dioxide and sulfur dioxide have decreased greatly across Canada since the 1970s.
- Statistical analysis suggests that concentrations of ground-level ozone and ultrafine particulate matter, the two air pollutants of most concern for human health, have been declining across Canada since 2000.

Summary

Canadian Environmental Indicators—Air Quality looks at the state of air quality in Canada and examines air quality regulations. The study examines long-term monitoring data from Environment Canada's National Air Pollution Surveillance network on five major air pollutants regularly cited as posing health risks to Canadians: ground-level ozone, particulate matter, nitrogen dioxide, sulfur dioxide, and carbon monoxide. The study also examines the air quality standards and regulatory mechanisms already in force in Canada to determine whether local air quality is getting better or worse, and how it compares to the clean-air targets in place across the country.

Canada's air quality objectives, which are enforced through a flexible yet comprehensive policy framework that involves all levels of government, are stringent by international standards. Industrial operations may not release substances into the air without obtaining approval from provincial governments; the provincial approval process imposes restrictions on emissions sources to ensure local pollution levels do not exceed ambient air-quality objectives set by the federal and provincial governments. Emissions from diffuse and mobile sources, such as motor vehicles, are controlled through standards and regulations imposed by all levels of government.

The data indicate that, in most instances, Canadians currently experience significantly better air quality than at any other time since monitoring of air quality commenced in the 1970s and that air quality continues to improve. Statistical analysis indicates that concentrations of ground-level ozone and ultrafine particulate matter, the two air pollutants of most concern for human health, have generally decreased Canada-wide since 2000. Concentrations of carbon monoxide, sulfur dioxide, and nitrogen dioxide have been decreasing across Canada for decades.

Contents

Overview

The state of air quality in Canada has improved considerably since the 1970s, in all regions, for all major pollutants—nitrogen dioxide, carbon monoxide, sulfur dioxide, ground-level ozone, and particulate matter. The opposite is sometimes asserted by Canadian environmental and health care organizations but, as this report shows, claims of increasing threats due to worsening air quality are not supported by Canadian data. Forming a clear, objective, and factual understanding of trends in air quality is important since fears about the effects of deteriorating air quality have led some commentators and policy makers to conclude that Canada's air-pollution policies are insufficiently stringent and advocate costly energy or environmental policies based on claims that air pollution is rising or that it exceeds safe levels. These claims need to be carefully scrutinized, since such policies can have large economic impacts and such claims are unlikely to be valid as they ignore the effectiveness of the current Canadian approach for controlling air pollution.

Canada has controlled air pollution for the past 40 years using a flexible yet comprehensive policy framework that involves all levels of government. Industrial operations may not release substances into the air without obtaining approval from provincial governments. The provincial approval process imposes restrictions on emissions sources to ensure local pollution levels do not exceed ambient air-quality objectives set by the federal and provincial governments. Emissions from diffuse and mobile sources, such as motor vehicles, are controlled through standards and regulations imposed by federal, provincial, and local governments.

Canadian air-quality objectives are stringent by international standards, and reflect current understanding of the potential health and environmental effects of air contaminants. As a practical matter, it is rarely optimal to try and achieve zero emissions of a man-made pollutant. The economic activities that give rise to pollution, such as industrial processes and use of motor vehicles, are valuable to people. People also value cleaner air, but achieving lower pollution levels requires caps on economic activities or imposition of pollution control rules that increase costs to businesses and households. At a certain point, the benefits from reduced pollution no longer outweigh the costs of achieving them, which is why it rarely makes sense to aim for zero pollution. Many communities may prefer to forego incremental improvements in air quality in order to permit increased economic activity. The current policy framework in Canada is flexible, combining overall national objectives with variations that account for local air-quality conditions and economic circumstances. The overall result has been a longstanding trend towards cleaner air amidst continued economic growth.

Canada has a large database of long-term air-quality monitoring data from locations across the country. Concentrations of nitrogen dioxide and sulfur dioxide have decreased sharply in the vast majority of locations in Canada over the past 30 years. The decrease is especially apparent in Canada's major urban centers. Carbon monoxide has decreased everywhere in Canada and since the mid-1990s there have been no exceedances of provincial air-quality standards in any of the 156 locations analyzed.

Concentrations of ground-level ozone, a key component of smog, and ultrafine particulate matter are more difficult to control since they are not emitted directly; instead, they are formed from complex chemical reactions in the atmosphere involving a mix of natural and man-made factors. Nonetheless they have, on average, decreased between 1980 and 2009 across Canada, and the trend in average levels continues to be downward, albeit slowly. More importantly, ozone is mainly a concern on days when weather conditions cause it to spike to high levels, but the data show that such occurrences followed a statistically significant downward trend from 1980 to 2009 across the county, and the number of days with very high ozone levels continues to show a significant downward trend after 2000. In addition, the trend in ultrafine particulate matter, for which the Canadian record is much shorter, is downward over the past decade as well.

Overall, for these air pollutants, air quality in Canada has clearly improved in recent history and the current policy framework, technological progress, and environmental policies in the United States have contributed to this improvement. Evaluating the potential benefit of new policies to reduce pollution needs to take this into account.

1 Introduction

If environmental and health care organizations are to be believed, Canadian air pollution is high enough to result in thousands of deaths, massive health care expenditures, and a threat to our current standard of living. However, despite the level of public interest and concern about air pollution,[1] few people seem to have a clear understanding of what the data show[2] and, as a result, little effort is put into verifying whether these claims are true, or even if air quality in Canada is getting better or worse.

Here are some of the studies that get widespread attention. A 2004 study conducted by scientists from Health Canada and Environment Canada estimated that exposure to human-caused air pollution leads to approximately 5,900 deaths[3] annually in Canada (Judek et al., 2004). A 2008 study by the Canadian Medical Association (CMA) estimated that exposure to two common air pollutants causes deaths, increased hospital admissions, and increased health care costs (CMA, 2008). The study also made long-range numerical predictions that show all of these costs increasing dramatically in the future. The Ontario Medical Association estimated that there were 9,500 deaths related to "smog" in Ontario alone in 2008 (OMA, 2008).[4] And, a paper published by the Suzuki Foundation in 2006 argued that results like these are proof that Canada needs to toughen the current approach to regulating air pollution (Boyd, 2006). Yet most of these studies do not provide any historical context.

The purpose of this publication is to bring objective information to the debate by examining long-term monitoring data from Environment Canada's National Air Pollution Surveillance network. It will focus on five major air pollutants that were the focus of the studies mentioned above: ground-level ozone (O_3), particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). It will explain the air-quality standards and regulatory mechanisms already in force in Canada and then examine the data

---

[1] "Air pollution/poor air quality" was reported as the "most important environmental problem" in a survey commissioned by Health Canada in 2001 (Environics Research Group, 2001).

[2] Eighty-five percent of Canadians in 2001 thought that air quality was remaining the same or getting worse in their communities (Environics Research Group, 2002).

[3] The authors actually report the estimate as 5,900 plus or minus 2,100 to reflect uncertainty in the estimated pollutant-mortality response functions. However, this uncertainty was ignored by journalists reporting on the study (e.g., CBC, 2005, May 2).

[4] The OMA's estimates are based on a model explained by DSS Management Consultants Inc. (2005)

to identify whether local air quality is getting better or getting worse, and how it compares to the clean-air targets in place across the country. The results overwhelmingly suggest that, for all five pollutants, air quality is improving in the vast majority of locations in Canada. Furthermore, adopting universal air-quality standards, as recommended by Boyd (2006) and the National Round Table on the Environment and the Economy (2008) would ignore the advantages of the regional flexibility provided by the current regulatory regime and would likely create inefficiencies and hinder implementation.

Canadian Environmental Indicators—Air Quality shows that Canada's air quality record has improved considerably since the 1970s and continues to improve. Predictions of groups like the CMA that claim illness and mortality caused by air pollution will get worse and argue that, therefore, we need aggressive new pollution-control measures, should be critically assessed in light of a clear understanding of the actual historical record, not headline-grabbing rhetoric based on computer simulations. The CMA study, for example, assumes that air quality in Canada will remain constant into the future; however, this assumption is inconsistent with the historical reality. The CMA's predictions, therefore, are biased and over-estimate the future costs of air pollution in Canada.

The current study is by no means the first to attempt to measure the state of air quality in Canada (see, e.g., Environment Canada, 2010a; Eisen and Green, 2009; McKitrick, 2008; CCME, 2006; Brown et al., 2004). However, the current study is more comprehensive in scope and analysis than any of the existing studies and incorporates as much monitoring data as possible. Some provincial governments also publish reports on provincial air quality (e.g., ON-MEnv, 2010a) that reinforce the picture of improving air quality but such reports are limited to individual provinces.

The following section will provide an overview of how air pollution is regulated in Canada. Sections 3 to 7 contain analyses of air-pollution monitoring data from across Canada for nitrogen dioxide, carbon monoxide, sulfur dioxide, ground-level ozone, and particulate matter. Concentration data from the National Air Pollution Surveillance database is examined for the eight largest provinces: Alberta, British Columbia, Manitoba, New Brunswick, Nova Scotia, Ontario, Quebec, and Saskatchewan. Section 8 discusses the conclusions of the study and suggests improvements in the collection of data.

2 Canadian regulatory framework for air pollution

While it is the ambient concentration of pollution that affects people, regulators can only control emissions at the source. In some cases, the two are closely related. Carbon monoxide and sulphur dioxide, for instance, disappear relatively quickly when the emissions disappear. But the relationship is much weaker in other cases: ozone and aerosols (which count in the readings of ultrafine particulate matter[5]) are formed in the atmosphere depending on the concentration of other pollutants, as well as wind patterns, sunlight, geography, and temperature. Changes in emissions of the precursor pollutants may or may not affect regional concentrations, depending on how these other factors change at the same time. For this reason, making a connection between trends in pollution concentrations and policy implications is more difficult for ultrafine particulates and ozone than for other air pollutants.

In Canada, municipal, provincial, and federal governments have all issued regulations to control emissions, though our focus in this section will be on provincial and federal policies. In Ontario, any industrial activity is required to obtain a Certificate of Approval for the emission of any regulated toxic substance (ON-MEnv, 2010b) through a process that may include site visits by evaluators or the implementation of prescribed technology to gain approval. The evaluators also take into account local air quality and aim to ensure that the new emissions will not lead to pollution concentrations that exceed Ontario's Ambient Air Quality Criteria (ON-MEnv, 2008). The provincial objectives can be very comprehensive: Ontario's Air Quality Criteria currently lists maximum concentration levels for over 300 chemical substances, including NO_2, CO, SO_2, and $PM_{2.5}$. Ontario also employs a trading system for approval certificates for sulfur dioxide and nitrogen dioxide emissions to lower the cost to large emitters (utilities, oil refineries, pulp and paper mills, etc.) of reducing emissions (ON-MEnv, 2005).

British Columbia employs a system of regulation similar to Ontario's where potential emitters are required to obtain permits and approvals to emit any substance regulated under the Environmental Management Act (BCME, no date). British Columbia also has Codes of Practice and Ministerial directives that stipulate the use of particular methods or technologies for specific industries (BCME, no date). The other provinces employ similar systems of granting emission approvals.

---

[5] Ultrafine particulate matter refers to airborne particulate matter with a mass median diameter less than 2.5 µm (µm = micrometer, 1×10^{-6} metre, or 0.001 mm). In the literature, it is generally referred to as $PM_{2.5}$.

Since the 1970s, the federal government has set emission standards on new vehicles to help control nitrogen dioxide and carbon monoxide emissions. The Vehicle and Engine Emission Regulations mandate fleet-average grams of nitrogen dioxide emitted per mile for particular model years and classes of motor vehicles . The regulations also specify a range of gram-per-mile exhaust emission standards for CO and NO_2 (Gov't of Canada, 2003). These standards have been instituted by Canada in concert with regulations imposed by the United States Environmental Protection Agency due to the highly integrated nature of the North American motor-vehicle market. Ontario and British Columbia also have vehicle emission inspection policies (*DriveClean* and *AirCare*, respectively) that establish emission standards for each model and year. The federal government regulates the release of volatile organic compounds, a precursor of ground-level ozone formation (Environment Canada, 2004).

To guide decision-making when granting pollution permits and setting vehicle emission standards, the federal and provincial governments use ambient air quality objectives. An air quality objective is always made with reference to an average over an interval of time. For instance, a 1-hour objective refers to the observed level averaged over a single hour, while an annual objective refers to an average over the whole year. Generally speaking, a 1-hour standard is higher than an annual standard; in other words, exposure to a higher level is acceptable if it is for a shorter period of time.

The federal criteria are referred to as National Ambient Air Quality Objectives (NAAQO), which specify maximum desirable, acceptable, and tolerable concentration levels for sulfur dioxide, nitrogen dioxide, carbon monoxide, ground-level ozone, and total suspended particulate matter (Environment Canada, 2007). Provincial governments also have their own ambient air quality objectives that often differ from the federal objectives. The objectives used by the Maritime Provinces are generally the least stringent federal objectives, whereas Alberta and British Columbia mainly adopt the most stringent federal objectives.[6] Ontario and Quebec generally create their own objectives that are not based on the federal objectives. A separate system for ground-level ozone and ultrafine particulate matter, called the Canada-wide Standard (CWS), was negotiated among the federal and provincial ministers of the environment (CCME, 2006).

Nitrogen dioxide

Air pollutant concentrations are measured continuously at monitoring stations across Canada. The 1-hour National Ambient Air Quality Objective (NAAQO) for NO_2 uses the average (mean) reading recorded over a 1-hour period at a station; so for each station there are potentially 24 1-hour average

---

[6] For several pollutants, British Columbia and Alberta have adopted objectives even more stringent than the National Ambient Air Quality Objectives.

concentrations recorded in a day, and 8,760 1-hour average concentrations recorded in a year. The federal Maximum Acceptable Level (MAL) for NO_2 is 213 parts per billion (ppb).[7] The annual NAAQO for NO_2 is the average of all the 1-hour average readings recorded at a station over an entire year. The annual federal Maximum Desirable Level is 32 ppb and the federal Maximum Acceptable Level is 53 ppb.

Most provinces use the 1-hour federal objective when regulating NO_2 emissions. Nova Scotia, New Brunswick, and Saskatchewan also consider the annual federal Maximum Acceptable Level when granting emission permits for NO_2. Alberta uses the annual federal Maximum Desirable Level in addition to the 1-hour objective when granting emission permits for NO_2. New Brunswick, Ontario, and Alberta also have an objective for 24-hour concentrations of 106 ppb. The federal and provincial objectives for NO_2 are displayed in table 1, which also shows air quality objectives and standards from other jurisdictions as well as the guidelines published by the World Health Organization (WHO). The National Ambient Air Quality Objectives for NO_2 do not compare favourably with the WHO guidelines for NO_2 concentrations. The World Health Organization's guideline for average 1-hour NO_2 concentrations is 106 ppb and its guideline for average annual concentrations is 21 ppb (WHO, 2006). The United States has a more stringent objective for average 1-hour concentrations (100 ppb) but a similar objective for average annual concentrations of 53 ppb (US-EPA, 2010).

Carbon monoxide

There are 1-hour and 8-hour National Ambient Air Quality Objectives for average atmospheric concentrations of CO (table 2). The federal 1-hour objective is 13 parts per million (ppm) and the federal 8-hour objective is 5 ppm. Provinces also have CO air quality objectives. British Columbia has the lowest 1-hour objective for CO of 12 ppm.[8] Four provinces—British Columbia, Alberta, Saskatchewan, and Manitoba—have an 8-hour objective of 5 ppm.

The Canadian and British Columbian objectives compare favourably to objectives from other jurisdictions. The United States 1-hour standard for CO is 35 ppm (US-EPA, 2010). The World Health Organization's guidelines do not have any recommendations for CO concentrations (WHO, 2006). Australia has only an 8-hour standard for CO of 9 ppm (AUS-DWSEWPC, 2009), higher than the lowest Canadian 8-hour objectives.

---

[7] Parts per billion is a common metric for measuring how much of a substance is contained in an area. One parts per billion is roughly equal to a tablespoon of a material in an Olympic-sized swimming pool. Parts per billion will be referenced in its abbreviated form "ppb" for the remainder of the paper.

[8] This is British Columbia's lowest air quality objective for CO (Level A). There are also Level-B and Level-C objectives of 24 ppm and 31 ppm, respectively.

Table 1: Existing Ambient Air Quality Objectives for Nitrogen Dioxide (NO_2)

Jurisdiction	1-hour Average	24-hour Average	Annual Average
Canada			
NAAQO	213	—	32/53
CWS	—	—	—
Provincial			
Nova Scotia	213	—	53
New Brunswick	213	106	53
Quebec	—	—	—
Ontario	213	106	—
Manitoba	—/213/532	106	32/53
Saskatchewan	213	—	53
Alberta	213	106	32
British Columbia	—	—	—
United States	100	—	53
World Health Organization	106	—	21
Australia	120	—	30
European Union	106	—	21

Notes: All numbers are in parts per billion (ppb). The 1-hour National Ambient Air Quality Objective is for a Maximum Acceptable Level. #/# represents Maximum Desirable Level/ Maximum Acceptable Level; #/#/# represents Maximum Desirable Level/Maximum Acceptable Level/ Maximum Tolerable Level.

Sources: Nova Scotia, Department of Justice, Legal Services Division, 2011; Alberta Environment, 2009; BCME, 2009; AUS-DSEWPC, 2009; Environment Canada, 2007; US-EPA, 2010; European Commission, no date; New Brunswick, Ministry of the Environment and Local Government 2002; Manitoba Conservation, 2005; ON-MEnv, 2008; SME, 1996; WHO, 2006.

Sulphur dioxide

The World Health Organization's guidelines for SO_2 recommend 24-hour average concentrations under 7 ppb. Canadian governments have set much more realistic objectives than these. Canadian objectives as well as those of other jurisdictions are listed in table 3. The National Ambient Air Quality Objective 24-hour average Maximum Desirable Level is 53 ppb and the lowest provincial objective is 44 ppb in Alberta. The federal 24-hour average Maximum Acceptable Level is 105 ppb. The federal 1-hour average Maximum Desirable Level is 158 ppb and the Maximum Acceptable Level is 315 ppb. No provinces have stated 1-hour objectives lower than 158 ppb. The federal annual average Maximum Desirable Level is 11 ppb and the Maximum Acceptable Level is 21 ppb. The lowest provincial objective for annual average SO_2 concentrations is 7 ppb in Alberta.

In 2010, the United States implemented an ambient air quality 1-hour standard for SO_2 of 75 ppb (with achievement based on the 3-year average

Table 2: Existing Ambient Air Quality Objectives for Carbon Monoxide (CO)

Jurisdiction	1-hour Average	8-hour Average
Canada		
NAAQO	13/31	5/13
Provincial		
Nova Scotia	30	11
New Brunswick	31	13
Quebec	30	11
Ontario	32	14
Manitoba	13/31	5/13/17
Saskatchewan	13	5
Alberta	13	5
British Columbia	12/24/31	5/10/12
United States	35	9
World Health Organization	—	—
Australia	—	9
European Union	—	9

Notes: All numbers are in parts per million (ppm). The 1-hour National Ambient Air Quality Objective is for a Maximum Acceptable Level. #/# represents Maximum Desirable Level/ Maximum Acceptable Level. #/#/# represents Maximum Desirable Level/Maximum Acceptable Level/ Maximum Tolerable Level.

Sources: Nova Scotia, Department of Justice, Legal Services Division, 2011; Alberta Environment, 2009; BCME, 2009; AUS-DSEWPC, 2009; Environment Canada, 2007; US-EPA, 2010; European Commission, no date; New Brunswick, Ministry of the Environment and Local Government 2002; Manitoba Conservation, 2005; QUE-MDDEP, 2010; ON-MEnv, 2008; SME, 1996.

of the 99th percentile of the daily maximum 1-hour average). This standard is much more stringent than the Canadian 1-hour objective. The United States also has a 24-hour standard of 140 ppb, which is higher than the 24-hour federal objective in Canada. The United States also has a higher annual average standard of 30 ppb. The Australian National Air Quality Standards for SO_2 concentrations are all less stringent than the Canadian federal objectives (1-hour: 200 ppb; 24-hour: 80 ppb; annual: 20 ppb).

Ozone

The federal 1-hour Maximum Desirable Level (MDL) for O_3 is 50 parts per billion (ppb) and the federal 1-hour Maximum Acceptable Level (MAL) for O_3 is 80 ppb (table 4). Many provinces (Nova Scotia, Quebec, Saskatchewan, and Alberta) have chosen 80 ppb as their provincial objective for O_3. Ontario uses 82.5 ppb as its 1-hour objective for O_3. Manitoba uses both federal O_3 objectives but has added a Maximum Tolerable Level of 200 ppb. All provinces looked at in this study have agreed to meet a Canada-wide standard

Table 3: Existing Ambient Air Quality Objectives for Sulphur Dioxide (SO_2)

Jurisdiction	1-hour Average	24-hour Average	Annual Average
Federal			
NAAQO	158/315	53/105	11/21
Provincial			
Nova Scotia	315	105	21
New Brunswick	315	105	21
Quebec	—	101	18
Ontario	242	96	19
Manitoba	158/315	53/105/280	11/21
Saskatchewan	158	53	11
Alberta	158	44	7
British Columbia	158/315	56/91/126	9/18/28
United States	75	140	30
World Health Organization	—	7	—
Australia	200	80	20
European Union	123	44	—

Notes: All numbers are parts per billion (ppb.) The 1-hour National Ambient Air Quality Objective is for a Maximum Acceptable Level. #/# shows Maximum Desirable Level/Maximum Acceptable Level; #/#/# shows Maximum Desirable Level/Maximum Acceptable Level/ Maximum Tolerable Level.

Sources: Nova Scotia, Department of Justice, Legal Services Division, 2011; Alberta Environment, 2009; BCME, 2009; DSEWPC, 2009; Environment Canada, 2007; US-EPA, 2010; European Commission, no date; New Brunswick, Ministry of the Environment and Local Government 2002; Manitoba Conservation, 2005; QUE-MDDEP, 2010; ON-MEnv, 2008; SME, 1996; WHO, 2006.

(CWS) for O_3 of 65 ppb for a specific measure of O_3 concentrations by 2010 (CCME, 2006). The specific measure for the Canada-wide standard takes into account the fact that O_3 levels fluctuate throughout the year and that effets upon human health are usually tied to short-term exposure to high levels. The standard is set by taking the daily maximum of 8-hour average concentrations each day, choosing the fourth-highest of these readings over the course of the previous year, and then taking the three-year moving average of such readings. The resulting measure is compared against the CWS of 65 ppb. The metric ignores the three highest daily maximum 8-hour average concentrations to dampen the effects of unusually high concentrations that may occur due to external factors like heat waves.

The Canada-wide standard for O_3 is in line with other international standards and guidelines. The United States has a standard of 75 ppb for the same measurement of O_3 concentrations (US-EPA, 2010). The European Union has set 60 ppb as their standard for 8-hour concentrations of O_3 (European Commission, no date). The World Health Organization's guideline for 8-hour average concentrations of O_3 is 50 ppb (WHO, 2006).

Table 4: Existing Ambient Air Quality Objectives for Ozone (O_3)

Jurisdiction	1-hour Average	8-hour Average	Annual Average
Federal			
NAAQO	50/80	—	—
CWS	—	65	—
Provincial			
Nova Scotia	80	—	—
New Brunswick	—	—	—
Quebec	80	62.5	—
Ontario	82.5	—	—
Manitoba	50/80/200	—	15
Saskatchewan	80	—	—
Alberta	80	—	—
British Columbia	—	—	—
United States	120	75	—
World Health Organization	—	50	—
Australia	100	—	
European Union	—	60	—

Notes: All numbers are in parts per billion (ppb). #/# represents Maximum Desirable Level/ Maximum Acceptable Level; #/#/# represents Maximum Desirable Level/Maximum Acceptable Level/ Maximum Tolerable Level. Achievement of the Canada-wide standard and the US standard are based on the 3-year moving average of the fourth-highest daily maximum 8-hour average concentration. The European Union's standard is based on the maximum daily 8-hour average but with 25 exceedences permitted over three years.

Sources: Nova Scotia, Department of Justice, Legal Services Division, 2011; Alberta Environment, 2009; BCME, 2009; CCME, 2006; DSEWPC, 2009; Environment Canada, 2007; US-EPA, 2010; European Commission, no date; New Brunswick, Ministry of the Environment and Local Government 2002; Manitoba Conservation, 2005; QUE-MDDEP, 2010; ON-MEnv, 2008; SME, 2006; WHO, 2006.

"Smog day" advisories

The original "smog day" designation (Smog Advisory) developed in 1993 by Environment Canada was based solely on concentrations of O_3 exceeding the federal 1-hour maximum acceptable level of 80 ppb (Environment Canada, 2001). The definition was changed to include other pollutant concentrations in the early 2000s when the Air Quality Index and then the Air Quality Health Index were developed (Environment Canada, 2001; Barn and Kosatsky, 2010).[9]

---

[9] The multiple changes to the definition have led to an increase in Smog Advisories. Care needs to be taken when comparing the number of advisories issued over time. Boyd falls victim to this trap and cites the increased number of smog days in Ontario in 2005 as evidence that air quality is getting worse without accounting for the change in definition (Boyd, 2006: 4).

Particulate matter

In Canada, there are federal objectives set for total suspended particulates but not $PM_{2.5}$. As with O_3, the provinces studied in this report have all agreed to meet a $PM_{2.5}$ Canada-wide standard concentration of 30 micrograms per cubic meter ($\mu g/m^3$) with achievement based on a specific measurement (CCME, 2006). The Canada-wide standard measurement for a station is based on concentrations readings averaged over a 24-hour period. There are potentially 365 of these 24-hour average concentration measurements in a year, so only one of the highest is selected as the annual measurement. The top 2% of 24-hour concentrations recorded at a station is ignored to correct for unusually high concentrations that may not occur regularly. The measure is then averaged over three years to dampen any year-to-year fluctuations. In technical terms, the Canada-wide standard measure of achievement for $PM_{2.5}$ is a 24-hour average concentration of $30\mu g/m^3$ with achievement based on the 3-year moving average of the annual 98th percentile (CCME, 2006).

The only province to implement a $PM_{2.5}$ objective over and above the CWS is British Columbia (BCME, 2009). British Columbia's objective is 25 $\mu g/m^3$ based on a 24-hour average concentration, the same as the World Health Organization's 24-hour average guideline and the Australian air quality standard for $PM_{2.5}$. The World Health Organization has also set an annual objective of 10 $\mu g/m^3$; the Australian government's annual objective is 8 $\mu g/m^3$. The United States has adopted a 24-hour standard of 35 $\mu g/m^3$ with achievement based on the 3-year average of the annual 98th percentile of daily averages (US-EPA, 2010). The United States also has an annual standard of 15 $\mu g/m^3$ with achievement based on the 3-year average of the annual average concentration. All of the objectives, standards, and guidelines for $PM_{2.5}$ are displayed in table 5.

Voluntary and legally binding objectives

As correctly pointed out by Boyd (2006), these objectives are voluntary and not legally binding for the provincial governments, as are objectives and standards in the United States and European Union. Boyd argues that Canada needs to adopt legally binding air-quality objectives in order to hold governments to account for air pollution concentrations in excess of the objectives. However, the regulations adopted by provinces and the federal government in order to achieve the targets are legally binding on emitters. Also, the data show that Canadian pollution levels have largely been brought into compliance with the federal and provincial objectives, and the cases where objectives have not yet been met (such as ground-level ozone) are trending in the right direction, so the combination of provincially adopted targets coupled with mandatory emission regulations appears to be effective. Moreover, introducing a US-style litigation system that allows groups to bring action against the government could easily lead to unreasonable and counterproductive

Table 5: Existing Ambient Air Quality Objectives for Particulate Matter ($PM_{2.5}$)

Jurisdiction	24-hour Average	Annual Average
Federal		
NAAQO	—	—
CWS	30	—
Provincial		
Nova Scotia	—	—
New Brunswick	—	—
Quebec	30	—
Ontario	30	—
Manitoba	30	
Saskatchewan	—	—
Alberta	30	—
British Columbia	25	8
United States	35	15
World Health Organization	25	10
Australia	25	8
European Union	25	—

Notes: All numbers are in micrograms per cubic metre (µg/m^3). Achievement of the Canada-wide standard and the US standard is based on the 3-year moving average of the annual 98th percentile daily average concentration. British Columbia's 24-hour objective is based on the annual 98th percentile of daily average concentrations.

Sources: Alberta Environment, 2009; BCME, 2009; CCME, 2006; DSEWPC, 2009; US-EPA, 2010; European Commission, no date; Manitoba Conservation, 2005; QUE-MDDEP, 2010; ON-MEnv, 2008; WHO, 2006.

disputes. For example, the majority of $PM_{2.5}$ comes from natural sources such as roads and forest fires (see section 8 below) and much of Ontario's ozone is formed from precursor emissions in the United States. There is little to be gained holding the government legally responsible for the air pollution resulting from other countries or from forest fires.

Another important aspect of air pollution policy is that the optimal concentration of pollution is generally not zero or, more technically, not necessarily the level with zero risks of human or environmental harm. This may appear counterintuitive but, when regulating pollution, the social benefit resulting from cutting back polluting activities needs to be weighed against the value of those activities. The objective of regulating pollution should be to reach a concentration—which will not be zero—where the incremental benefit from reducing polluting activities equals the incremental cost of the emission reductions. Further, the optimal stringency of regulations often differs from one region to another. For example, an urban area will have more people exposed and harmed by air pollution than a rural area because its population is more concentrated, suggesting generally a greater incremental benefit from reducing pollution. Further, rural areas often rely on fewer industries so, if one of those industries is relatively pollution-intensive, the incremental costs to the local economy from reducing the polluting activity may be higher than in an urban area. Both of these factors may lead policy makers to prefer less stringent air pollution control rules in a rural area than an urban area. The current regulatory framework, because of its mix of negotiated objectives and regional regulations, has the flexibility to respond to local economic and environmental conditions. Uniform, legally binding air quality objectives as advocated by Boyd (2006) and the National Roundtable on the Environment and the Economy (NRTEE, 2008) ignore this aspect of air pollution regulation and may unfairly harm the livelihoods of rural communities that have relatively undiversified economies.

3 Air quality in Canada—Nitrogen Dioxide

Effects on health and the environment

Most nitrogen dioxide (NO_2) found in the atmosphere is emitted as nitric oxide (NO) but is then oxidized into NO_2. Nitrogen dioxide, when combined with volatile organic compounds and intense sunlight, produces ground-level ozone. Atmospheric NO_2 can also transform into nitrate aerosols, which contribute to particulate matter producing smog and reduced visibility. Exposure to high levels of atmospheric NO_2 has been linked in epidemiological studies to increased mortality (Burnett et al., 2004) and can irritate the lungs, especially among individuals with respiratory conditions such as asthma and bronchitis (Environment Canada, 2011). However, recent Canadian research has called into question the effects of exposure to NO_2 on human health. Koop et al. (2010) find that, when smoking habits are accounted for, NO_2 exposure is not correlated with hospital admissions for all lung diagnostic categories; Shin et al. (2008) find that, despite decreasing concentrations of NO_2, public health risks from NO_2 were increasing in Canadian cities. Their results suggest that it is not NO_2 that is causing these increased health risks but unaccounted for "co-pollutants" that are released with NO_2 emissions.

Sources

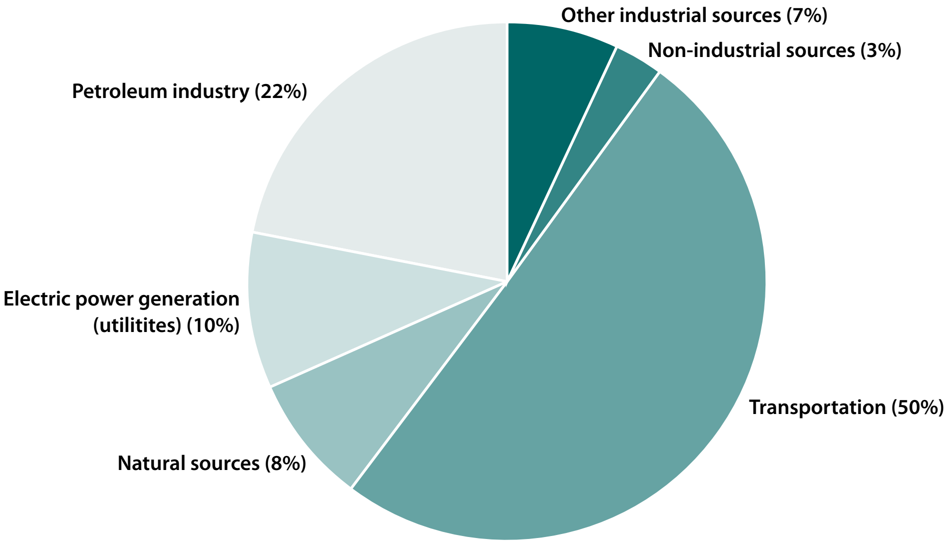
In 2008, transportation was responsible for 50% of Canadian emissions of nitrogen dioxide (figure 1). The petroleum industry was responsible for 22% of NO_2 emissions; electricity generation was responsible for 10% of NO_2 emissions.

Data—annual concentrations

Analyzing the monitoring data for eight provinces covering the period from 1980 to 2009 finds that all stations show average annual concentrations less than the federal Maximum Desirable Level (32 ppb) since 1998. Between 2008 and 2009, only Montreal, Toronto, Calgary, and Vancouver have stations reporting concentrations greater than, or equal to, the average annual concentrations of the World Health Organization's guideline of 21 ppb. All six of the stations in these cities are either located downtown or in near proximity to major highways and all stations reported annual average concentrations less than 23 ppb. Figure 2 shows average annual NO_2 concentrations from the downtown monitoring stations located in the five largest Canadian cities. A noticeable decline over the 30-year time period is clear in the graph.

This substantial decline is not just restricted to concentrations in major cities. It is clear from figure 3 that average annual concentrations of nitrogen dioxide have declined at the vast majority of monitoring stations across

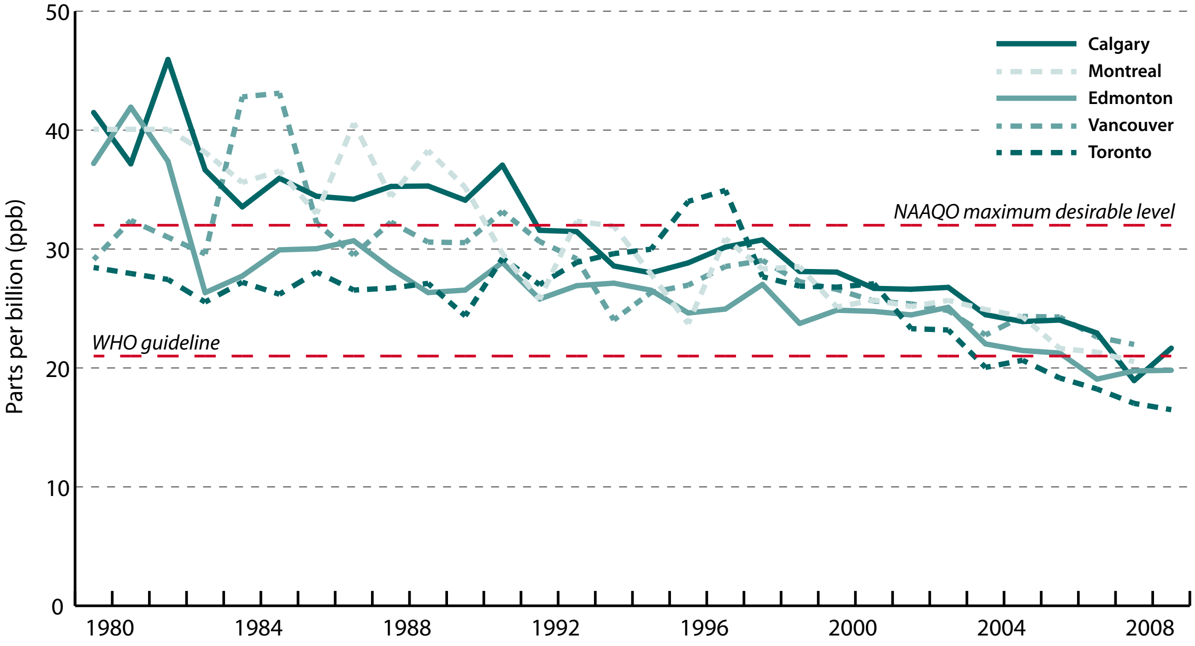
Figure 1: Sources of Nitrogen Dioxide emissions in Canada, 2008



Note: Emissions of Nitrogen Oxides (NO_x) expressed as Nitrogen Dioxide (NO_2).

Sources: Environment Canada, 2010c; calculations by author.

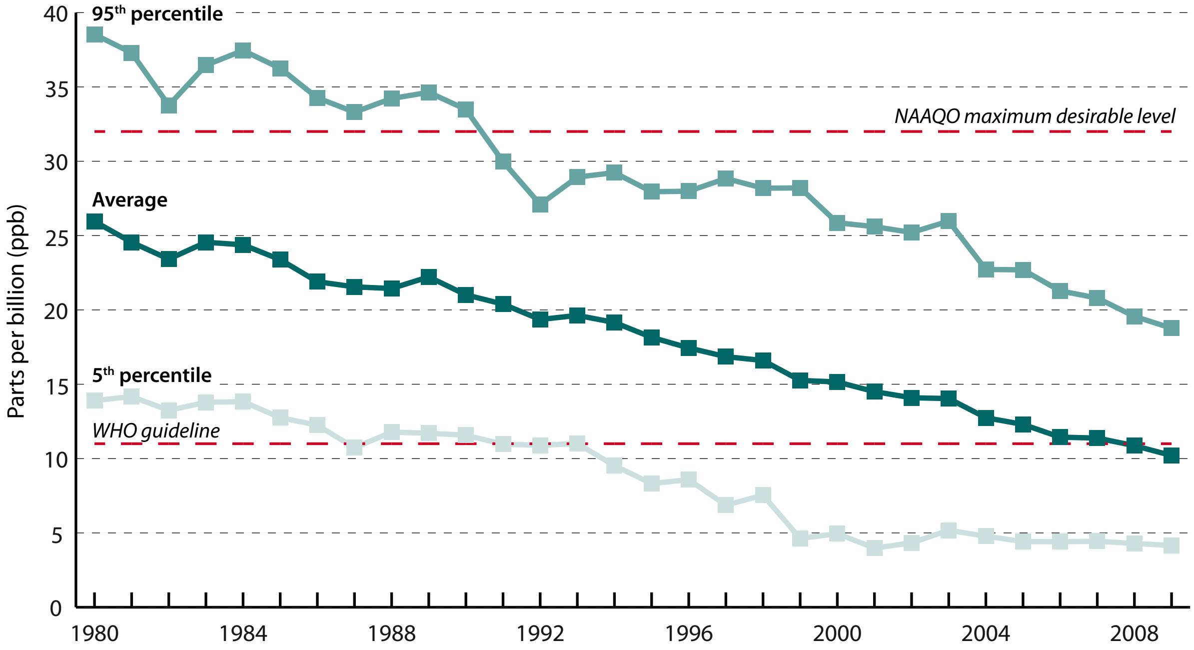
Figure 2: Annual concentrations of Nitrogen Dioxide in major Canadian cities, 1980–2009



Note: The data are annual average concentrations. For Calgary and Toronto, the monitoring record used multiple stations within a 5 km radius. The station numbers are: 050115, 060401, 060417, 060424, 060425, 060433, 080130, 080227, 080228, 100112.

Sources: Environment Canada, 2010b; calculations by author.

Figure 3: Average annual concentrations of Nitrogen Dioxide in Canada, 1980–2009



Notes: The figure displays average, 95th percentile, and 5th percentile values of annual average NO_2 concentrations from stations across Canada. In a given year, 95% of stations have concentrations below the 95th percentile value. Similarly, 5% of stations report concentrations below the 5th percentile value.

Sources: Environment Canada, 2010b; calculations by author.

Canada between 1980 and 2009. It is also clear from figure 3 that 95% of stations reported concentrations below the World Health Organization's annual guideline of 21 ppb in 2007, 2008, and 2009. Combined, figures 2 and 3 show that NO_2 concentrations have decreased substantially over the past 30 years in Canada.

Data—hourly concentrations

Examining the Canadian monitoring data focusing on average 1-hour concentrations in excess of 213 ppb (the federal Maximum Acceptable Level) reveals only one "exceedance"[10] between 2000 and 2009: Bitumount in northern Alberta (north of Fort McKay) had one hour out of 7,789 hours in excess of 213 ppb in 2008. When using the World Health Organization's guideline of 106 ppb the results are not as encouraging for some provinces (table 6). British Columbia had only one observation that was equal to or greater than the WHO's guideline (106 ppb) between 2000 and 2008 (and none since 2002). However, the one violating observation was recorded in Taylor, BC in 2001 and monitoring in Taylor was discontinued in 2002. Therefore, any further violations would have gone unrecorded.

---

[10] An "exceedance" is an observation that is greater than, or equal to, a specific air-quality objective or guideline.

Table 6: Exceedances of the World Health Organization's 1-hour guideline for NO_2 (106 ppb) by various provinces

		Exceeding hours	Exceeding stations	Total stations	% of stations with exceeding hours
British Columbia	1980–1989	512	14	17	82%
	1990–1999	31	10	32	31%
	2000–2008	1	1	43	2%
Alberta	1980–1989	793	4	5	80%
	1990–1999	256	9	16	56%
	2000–2009	94	12	48	25%
Saskatchewan	1980–1989	42	2	3	67%
	1990–1999	0	0	4	0%
	2000–2009	3	2	4	50%
Manitoba	1980–1989	4	1	2	50%
	1990–1999	26	2	3	67%
	2000–2009	3	1	3	33%
Ontario	1980–1989	1,409	39	48	81%
	1990–1999	464	26	42	62%
	2000–2009	96	10	52	19%
Quebec	1980–1989	1,248	15	16	94%
	1990–1999	660	17	25	68%
	2000–2008	29	6	22	27%
New Brunswick	1980–1989	138	1	2	50%
	1990–1999	3	1	5	20%
	2000–2009	2	1	6	17%
Nova Scotia	1980–1989	77	3	3	100%
	1990–1999	2	1	3	33%
	2000–2008	3	1	4	25%

Notes: The calculations considered all stations with any amount of monitoring data. An exceedance was defined as an average 1-hour NO_2 concentration greater than, or equal to, 106 ppb. An exceeding station is any monitoring station with at least one 1-hour average concentration equal to, or greater than, 106 ppb, the World Health Organization's guideline.

Sources: Environment Canada, 2010b; calculations by author.

Alberta had 94 observations greater than, or equal to, the World Health Organization's guideline between 2000 and 2009, of which 74 occurred between 2005 and 2009, at only 8 of 47 monitoring stations; 78% occurred in 2008. Only 11 of the violations from 2005 to 2009 occurred in an urban area (Calgary-East). Thirty-six of the exceeding observations were recorded in 2008 by two stations in close proximity to one another: a station located in Redwater and a station located north of Fort Saskatchewan. Twenty three of the exceeding observations were recorded by three stations in the Fort McKay area (including Bitumount), 19 of which occurred in 2008. The additional exceeding observations occurred in Violet Grove and Airdrie. These results are not surprising considering that, according to data from the National Pollutant Release Inventory, oil sands processing is one of the largest sources of NO_2 emissions in Canada (Environment Canada, 2010d). It should be noted that these results are not an indictment of oil sands development since the results on their own do not take into account the massive economic benefits to be attributed to the development.

Saskatchewan has three observations exceeding the World Health Organization's guideline between 2000 and 2009 (Regina and Saskatoon both had exceedances). However, there have been no observations greater than, or equal to, 106 ppb since 2006. Between 2000 and 2009, Winnipeg (Manitoba) has three observations at the downtown monitoring station exceeding 106 ppb; Saint John (New Brunswick) has two observations exceeding the WHO's guideline but none after 2004; downtown Halifax (Nova Scotia) has three exceedances. There are 29 observations from the province of Quebec that exceed the WHO's guideline; all of these exceedances occurred in Greater Montreal at six monitoring stations.

Ontario has made substantial progress in achieving low NO_2 concentrations over the past 10 years. Between 2000 and 2004, Ontario recorded 96 observations at 10 stations (Ottawa, Sarnia, Oakville, Hamilton, Toronto, London, Barrie) that were greater than the World Health Organization's guideline. All of these observations were below 213 ppb, the federal Maximum Acceptable Level. However, all stations in Ontario have reported NO_2 concentrations over 1-hour below the World Health Organization's guideline since 2005. Clearly, short-term exposure to NO_2 in Ontario cannot be considered a problem anymore. These recent improvements would likely decrease the estimated number of deaths due to short-term exposure to air pollution in Canada (1,800 ± 700 by Judek et al., 2004), especially since Ontario represents around a third of Canada's total population. However, as noted earlier in this section, recent Canadian studies have found that the effects of NO_2 exposure upon human health may not be significant.

Conclusion

Nitrogen dioxide concentrations in Canada in the vast majority of locations are well within Canadian objectives and World Health Organization's guideline. Between 2000 and 2009, 148 out of 182 monitoring stations (81%) reported no annual average concentrations greater than the World Health Organization's guideline of 21 ppb. Average annual NO_2 concentrations in major cities and across Canada decreased substantially between 1980 and 2009 (figures 2 and 3). Furthermore, all monitoring stations in Ontario, the most populated province in Canada, have achieved 1-hour average concentrations below the WHO's guideline since 2005.

The evidence discussed in this section overwhelmingly suggests that the majority of Canadians currently experience significantly less exposure to nitrogen dioxide than they have in the past 30 years. The analysis is so conclusive that statistical analysis is not needed to identify whether NO_2 concentrations are increasing or decreasing; they are clearly decreasing.

4 Air quality in Canada—Carbon Monoxide

Effects on health

In high concentrations, carbon monoxide (CO) is poisonous to humans as it can enter the bloodstream and prevent oxygen absorption by tissues and organs. Individuals with heart conditions are more sensitive to exposure to CO. Exposure to high CO concentrations also interferes with vision and brain function (Environment Canada, 2011).

Sources

Carbon monoxide is mainly produced through the incomplete combustion of fossil fuels by internal combustion engines. Therefore, the overwhelming majority of CO emissions are produced by the transportation sector in Canada. Figure 4 displays the sources of CO emissions in Canada in 2008.

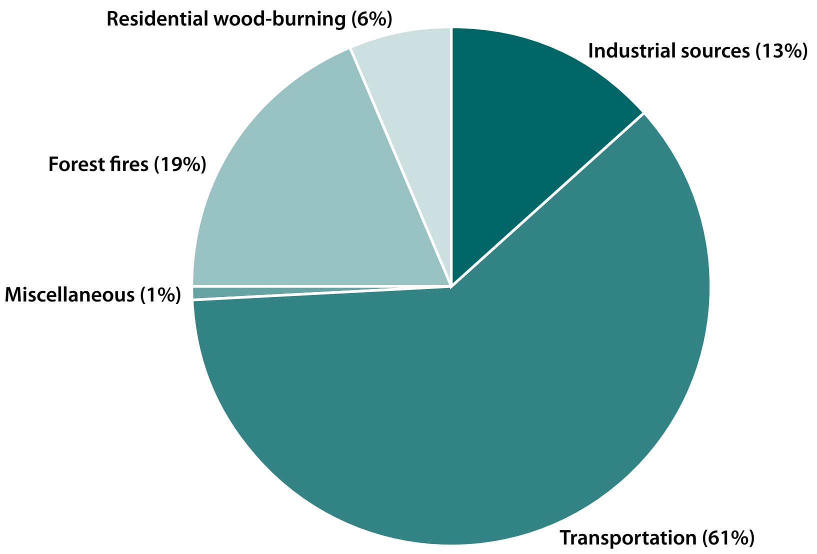
Data

Analyzing data collected from 158 monitoring stations located in eight provinces between 1974 and 2009 reveals that there has been no 1-hour average concentrations of CO greater than, or equal to, 12 ppm since 1998. Table 7 shows the number of hours during which there were exceedances of British Columbia's objective for CO of 12 ppm—the most stringent objective in Canada—and number of stations for each province for four time periods. It is clear that 1-hour concentrations of CO have decreased substantially since 1974. Looking at tables of exceedances does not do justice to the massive improvement in air quality. Figure 5 displays average annual maximum 1-hour average concentrations from monitoring stations from across Canada between 1974 and 2009. It is evident that carbon monoxide concentrations have decreased massively over the past 35 years everywhere in Canada and carbon monoxide is clarly no longer a serious pollutant in Canada and stricter regulation is unnecessary.

Conclusion

Implementing legally binding, provincial air-quality standards for CO similar to those of the United States and Australia as advocated by Boyd (2006) would result in no improvement in air quality in Canada since CO concentrations have not exceeded the current objectives in over 10 years. What is particularly noteworthy is that these massive decreases in concentrations of carbon monoxide occurred alongside sustained economic growth. Recent research suggests that in Canada, increases in per-capita income cause decreases in concentrations of carbon monoxide (Wood, 2010) and that, for carbon monoxide at least, economic growth is good for the environment.

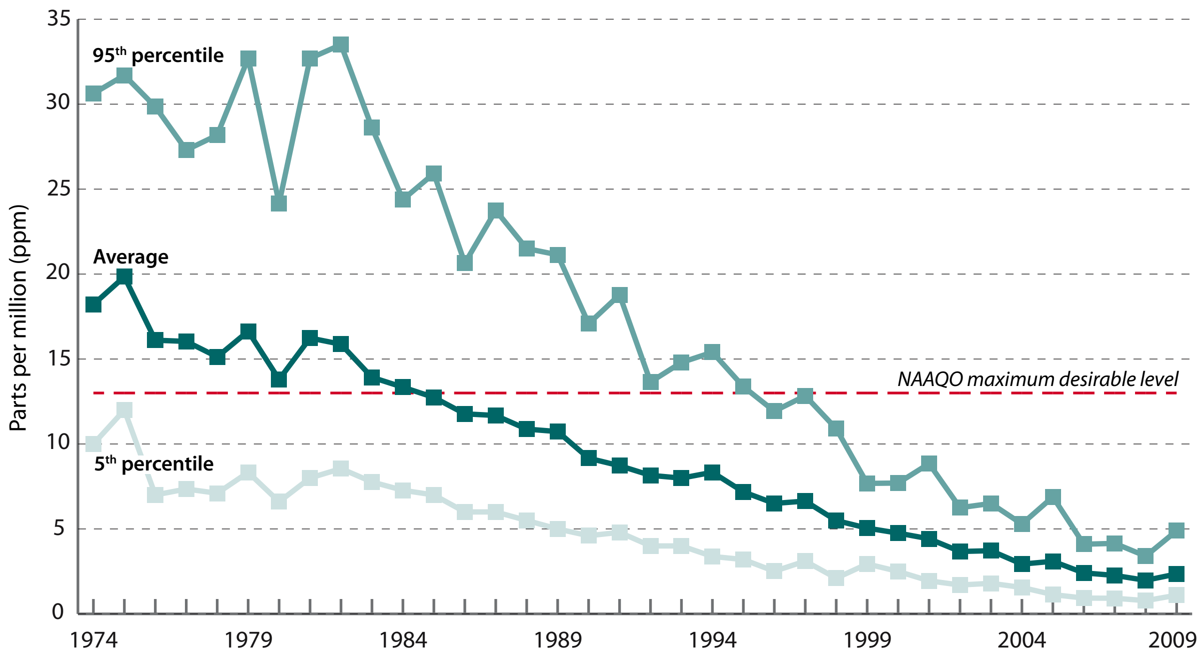
Figure 4: Sources of Carbon Monoxide emissions in Canada, 2008



Note: The petroleum, the wood, and the aluminum industries are the largest industrial sources.

Sources: Environment Canada, 2010c; calculations by author.

Figure 5: Average annual concentrations of Carbon Monoxide in Canada, 1974–2009



Notes: The figure displays average, 95th percentile, and 5th percentile values of annual maximum 1-hour average CO concentrations from stations across Canada. In a given year, 95% of stations have concentrations below the 95th percentile value. Similarly, 5% of stations report concentrations below the 5th percentile value. MDL = maximum desirable level.

Sources: Environment Canada, 2010b; calculations by author.

Table 7: Exceedances of British Columbia's 1-hour 0bjective for CO (12 ppm) by various provinces

		Exceeding hours	Exceeding stations	Total stations	% of stations with exceeding hours
British Columbia	1974–1979	1,186	6	7	86%
	1980–1989	352	7	8	88%
	1990–1999	3	1	8	13%
	2000–2008	0	0	30	0%
Alberta	1974–1979	998	7	7	100%
	1980–1989	1,056	5	5	100%
	1990–1999	158	5	8	63%
	2000–2008	0	0	14	0%
Saskatchewan	1974–1979	32	3	4	75%
	1980–1989	65	3	3	100%
	1990–1999	1	1	3	33%
	2000–2008	0	0	2	0%
Manitoba	1974–1979	77	4	4	100%
	1980–1989	15	3	4	75%
	1990–1999	0	0	2	0%
	2000–2008	0	0	2	0%
Ontario	1974–1979	1,566	20	23	87%
	1980–1989	2,539	24	31	77%
	1990–1999	97	9	26	35%
	2000–2008	0	0	34	0%
Quebec	1974–1979	1,159	11	12	92%
	1980–1989	464	16	17	94%
	1990–1999	5	4	20	20%
	2000–2008	0	0	12	0%
New Brunswick	1974–1979	2	1	1	100%
	1980–1989	23	1	1	100%
	1990–1999	1	1	4	25%
	2000–2008	0	0	3	0%
Nova Scota	1974–1979	12	1	2	50%
	1980–1989	45	1	2	50%
	1990–1999	0	0	2	0%
	2000–2008	0	0	2	0%

Notes: The calculations considered all stations with any amount of monitoring data. An exceedance was defined as an average 1-hour CO concentration greater than, or equal to, 12 ppm. An exceeding station is any monitoring station with at least one 1-hour concentration equal to, or greater than, 12 ppm. British Columbia's objective of 12 ppm is the most stringent in Canada.

Sources: Environment Canada, 2010b; calculations by author.

5 Air quality in Canada—Sulfur Dioxide

Effects on health and the environment

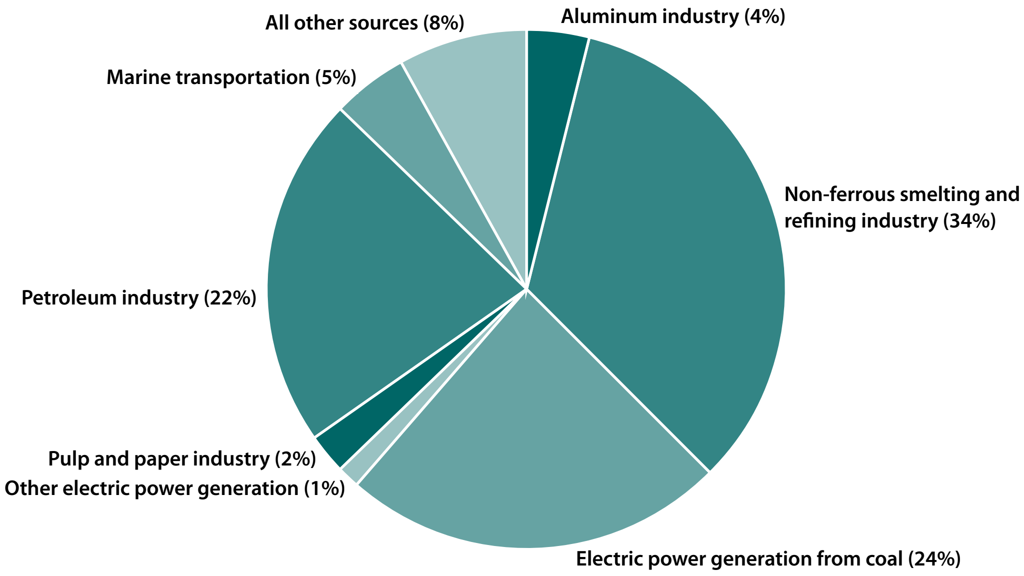
Concentrations of sulfur dioxide (SO_2) have been monitored nationally in Canada since 1974. High levels of SO_2 may cause acid rain and lead to the acidification of rivers, lakes, and ecosystems and, thus, decrease biodiversity (Environment Canada, 2011). The majority of SO_2 emissions in Canada come three sources: 32% from smelting and refining non-ferrous metals, 22% from coal-fired electricity generation, and 21% from the petroleum industry (figure 6).

High concentrations of SO_2 may have adverse effects on human health (Environment Canada, 2011). There is currently uncertainty over whether low levels of SO_2 have effects on human health. The World Health Organization recommends 24-hour average concentrations under 7 ppb (20 $\mu g/m^3$), a recommendation based on a handful of cited studies that the World Health Organization has misinterpreted. The World Health Organization's report (2006) cites a time-series study on hospital admissions for cardiac disease in Hong Kong and London by Wong et. al. (2002). However, the results for SO_2 of this study are not statistically significant when other pollutants are included in the statistical model and the study actually suggests that SO_2 has no discernible effects on cardiac disease.

The World Health Organization then cites a Canadian study (Burnett et al., 2004) linking SO_2 concentrations with mortality rates; however, WHO's report misinterprets the units of measurement, claiming that the cities included in the study had average concentrations over a 24-hour period between 5 $\mu g/m^3$ and 10 $\mu g/m^3$. Closer analysis of Burnett et al. (2004) reveals that the average concentrations are between 5 ppb (14.28 $\mu g/m^3$) and 10 ppb (29 $\mu g/m^3$); the World Health Organization misread the units of measure in the Canadian study. Burnett and his colleagues find a very small positive effect on mortality for SO_2 when nitrogen dioxide (NO_2) is included in the model (the result is statistically significant at the 5% level but not the 1% level). The effect is relatively smaller than that of other pollutants, suggesting that reductions of SO_2 provide lower health benefits than reductions of other pollutants.

It should also be noted that the study by Burnett et al. only proves correlation between SO_2 and mortality and is not evidence of a causal relationship. Two other studies (Buringh et al., 2000; Wichman et al., 2000) cited by the World Health Organization's report show no causal relationship between SO_2 and mortality when particulate matter is included in the analysis. Thus, the report by Burnett and colleagues (2004) does not prove a link between

Figure 6: Sources of Sulphur Dioxide emissions in Canada, 2008



Sources: Environment Canada, 2010c; calculations by author.

SO_2 and mortality since particulate matter and SO_2 were never included in the analysis at the same time.[11] Clearly, the extent of the effects upon health of exposure to SO_2 is still open for debate.

Data—24-hour concentrations

Between 2000 and 2009, there were only 27 stations Canada-wide (19 cities) that had observations that were greater than, or equal to, the Alberta 24-hour objective of 44 ppb, the lowest Canadian objective. That is only 15% of the stations that monitor SO_2 in Canada. Montreal and Halifax were the only major cities that reported 24-hour concentrations exceeding 44ppb in this time period. The summary results for each province are displayed in table 8.

It is clear from table 8 that a very large number of additional SO_2 monitoring stations were established in British Columbia and Alberta in the 2000s. As a result, the data indicate that, between 2000 and 2008, British Columbia had 34 days for which the 24-hour SO_2 concentrations exceeded 44 ppb, as compared to four between 1990 and 1999. However, 30 of these days occurred in Trail where continuous monitoring did not commence until the year 2000.[12] Alberta experienced 21 days for which the 24-hour SO_2 concentrations were greater than 44 ppb between 2000 and 2009. All of these days occurred at three of 48 stations: six days near Fort McKay and 15 days

---

[11] To be fair to Burnett et al., the focus of their study was the effects of NO_2 and not of SO_2.

[12] The other four days occurred in Prince George.

Table 8: Exceedances of Alberta's 24-hour objective for SO_2 (44 ppb) by various provinces

		Exceeding days	Exceeding stations	Total stations	% of stations with exceeding hours
British Columbia	1974–1979	29	3	9	33%
	1980–1989	12	3	10	30%
	1990–1999	4	1	7	14%
	2000–2008	34	4	50	8%
Alberta	1974–1979	3	2	9	22%
	1980–1989	1	1	6	17%
	1990–1999	1	1	5	20%
	2000–2008	21	3	48	6%
Saskatchewan	1974–1979	0	0	6	0%
	1980–1989	0	0	7	0%
	1990–1999	0	0	3	0%
	2000–2008	0	0	4	0%
Manitoba	1974–1979	10	2	9	22%
	1980–1989	0	0	4	0%
	1990–1999	0	0	2	0%
	2000–2008	162	1	2	50%
Ontario	1974–1979	1,603	31	33	94%
	1980–1989	650	31	45	69%
	1990–1999	307	10	36	28%
	2000–2008	85	6	49	12%
Quebec	1974–1979	2,980	25	26	96%
	1980–1989	2,093	26	34	76%
	1990–1999	1,012	14	33	42%
	2000–2008	855	11	23	48%
New Brunswick	1974–1979	110	2	2	100%
	1980–1989	64	2	2	100%
	1990–1999	161	3	3	100%
	2000–2008	9	1	3	33%
Nova Scota	1974–1979	137	6	7	86%
	1980–1989	132	8	8	100%
	1990–1999	21	4	5	80%
	2000–2008	3	1	4	25%

Notes: The calculations considered all stations with any amount of monitoring data. An exceedance was defined as an average 24-hour SO_2 concentration greater than, or equal to, 44 ppb. An exceeding station is any monitoring station with at least one 24-hour concentration equal to, or greater than, 44 ppb.

Sources: Environment Canada, 2010b; calculations by author.

in Redwater. Clearly all of these exceedances are related to economic activity (smelting in Trail, pulp and paper processing in Prince George, oil sands processing in Fort McKay and Redwater) and do not affect large proportions of the provincial populations. To put these numbers in perspective, a Vancouver monitoring station reported 16 days with concentrations exceeding 44 ppb between 1974 and 1979, corresponding to 2.7 days a year compared to three days a year for the Trail monitoring station with the most data.[13] However, there are many fewer people residing in Trail than Vancouver, so the impact would be much less severe than in the 1970s.

Manitoba experienced 162 days for which concentrations exceeded 44 ppb between 2000 and 2009, but a closer inspection of the data reveals that this may not be a major problem. All of these days occurred at one monitoring station in Flin Flon. All other continuous SO_2 monitoring in Manitoba was discontinued in 1992 since there were no reported instances of high SO_2 concentrations at any of the other stations. Between 2000 and 2009, Flin Flon had 104 days with concentrations over 53 ppb (the Manitoba Maximum Desirable Level) and 13 days with concentrations over 105 ppb (the Manitoba Maximum Acceptable Level). However, Manitoba is the only province that also employs a Maximum Tolerable Level (280 ppb), and Flin Flon had no days exceeding this level. Therefore, it is likely that the Manitoba government has balanced the costs of this pollution against the benefits of the mining and smelting operations in Flin Flon and granted emission approvals that allow concentrations above 53 ppb and 105 ppb on occasion.

Saskatchewan has reported no days for which concentrations exceeded 44 ppb since monitoring commenced in 1974. New Brunswick had nine days exceeding 44 ppb between 2000 and 2009, all at one monitoring station located in north-east Saint John. Nova Scotia had only three days that exceeded 44 ppb, all at the monitoring station in downtown Halifax.

Ontario had 85 days for which 24-hour concentrations exceeded 44 ppb between 2000 and 2009. The vast majority of these days occurred in Sarnia (78 days). Windsor (2 days), Sudbury (4 days), and Long Point Provincial Park (1 day) also reported concentrations above 44 ppb. Furthermore, SO_2 24-hour concentrations have decreased substantially in Ontario over time. Between 1974 and 1979, 24-hour concentrations were above 44 ppb an amazing 1,603 days for 31 out of 33 monitoring stations. Between 1990 and 1999, 24-hour concentrations were above 44 ppb only 307 days for 10 out of 36 monitoring stations. Between 2000 and 2009, 24-hour concentrations were above 44 ppb only 85 days for 6 out of 49 monitoring stations. And in 2009, no stations reported average concentrations over a 24-hour period above 44 ppb. Clearly, as far as it concerns SO_2 concentrations, Ontario's air is currently much cleaner than it has been in the past 35 years.

---

[13] Twenty-seven days between 2000 and 2008 at Trail's downtown station.

Quebec has by far the most days (855) on which average SO_2 concentrations over a 24-hour period exceeded 44 ppb between 2000 and 2008. These days occurred at 11 of 23 monitoring stations. Quebec is the only province in which exceedances occurred in a major city (Montreal had five exceeding days). Approximately 50% of the days occurred in Temiscaming, a small town in western Quebec near the Ontario border with a pulp-and-paper facility. Other cities and towns with exceeding days are Rouyn-Noranda (43 days), Saguenay (157 days), Shawinigan (30 days), Sorel (128 days), Murdochville (64 days), and Cap-de-la-Madeleine (9 days). However, these 855 exceeding days actually represent an improvement in air quality in Quebec. Between 1974 and 1979, Quebec recorded 2,980 days exceeding 44 ppb (at 25 of 26 stations). Between 1980 and 1989, the number of exceeding concentrations fell to 2,093 days at 26 of 34 stations. Between 1990 and 1999, the number of exceeding concentrations was halved to 1,012 days at 14 of 33 stations. Clearly, SO_2 concentrations in Quebec have decreased over the past 35 years.

Data—annual concentrations

The vast majority of monitoring stations in Canada report annual average SO_2 concentrations below the lowest provincial air-quality objective of 7 ppb (Alberta's objective). In British Columbia, all stations have had concentrations below 7 ppb since 1998 except for those in Trail and Chetwynd. Furthermore, the station in Chetwynd has reported concentrations below 7 ppb since 2007. All monitoring stations in Alberta except Fort Saskatchewan-North and Redwater[14] have had concentrations below 7 ppb since 1986. All stations in Saskatchewan have been below 7 ppb since the late 1970s. All stations in New Brunswick reported annual concentrations below 7 ppb in 2009, but concentrations at the Saint-John-Northeast station have only been below 7 ppb since 2008.

Manitoba is an interesting case. SO_2 concentrations were low (below 7 ppb) in Winnipeg and Brandon, and monitoring was discontinued in 1992. However, Flin Flon has had the highest reported annual concentrations in Canada since continuous monitoring was initiated there in 2002. The average annual concentration in Flin Flon between 2002 and 2009 was 73 ppb, which is much higher than the high concentrations reported in major cities in the 1970s. However, since monitoring in Flin Flon only commenced in 2002, it is plausible that concentrations in Flin Flon could have been even higher in the past.

Ontario has experienced large decreases in annual SO_2 concentrations over the past 35 years. All cities with monitoring stations except Sarnia have reported concentrations below 7 ppb since 2006; all stations, including that in Sarnia, reported concentrations are below 7 ppb in 2009. There is also a

---

[14] Monitoring stations 090603 and 092301 in the National Air Pollution Surveillance network.

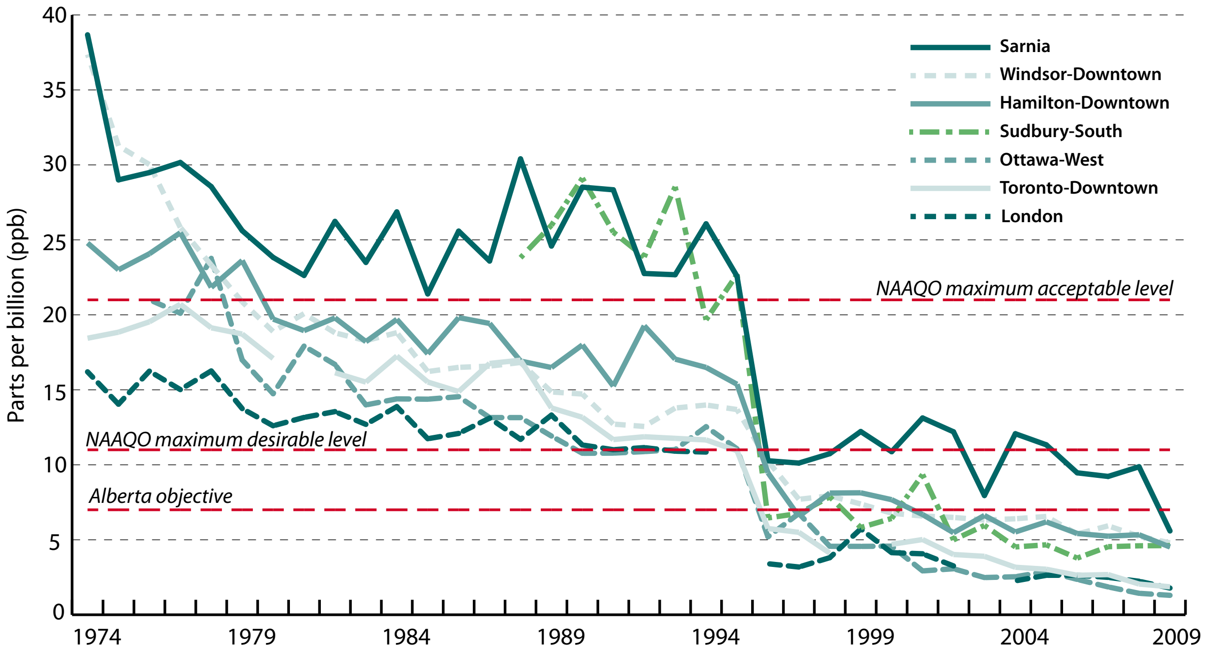
noticeably large decrease in annual concentrations recorded in major Ontario cities between 1995 and 1996 (figure 7) and a similar pattern is visible for most Ontario monitoring stations. The timing of this decrease corresponds with the implementation of reductions laid out in the Canada-US Air Quality Agreement to control acid rain.

All stations in Quebec, except the station in Temiscaming, have reported annual average concentrations below the Quebec Air Quality Objective of 18 ppb since 1999. All concentrations were below 7 ppb in 2008 except in Temiscaming, Saguenay, and Saint Joseph de Sorel.

Conclusion

Overall, SO_2 concentrations are in most instances lower than in previous decades. Extremely high concentrations occur in isolated areas: for example, Flin Flon, Temiscaming, between Fort McKay and Fort McMurray, between Redwater and Fort Saskatchewan, and Saguenay. Most of these locations with high concentrations have not been monitored long enough to allow us to evaluate the data and decide whether concentrations are decreasing or not. However, SO_2 concentrations in Canada are clearly decreasing at the vast majority of monitoring stations. This decline is clear in figure 8, which

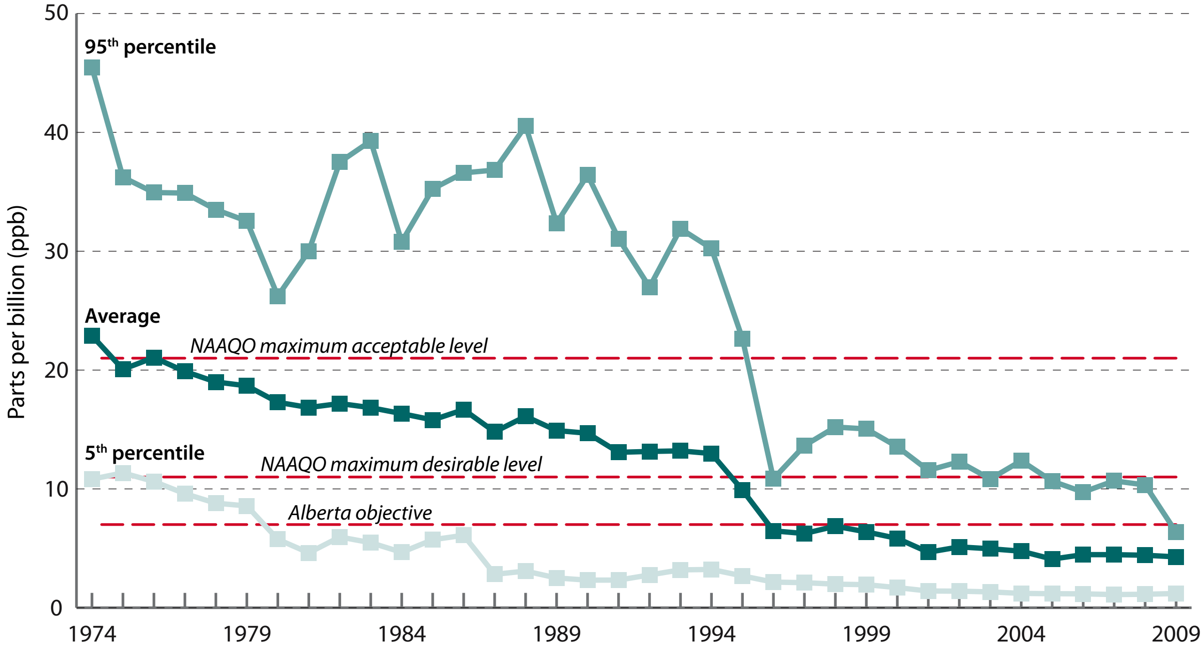
Figure 7: Annual concentrations of Sulfur Dioxide in selected Ontario cities, 1974–2009



Notes: The data are annual average SO_2 concentrations. Some of the data required the use of multiple monitoring stations within a 5km radius. The station numbers are: 060401, 060417, 060424, 060425, 060433, 060501, 060512, 061001, 061004, 060607, 060608, 060901, 060903, 060204, 060104.

Sources: Environment Canada, 2010b; calculations by author.

Figure 8: Average annual concentrations of Sulfur Dioxide in Canada, 1974–2009



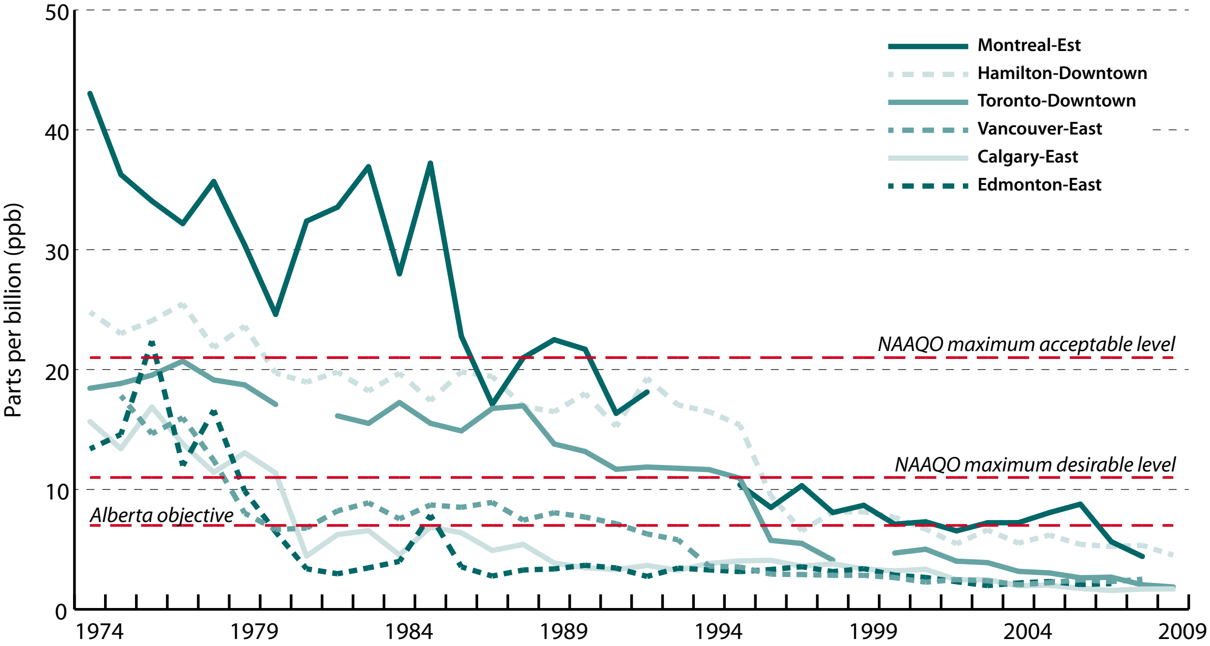
Notes: The figure displays average, 95th percentile, and 5th percentile values of annual average SO_2 concentrations from stations across Canada. In a given year, 95% of stations have concentrations below the 95th percentile value. Similarly, 5% of stations report concentrations below the 5th percentile value.

Sources: Environment Canada, 2010b; calculations by author.

graphs Canadian average concentrations and other distributional indicators between 1974 and 2009. Furthermore, concentrations in Canada's major cities declined substantially between 1974 and 2009: see figure 9, which displays annual concentrations in six major Canadian cities. Clearly, the proportion of the Canadian population that is exposed to high SO_2 concentrations has decreased over time. Table 8 combined with figures 7, 8, and 9 paints a very conclusive picture of decreasing SO_2 concentrations for the majority of Canadian locations. In this case, statistical analysis is not required to identify whether concentrations are decreasing.

The evidence suggests that legally binding objectives for SO_2 (as proposed by Boyd, 2006) would not have a significant effect on the air quality to which the majority of Canadians are exposed. They would, however, have a negative impact on economic activity in the small, isolated communities that rely on smelting, mining, oil-sands development, and pulp-and-paper processing for their livelihoods. The resulting effect of decreased economic activity upon poverty in these communities and, thus, upon human health is difficult to predict and may outweigh the benefits to human health from increased emission restrictions in these communities.

Figure 9: Annual concentrations of Sulfur Dioxide in major Canadian cities, 1974–2009



Note: The data are annual average SO_2 concentrations. The stations' numbers are: 100110, 090121, 090218, 060401, 060417, 060424, 060425, 060433, 050103, 060501, 060512.

Sources: Environment Canada, 2010b; calculations by author.

Since these locations reporting high concentrations are in isolated areas, there is insufficient monitoring in surrounding areas to identify how many communities and people are affected. Also, some locations with high emitters do not even have monitoring stations. Thompson, Manitoba is home to a smelting operation that produced the second-highest SO_2 emissions in Canada in 2008 (Environment Canada, 2010d),[15] yet Thompson does not have a continuous monitoring station in the National Air Pollution Surveillance network. If SO_2 is considered a problem pollutant, then monitoring in the actual problem areas needs to be more comprehensive in order to identify how many people actually are exposed to high concentrations.

---

[15] Flin Flon was home to the largest SO^2 emitter.

6 Air quality in Canada—Ground-Level Ozone

Sources

Ground-level ozone (O_3) is not emitted directly into the air but forms in the atmosphere through a chemical reaction involving nitrogen oxides, of which nitrogen dioxide (NO_2) is the largest portion, volatile organic compounds, and intense sunlight. According to data from Environment Canada (2010c), NO_2 is generally emitted by transportation, the petroleum industry, and the generation of electricity (figure 1, p. 18). Natural sources like vegetation, soils, and forest fires are responsible for over 90% of the volatile organic compounds emitted into the atmosphere in Canada. Of the human activities that are sources of volatile organic compounds, transportation and the petroleum sectors are the largest (figure 10).

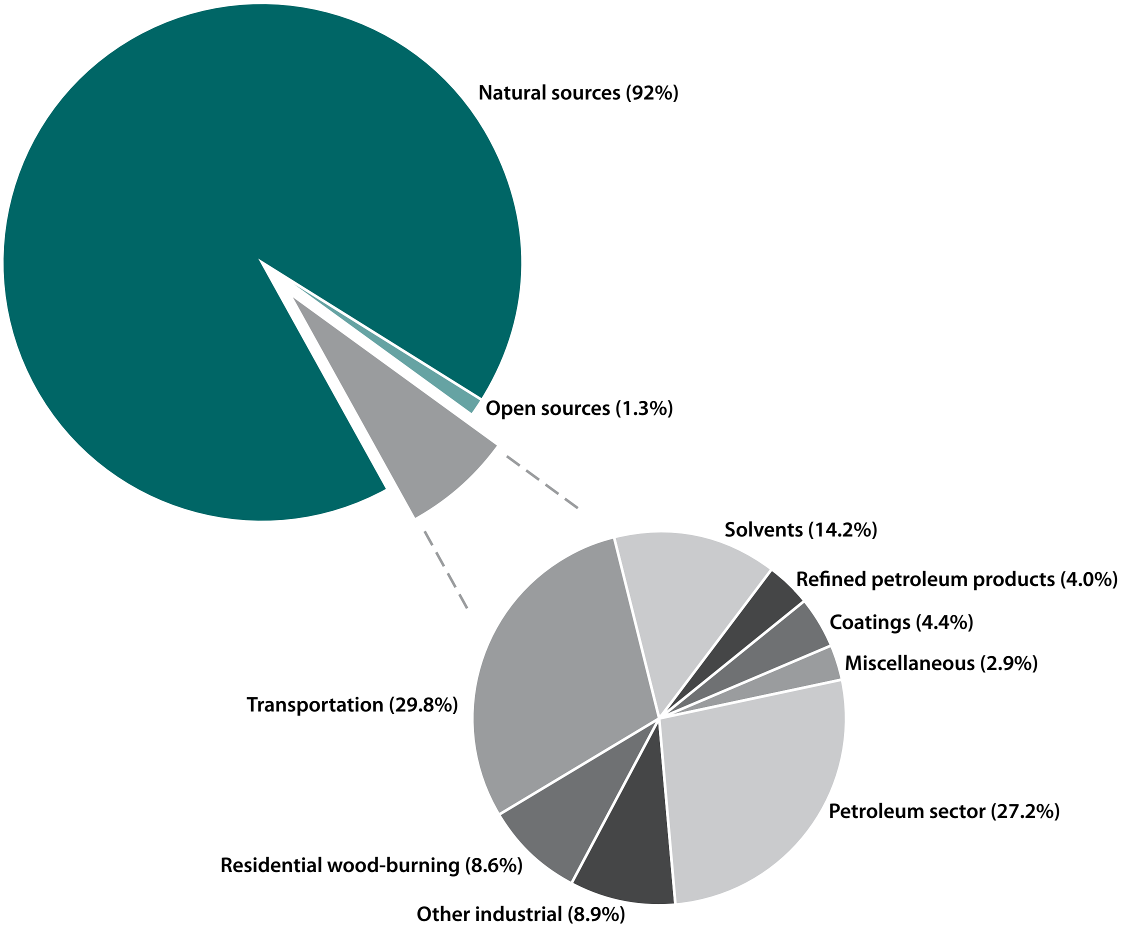
Effects on health

Exposure to ground-level ozone can cause irritation of the respiratory tract, especially for children, asthmatics, and individuals with pre-existing respiratory problems (Environment Canada, 2011). Epidemiological studies have linked exposure to O_3 to premature mortality, increased hospital admissions, aggravated asthma, and reduced lung function (Bell et al., 2004). The Canadian Medical Association's study published in 2008 bases its estimates of premature mortality on ambient concentrations of O_3 and ultrafine particulate matter (CMA, 2008). High concentrations of O_3 can have adverse effects on vegetation (causing, for example, crop losses) and buildings. O_3 also contributes to "smog," which results in reduced visibility (Environment Canada, 2011). Recent research suggests that exposure to ground-level ozone has adverse effects on the productivity of agricultural workers (Graff Zivin and Neidell, 2011).

Data

It is difficult to determine from graphs alone whether O_3 concentrations are declining. Figure 11 displays distributional statistics of concentrations of ground-level O_3 from all monitoring stations across Canada from 1982 to 2009 against the Canada-wide Standard (CWS). The average appears to be slightly decreasing over time. Also, the 95th percentile appears to be decreasing between 1982 and 2009. This means that the top end of the range containing 95% of all data points has been declining. However, these trends are slight and may not be true in all provinces.

Figure 10: Sources of volatile organic compounds in Canada, 2008



Notes: Natural sources include vegetation, soils, and forest fires. Residential Fuel Wood refers to residential fuel wood combustion for home heating.

Sources: Environment Canada, 2010c; calculations by author.

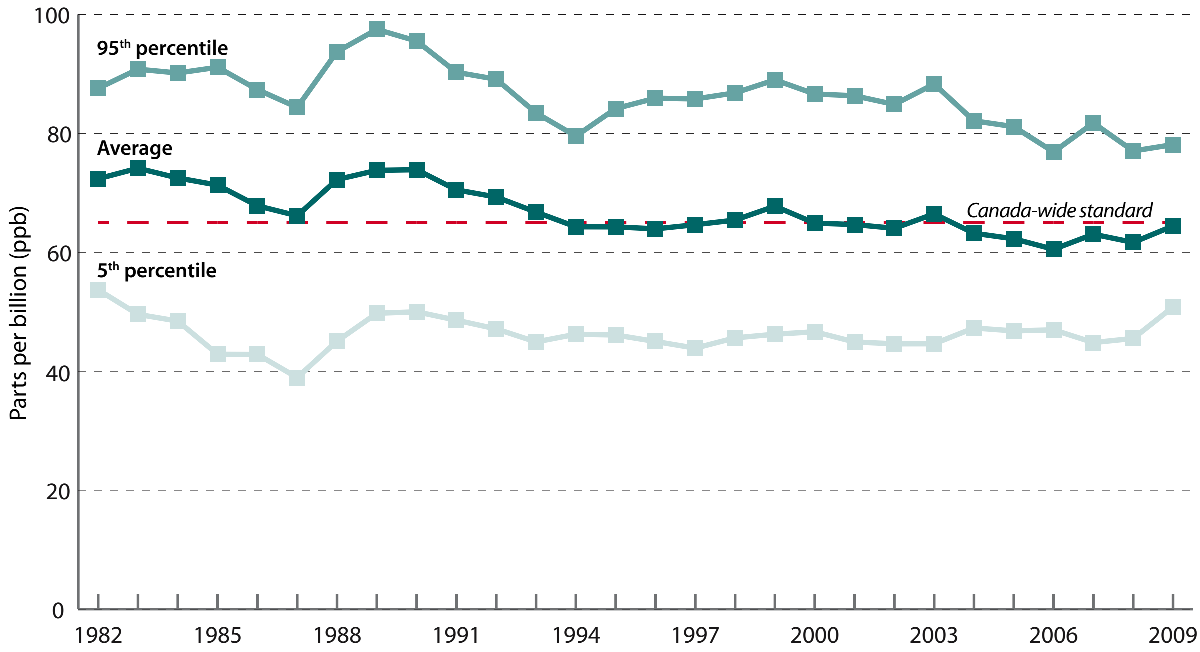
Table 9 displays exceedances of the federal Maximum Acceptable Level for 1-hour average concentrations of O_3. In most provinces, the total number of hours exceeding the 1-hour objective has declined since the 1980s, as has the fraction of monitoring locations where at least one exceedance was observed. However, it is difficult to infer a strong overall pattern in table 9. Some provinces, such as British Columbia and Ontario, show decreasing exceedances. However, despite the decrease in exceedances, the percentage of stations in Ontario reporting exceedances is relatively constant over time.

All stations in British Columbia were in compliance with the CWS as of the latest three-year average (2006–2008) available for British Columbia.[16] There has been improvement since the 1980s when as many as nine stations

---

[16] Spreadsheet of CWS achievements is available from the author upon request.

Figure 11: Concentrations of ground-level Ozone in Canada, 1982–2009



Note: The figure displays average, 95th percentile, and 5th percentile values of the 3-year moving average of annual 4th-highest daily maximum 8-hour average for ground-level Ozone at monitoring stations across Canada. In a given year, 95% of stations have concentrations below the 95th percentile value. Similarly, 5% of stations report concentrations below the 5th percentile value.

Sources: Environment Canada, 2010b; calculations by author.

(1988–1989) reported concentrations in excess of the current CWS. Since the setting of the CWS in 2000, only two of 32 BC stations have measured concentrations exceeding the standard: Chilliwack in 2004–2006; Hope has five consecutive violations between 2001–2003 and 2005–2007. It is clear that Hope remains a place to watch for exceedances and requires further analysis as data becomes available; however, it is also evident that most of British Columbia's stations met the CWS in all years.

Concentrations in Saskatchewan and Manitoba have almost always been lower than the CWS, the only exceedances being in Winnipeg and Brandon for 1987–1989. All stations in New Brunswick were in compliance with the CWS in 2007–2009; however, there have been three of 13 stations not in compliance for at least a year since 2000. The most recent station out of compliance for New Brunswick is located in Fundy National Park, which had concentrations equal to, or above, the CWS for the only three periods of monitoring data available (consecutive data are only complete for 1991–1996 and 2004–2008). Of the three current monitoring stations in Saint John, only one has recorded concentrations higher than the CWS, the most recent in the 2000–2003 period. The monitoring data for Nova Scotia is intermittent but the stations located in Kejimkujik National Park and Aylesford have

Table 9: Exceedances of the federal maximum acceptable level 1-hour objective for O_3 (80 ppb) by various provinces

		Exceeding hours	Exceeding stations	Total stations	% of stations with exceeding hours
British Columbia	1980–1989	1,215	22	26	85%
	1990–1999	433	29	40	73%
	2000–2008	162	19	44	43%
Alberta	1980–1989	149	5	5	100%
	1990–1999	136	9	19	47%
	2000–2009	229	25	41	61%
Saskatchewan	1980–1989	66	2	3	67%
	1990–1999	1	1	6	17%
	2000–2009	9	1	5	20%
Manitoba	1980–1989	35	3	3	100%
	1990–1999	19	3	3	100%
	2000–2009	2	2	3	67%
Ontario	1980–1989	21,668	58	61	95%
	1990–1999	21,085	61	64	95%
	2000–2009	15,683	64	70	91%
Quebec	1980–1989	4,108	29	31	94%
	1990–1999	4,755	52	55	95%
	2000–2008	2,794	50	54	93%
New Brunswick	1980–1989	1,209	6	7	86%
	1990–1999	928	13	13	100%
	2000–2009	180	13	15	87%
Nova Scotia	1980–1989	175	5	5	100%
	1990–1999	295	5	6	83%
	2000–2009	317	6	9	67%

Notes: The calculations considered all stations with any amount of monitoring data. An exceedance was defined as O_3 concentrations averaged over a 1-hour period greater than, or equal to, 80 ppb (the federal NAAQO maximum acceptable level). An exceeding station is any monitoring station with at least one 1-hour average concentration equal to, or greater than, 80 ppb.

Sources: Environment Canada, 2010b; calculations by author.

repeatedly reported O_3 levels higher than the CWS. However, the final years for which usable data exist show concentrations in compliance with the CWS.

Alberta continues to have stations reporting concentrations not in compliance with the CWS; however, the two largest cities, Calgary and Edmonton, have not had a station reporting concentrations out of compliance since 2001–2003. As of 2007–2009, Tomahawk (66.46 ppb), Violet Grove (65.00 ppb), and Thorsby (64.79 ppb) were the only places in Alberta with concentrations in excess of, or equal to, the CWS.

Monitoring data for Quebec for O_3 are only available up to 2008. In 2006–2008, 15 of 48 monitoring stations (32%) had concentrations equal to, or above, the CWS. However, in 1998–2000, when the CWS was agreed upon, 21 out of 31 stations (68%) reported concentrations equal to, or above, the CWS of 65 ppb. The number of stations in Quebec that are not in compliance with the CWS has declined despite a significant increase in the number of monitoring stations.

The data for Ontario suggest that it has the largest problem with O_3. In the 2007–2009 averaging period, 39 out of 41 (95%) monitoring stations had concentrations equal to, or above, the CWS. In the 1998–2000 averaging period, 34 out of 37 (92%) monitoring stations had concentrations equal to, or above, the CWS. It appears that excessive concentrations of O_3 in Ontario are persistent: see figure 12, which shows distributional statistics of concentrations of ground-level O_3 from all monitoring stations in Ontario between 1982 and 2009 against the Canada-wide Standard (CWS).

Although O_3 concentrations appear to be decreasing slightly across Canada, it is still unclear by how much and whether they are decreasing or not in all relevant metrics and in all provinces. Given the importance of O_3 in the Canadian Medical Association's report, it would be useful to identify trends in the data using statistical, rather than merely visual, methods.[17]

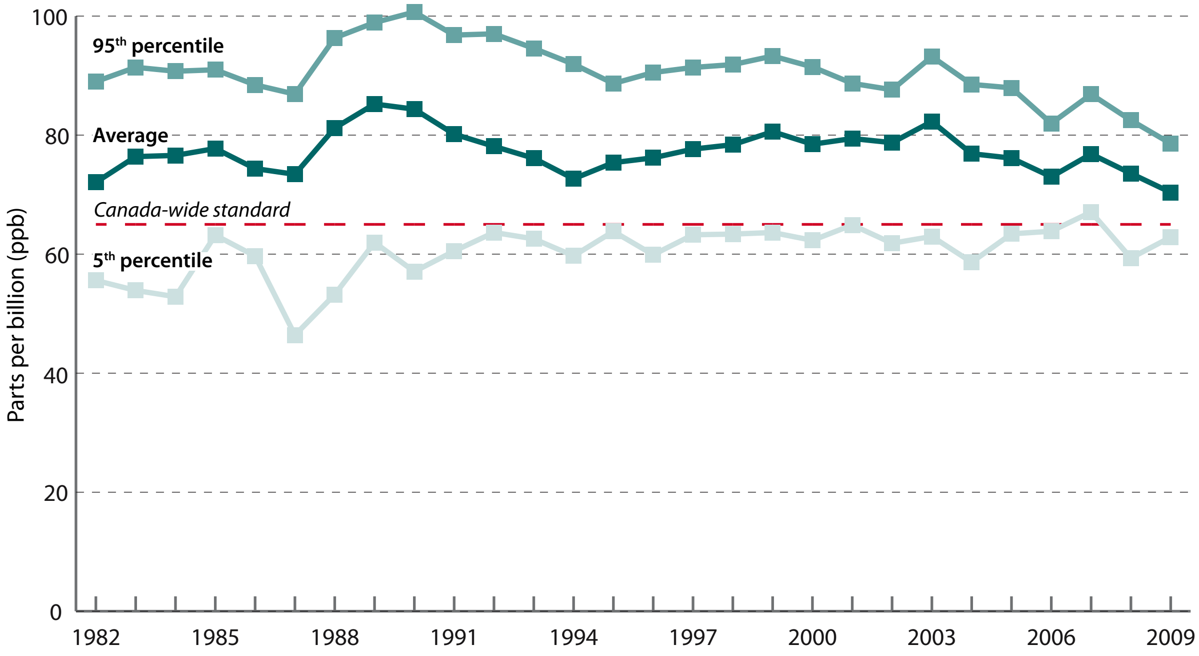
Statistical analysis

Data that are collected in cross-sectional groups, each one containing a time-series, is referred to as "panel data." Statistical methods using panel data can be used to identify whether concentrations are generally decreasing, increasing, or remaining constant over time. The advantage of panel methods is that they take into account the information in both the cross-sectional and time-series dimensions. With respect to the monitoring data, the cross-sectional dimension is the number of monitoring stations and the time dimension is the data recorded at each monitoring station over time. Panel regression

---

[17] The remainder of section 6 discusses quantitative trend estimation; readers without a background in statistics may want to proceed to the brief non-technical summary at the end. Readers with an intermediate background in statistics or econometrics are encouraged to continue through the following discussion.

Figure 12: Concentrations of ground-level Ozone in Ontario, 1982–2009



Note: The figure displays average, 95th percentile, and 5th percentile values of the 3-year moving average of annual 4th-highest daily maximum 8-hour average for ground-level Ozone at monitoring stations in Ontario. In a given year, 95% of stations have concentrations below the 95th percentile value. Similarly, 5% of stations report concentrations below the 5th percentile value.

Sources: Environment Canada, 2010b; calculations by author.

analysis can be used to identify common linear time-trends in the monitoring data while accounting for the unobservable individual characteristics of each monitoring station (the "fixed effects"). The method essentially estimates a number of fitted trend lines that have equal slope estimates, but with a different intercept estimate for each cross-sectional unit. The method estimates a line for every cross-section. The methodology and statistical tests involved are described in greater detail in the technical appendix (p. 54).

To analyze 1-hour O_3 concentrations across Canada between 1980 and 2009, a linear time trend is fitted through the provincial average 1-hour exceedances per station using panel regression with eight provinces as the cross-sectional units.[18] The results are displayed in table 10. The results indicate a decreasing common trend in the average number of exceedances per exceeding station when exceedance is defined with respect to the federal Maximum Acceptable Level of 80 ppb. The results suggest that average exceeding hours per exceeding station decreased by 0.73 hours annually, a

---

[18] This dependent variable was calculated by dividing the total number of exceeding observations for a province in a year by the number of monitoring stations that recorded exceeding observations in that province in that year.

Table 10: Panel-data regression results on average exceedances of O_3 concentrations per exceeding station

Air quality objective	Time period	Sample size	Common trend coefficient	Standard error	Adj-R^2	F-stat
NAAQO–MAL	1980–2009	(Total Obs. = 237, N = 8)	$-0.72644^{1\%}$	0.27933	0.469	$24.24^{1\%}$
NAAQO–MDL	1980–2009	(Total Obs. = 237, N = 8)	−0.27896	2.68566	0.7728	$90.93^{1\%}$

Notes: NAAQO–MAL = National Ambient Air Quality Objectives—maximum acceptable level; NAAQO–MDL = National Ambient Air Quality Objectives—maximum desirable level. The dependent variable is the provincial average number of average 1-hour concentrations exceeding the objective per station with exceeding observations. The independent variable is a common linear trend for all eight provinces. The results are interpreted for the NAAQO-MAL regression as follows: between 1980 and 2009. Canadian provinces on average experienced 0.7 fewer hours annually for which O_3 concentrations exceeded 80 ppb (21.8 fewer hours over 30 years). More details on the econometric method can be found in the Appendix (p. 54). Superscript $^{1\%}$ denotes statistical significance at the 1% level. The fixed-effects model was estimated using Least Squares Dummy Variable estimation. The standard errors are robust to heteroskedasticity and serial correlation using the method proposed by Arellano (1987). Adj-R^2 refers to the Adjusted-R^2, a measure of the goodness of fit. The F-stat is a goodness-of-fit test statistic; significance indicates that the model provides non-negligible explanatory power.

Sources: Environment Canada, 2010b; author's statistical analysis.

decrease of 21.8 exceeding hours over 30 years. However, when exceedance is defined with respect to the federal Maximum Desirable Level of 50 ppb, there is no statistically significant trend.[19] These results suggest that over the past 30 years Canadians are experiencing fewer extreme O_3 events but the number of moderate O_3 events remains unchanged.

In a further analysis to discover whether O_3 concentrations are decreasing, annual fourth-highest daily maximum 8-hour averages for each station are examined from 1980 to 2009. Eight panel regressions are undertaken to estimate a common linear-time trend for the monitoring stations of each province. The results for all eight provinces are listed in table 11. For Ontario, the results indicate that, on average between 1980 and 2009, O_3 concentrations in Ontario have decreased by 0.22 ppb annually (around 6.6 ppb over 30 years). The only provinces that did not experience a decrease in concentrations were Saskatchewan and Nova Scotia. Saskatchewan had a small but statistically significant increasing trend. However, Saskatchewan has relatively low O_3 concentrations compared to other provinces, so this result does not indicate a problem. Nova Scotia had a decreasing trend that was not statistically significant. New Brunswick experienced the largest annual decrease of 0.843 ppb (a decrease of 25.29 ppb over 30 years). And, Alberta had the lowest decrease of 0.1 ppb annually (a decrease of 3 ppb over 30 years). The results for Saskatchewan, Manitoba, New Brunswick, and Nova Scotia need to be taken with a grain of salt since the samples are much smaller than those

---

[19] The estimated coefficient was negative but was not statistically significant when using standard errors robust to heteroskedasticity and serial correlation.

Table 11: Panel-data fixed-effects regression results for O_3 concentrations in each province

Province	Time period	Sample size	Common trend coefficient	Standard error	Adj-R^2	F-stat
Alberta	1980-2009	(Total Obs. = 374, N = 32)	$-0.100^{10\%}$	0.0599	0.994	$1,781.0^{1\%}$
British Columbia	1980-2008	(Total Obs. = 641, N = 57)	$-0.374^{5\%}$	0.1688	0.984	$685.6^{1\%}$
Saskatchewan	1980-2009	(Total Obs. = 65, N = 7)	$0.005^{1\%}$	0.0599	0.986	$496.2^{1\%}$
Manitoba	1980-2009	(Total Obs. = 76, N = 3)	$-0.319^{1\%}$	0.0781	0.986	$1,313.0^{1\%}$
Ontario	1980-2009	(Total Obs. = 1,196, N = 98)	$-0.222^{1\%}$	0.0572	0.987	$950.7^{1\%}$
Quebec	1980-2008	(Total Obs. = 793, N = 69)	$-0.367^{1\%}$	0.0497	0.986	$813.4^{1\%}$
New Brunswick	1980-2009	(Total Obs. = 206, N = 17)	$-0.843^{1\%}$	0.1379	0.978	$502.6^{1\%}$
Nova Scotia	1980-2009	(Total Obs. = 103, N = 13)	−0.332	0.2338	0.985	$493.4^{1\%}$

Notes: A panel regression was conducted for each province with individual effects for each monitoring station (N = the number of stations). The dependent variable is the annual fourth-highest daily maximum 8-hour average O_3 concentration. The independent variable is a common linear trend. The results for Alberta are interpreted as follows: between 1980 and 2009, O_3 concentrations at monitoring stations in Alberta decreased on average 0.1 ppb annually (3 ppb over 30 years). Superscripts $^{1\%}$, $^{5\%}$, and $^{10\%}$ denote statistical significance at the 1%, 5%, and 10% levels, respectively. The standard errors are robust to heteroskedasticity and serial correlation using the method proposed by Arellano (1987). Adj-R^2 refers to the Adjusted-R^2, a measure of the goodness of fit. The F-stat is a goodness-of-fit test statistic; significance indicates that the model provides non-negligible explanatory power.

Sources: Environment Canada, 2010b; author's statistical analysis.

of the other four provinces. Overall, the results indicate that, with respect to O_3, air quality on average is improving in Canada.

In a third analysis to discover whether O_3 levels are decreasing in Canada, a panel regression with a linear time-trend was estimated using all monitoring data (1,590 observations from 225 stations) from eight provinces for the period (2000–2009) since the Canada-wide standard was agreed upon. The results (table 12) indicate that, over the time the Canada-wide standard has been in place, O_3 levels in Canada have decreased on average by 0.466 ppb annually.[20] This corresponds to a decrease of 4.66 pb over 10 years. The evidence is clear: O_3 concentrations are, on average, decreasing in Canada at a slow but statistically significant rate.

Summary of analysis

The statistical analysis provides insight into trends in O_3 concentrations in Canada. The first analysis suggests that, on average, there has been a decrease in the average number of hours with concentrations above 80 ppb, the federal maximum acceptable level, between 1980 and 2009 for individual provinces. However, at the same time there is no significant change in the average number

---

[20] The estimated coefficient is statistically significant at the 1% level.

Table 12: O_3, Canada-wide panel regression, 2000–2009

Total observations	1,590
Total stations	N = 225
Common trend coefficient	–0.4664 $^{1\%}$
Standard error (robust)	0.0688
Adjusted-R^2	0.99

Notes: The dependent variable is the annual fourth highest daily maximum 8-hour average O3 concentration. The independent variable is a common linear trend. The results are interpreted as follows: Between 2000 and 2009 on average O3 concentrations in Canada decreased by 0.4664 ppb annually (a decrease of 4.664ppb over ten years). Superscript, $^{1\%}$, denotes statistical significance at the 1% level. The estimation was conducted using Least Squares Dummy variable estimation. The method of calculating robust standard errors proposed by Arellano (1987) was used to correct for heteroskedasticity and seriel correlation. Adjusted-R2 is a measure of goodness of fit. Further results from other goodness-of-fit tests and other diagnostic tests can be found in the Appendix (p. 54).

Sources: Environment Canada, 2010b; author's statistical analysis.

of hours with concentrations above 50 ppb, the federal maximum desirable level, between 1980 and 2009 for individual provinces. These two results combined suggest that there has been improvement with respect to the frequency of high O_3 exposure, but not the frequency of moderate O_3 exposure.

Further statistical analysis shows that concentrations in all provinces except Saskatchewan and Nova Scotia have decreased overtime between 1980 and 2009. The results even suggest that concentrations at stations in Ontario were decreasing on average over this period.

The final statistical analysis identified the Canada-wide trend of O_3 concentrations. The results suggest that, on average, concentrations of O_3 have decreased at monitoring stations across Canada between 2000 and 2009. The results of the statistical analysis have made it clear that, with respect to ground-level ozone, air quality in Canada is improving.

Conclusion

The results discussed here call into question an assumption used in the Canadian Medical Association 2008 report. When making forecasts of the number of air pollution deaths and air pollution related medical costs, the Canadian Medical Association report relies on the assumption that O_3 concentrations in Canada will remain constant into the future. However, this assumption is not consistent with the trends in historical monitoring data. The federal 1-hour Maximum Acceptable Level exceedance results (table 10) and the analysis using the Canada-wide standard unit of measure both indicate an ongoing declining trend (table 11 and table 12). The average violations of the federal Maximum Acceptable Level for an exceeding station have decreased on average since 1980. Also, O_3 concentrations in the most populated provinces have trended downward between 1980 and 2009. Furthermore, O_3 concentrations in Canada decreased overall following the implementation of the Canada-wide standard, indicating that substantial improvements in air quality have continued to occur over the past decade. There is no justification for the assumption that these patterns will change in the near future.

7 Air quality in Canada—Particulate Matter

Airborne particulate matter (PM) is often measured as total suspended particulates (TSP), fine particulate matter (PM_{10}), or ultrafine particulate matter ($PM_{2.5}$).[21] Concentrations of total suspended particulates have decreased substantially in major Canadian cities since the 1970s and are no longer considered a major air-quality issue. In the 1990s, research suggested that fine particulate matter has a more serious effect upon human health than total suspended particulates. In the mid-1990s, the National Air Pollution Surveillance network began continuous monitoring of PM_{10} and $PM_{2.5}$ concentrations and discontinued monitoring of total suspended particulates but much monitoring of PM_{10} has now been discontinued except in British Columbia. This may be due to scientific evidence that exposure to coarse particulate matter (the particulates between 10 μm and 2.5 μm in diameter) is not correlated with adverse health effects (Peng et al., 2008). The analysis in this section will focus on $PM_{2.5}$ concentrations in Canada.

Sources of $PM_{2.5}$

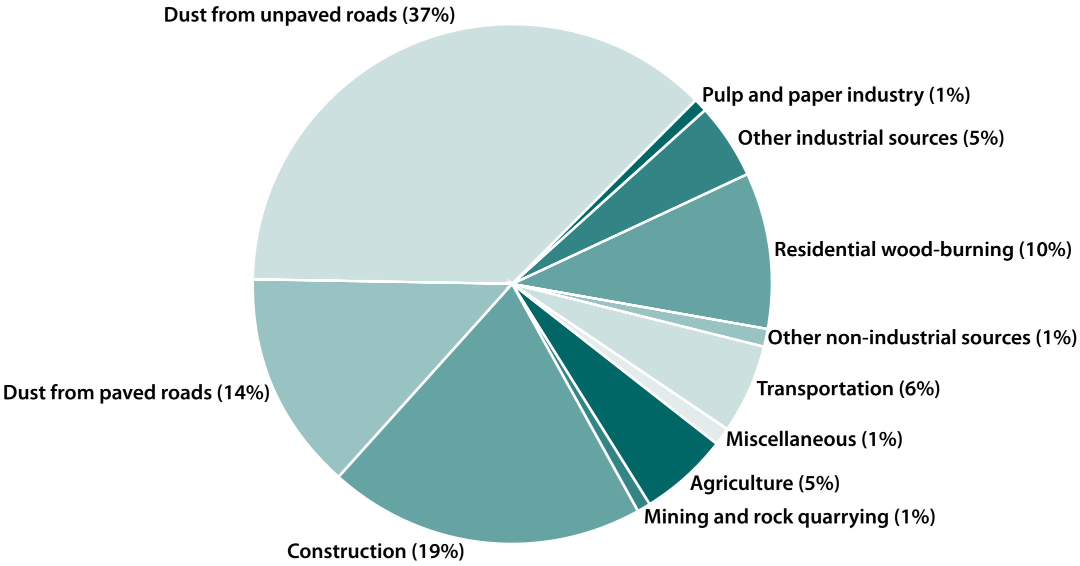
$PM_{2.5}$ is emitted into the atmosphere from natural sources such as forest fires and from human industries like pulp and paper mills and refining. $PM_{2.5}$ can also form in the atmosphere from chemical and physical reactions between other air pollutants (Environment Canada, 2011). The human sources of $PM_{2.5}$ for Canada in 2008 are shown in figure 13. The natural and human sources of $PM_{2.5}$ are shown in figure 14. The sources of $PM_{2.5}$ will obviously depend on location: for example, locations in British Columbia may have more $PM_{2.5}$ from unpaved roads and forest fires than locations in southern Ontario. However, it is still clear that nationally the vast majority of $PM_{2.5}$ emissions are not from industrial sources. Dust from paved and unpaved roads is the largest human source of $PM_{2.5}$ (these along with construction and agriculture are considered "open" sources).[22] The largest human source of $PM_{2.5}$ emissions in Canada not classed as "open" is the burning of wood and wood pellets for residential heating ("residential wood-burning" in figures 4, 10, and 13).

---

[21] Total suspended particulates (TSP) are all particles of solid matter suspended in the air; fine particulate matter (PM_{10}) consists of airborne particulate matter with a mass median diameter less than 10 μm; ultrafine particulate matter consists of airborne particulate matter with a mass median diameter less than 2.5 μm (μm = micrometer, 1×10^{-6} metre, or 0.001 mm). In the literature, it is generally referred to as $PM_{2.5}$.

[22] "Open" sources are those that are not the result of combustion, like dust coming off a construction site or soil blowing off a farm field while tilling is going on. Open sources are usually difficult to control.

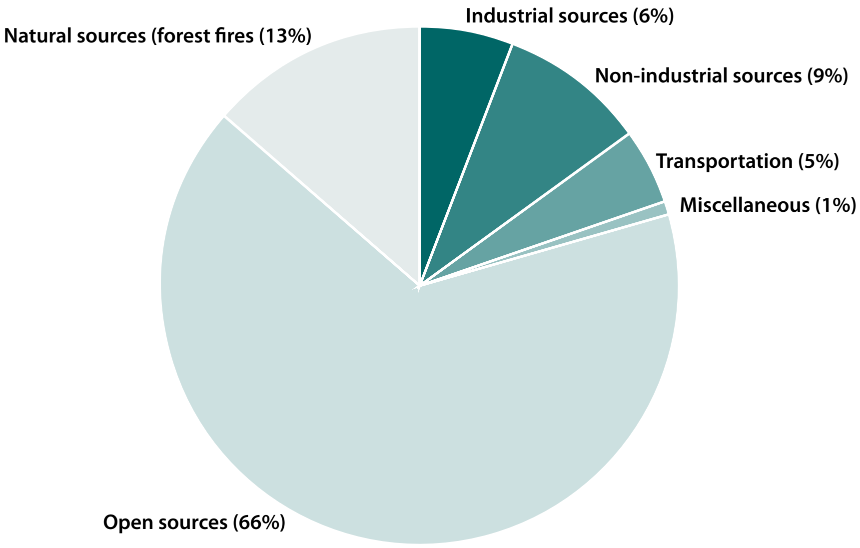
Figure 13: Sources of volatile organic compounds in Canada, 2008



Notes: road dust, construction, and agriculture are considered "open" sources (i.e., not the result of combustion); they are usually difficult to control.

Sources: Environment Canada, 2010c; calculations by author.

Figure 14: Sources of ultrafine Particulate Matter ($PM_{2.5}$) in Canada, 2008



Note: Open sources include road dust, agriculture, and construction; forest fires are the sole natural source.

Sources: Environment Canada, 2010c; calculations by author.

Effects on health

Epidemiological studies have found strong evidence linking exposure to $PM_{2.5}$ to several adverse health outcomes, including mortality (Dominici et al., 2003; Burnett et al., 2004; Dominici et al., 2006; Pope et al., 2006; Peng et al., 2008; Pope et al., 2009).[23] The Canadian Medical Association's report published in 2008 assumes that the adverse health effects of $PM_{2.5}$ exposure get worse as the population ages.

Data

In 2008, the latest year for which data are available for all eight provinces, only two out of the 125 stations with sufficient data (for 2006–2008) failed to achieve the Canada-wide standard.[24] Sarnia had a concentration of 31.5 µg/m^3 and Shawinigan had a concentration of 39 µg/m^3. Data from 2007–2009 show that Sarnia had a concentration of 29 µg/m^3, which is below the CWS. All stations in Nova Scotia, New Brunswick, Manitoba, Saskatchewan, and Alberta have achieved the CWS for all periods of available continuous $PM_{2.5}$ monitoring data. However, incomplete monitoring data for a station near Fort McMurray, AB in 2007 is a concern since this station had a concentration of 39 µg/m^3 in 2006. This station achieved the CWS in all periods, but the presence of a large number of missing observations in 2007 suggests that the 2005-2007 and 2006-2008 values could be higher or lower than calculated.

Figure 15 displays Canadian average $PM_{2.5}$ concentrations between 2000 and 2009. The graph shows that, on average, concentrations have been below the CWS. Average concentrations appear to be slightly decreasing between 2000 and 2009 although statistical analysis is needed to confirm the trend. Also, 95% of monitoring stations achieved the CWS in 2008 and 2009.

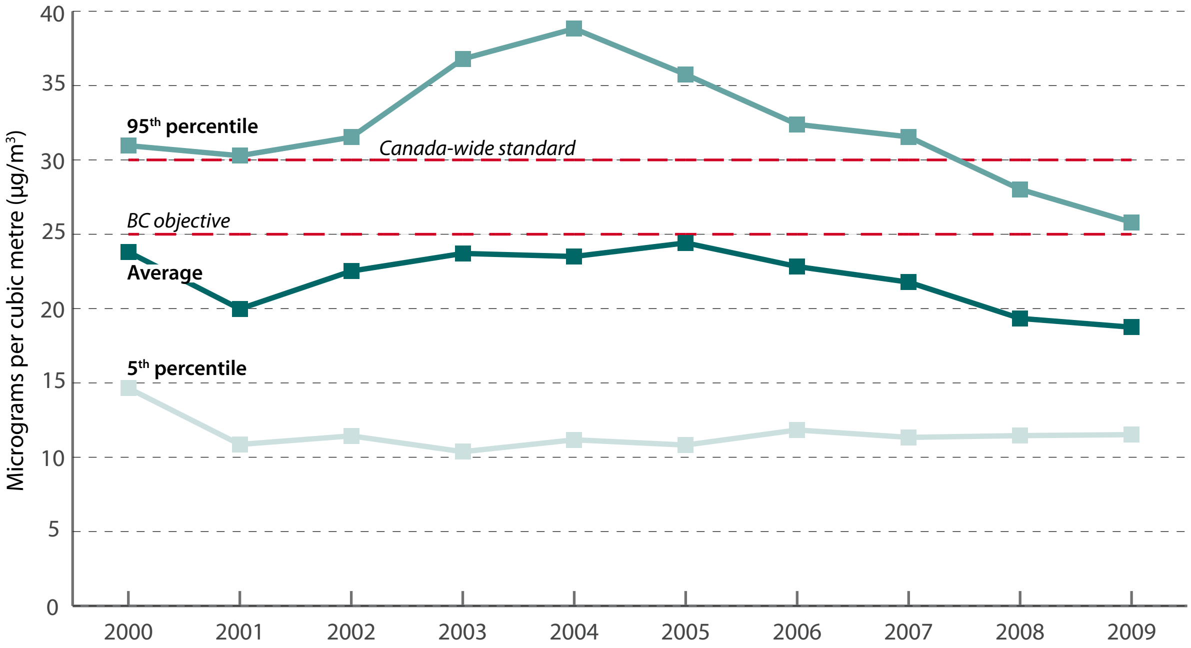
The $PM_{2.5}$ monitoring data from British Columbia reveals a problem with the CWS unit of measure. In 2003, Golden, Kamloops, Kelowna, and Prince George all had large spikes in concentrations; 2003 was also a year in which British Columbia was ravaged by forest fires. In many parts of Canada, forest fires may affect local air quality for more than 2% of the days in a year. Therefore, for some monitoring stations the Canada-wide standard measure may not be a good indicator of the human effect on local air quality. Environment Canada did not produce $PM_{2.5}$ provincial emission accounts that include natural sources prior to 2006, so it is unclear whether these spikes in concentrations should be attributed to increased forest fires rather than industrial sources. Further analysis is needed to evaluate whether stricter regulation of industrial emissions of $PM_{2.5}$ have a significant effect on ambient concentrations in some areas.

---

[23] Some of the listed studies use PM_{10} but the study by Peng et al. (2008) suggests that $PM_{2.5}$ is the cause.

[24] Spreadsheet available from author upon request.

Figure 15: Concentrations of ultrafine particulate matter in Canada, 2000–2009



Note: The figure displays average, 95th percentile, and 5th percentile values of the 3-year moving average of annual 98th-percentile 24-hour average $PM_{2.5}$ concentrations from monitoring stations across Canada. In a given year, 95% of stations have concentrations below the 95th percentile value. Similarly, 5% of stations report concentrations below the 5th percentile value.

Sources: Environment Canada, 2010b; calculations by author.

The Canada-wide standard is more stringent than the 24-hour standard of the United States but not than the objectives of the World Health Organization, Australia, or British Columbia. Table 13 displays exceedances of British Columbia's objective for each province between 1995 and 2009. No discernible pattern can be inferred from this table and, therefore, statistical analysis is required to identify whether exceedances are increasing per station or decreasing over time. Given the importance of $PM_{2.5}$ concentrations to the forecasts made in the report of the Canadian Medical Association (2008), it is imperative to identify what has happened to these concentrations over time.[25]

Statistical analysis

Analyzing the Canadian data for each province against British Columbia's 24-hour objective to see the average number of exceedances per exceeding station produces interesting results. Calculating the average exceedances per exceeding station for each year for each province and then applying a panel fixed-effects regression model produces an estimate of a decreasing common

---

[25] Readers without a background in statistics may want to proceed to the brief non-technical summary at the end. Readers with an intermediate background in statistics or econometrics are encouraged to continue through the following discussion.

Table 13: Exceedances of British Columbia's 24-hour objective for $PM_{2.5}$ (25 µg/m^3) by various provinces

		Exceeding hours	Exceeding stations	Total stations	% of stations with exceeding hours
British Columbia	1995–1999	31	6	9	67%
	2000–2004	347	21	41	51%
	2005–2009	143	28	50	56%
Alberta	1997–1999	39	3	5	60%
	2000–2004	174	21	25	84%
	2005–2009	198	32	42	76%
Saskatchewan	1995–2000	0	0	0	n/a
	2001–2004	2	2	2	100%
	2005–2009	0	0	3	0%
Manitoba	1997–1999	2	1	1	100%
	2000–2004	8	4	4	100%
	2005–2009	27	3	4	75%
Ontario	1997–1999	535	14	15	93%
	2000–2004	1,713	45	46	98%
	2005–2009	1,689	45	45	100%
Quebec	1997–1999	222	8	9	89%
	2000–2004	1,427	52	54	96%
	2005–2009	1,401	47	49	96%
New Brunswick	1996–1999	6	3	4	75%
	2000–2004	74	9	9	100%
	2005–2009	57	9	12	75%
Nova Scotia	1998–1999	3	2	2	100%
	2000–2004	40	5	5	100%
	2005–2009	45	5	12	42%

Notes: The calculations considered all stations with any amount of monitoring data. An exceedance was defined as an average 24-hour $PM_{2.5}$ concentration greater than, or equal to, 25 µg/m^3. An exceeding station is any monitoring station with at least one 24-hour average concentration equal to, or greater than, 25 µg/m^3, the British Columbia objective.

Sources: Environment Canada, 2010b; calculations by author.

trend that is not statistically significant. The results are displayed in table 14. This result is surprising considering that the trend in Ontario appears to be especially pronounced in the data. Ontario stations went from a high of 23.5 average exceeding days per exceeding station in 1998 to a low of 1.8 in 2009. In other words, in Ontario, areas that had high $PM_{2.5}$ went from having 23.5 bad days in 1998 to only 1.8 bad days in 2009. $PM_{2.5}$ concentrations have become less of a problem in Ontario but, clearly, a more detailed analysis is necessary.

In a second analysis of whether $PM_{2.5}$ concentrations in Canada are decreasing, all available annual 98th percentiles of daily averages are looked at for each province between 1995 and 2009. Estimating a panel-regression model to account for the unobserved individual characteristics of each monitoring station finds a statistically significant, decreasing common time-trend in British Columbia, Saskatchewan, Ontario, and Quebec (table 15). Alberta, Manitoba, and New Brunswick reported decreasing trends; however, the results were not statistically significant. Ontario and Quebec had the largest sample sizes and the largest decreasing trends. In Ontario, monitoring stations on average reported an annual decrease of 1.3 $\mu g/m^3$, corresponding to a decrease of 16.6 $\mu g/m^3$ over 13 years. The monitoring stations in Quebec reported an average decrease of 1 $\mu g/m^3$ per year, corresponding to a decrease of 12 $\mu g/m^3$ between 1998 and 2009. Caution should be employed when interpreting the results for Manitoba, Nova Scotia, and Saskatchewan because of the small number of observations available for these provinces.

A third panel-regression analysis was conducted using all of the provincial data for the period since the Canada-wide standard agreement (2000–2009) (table 16). The estimated common trend for concentrations at monitoring stations in the eight Canadian provinces is decreasing and statistically significant. The results suggest that, on average, $PM_{2.5}$ concentrations have decreased 0.82 $\mu g/m^3$ annually, which corresponds to a 8.2 $\mu g/m^3$ total decrease over the ten-year period.

Summary of analysis

The first result from the statistical analysis is that there has been no identifiable Canada-wide decrease in the number of exceedances of British Columbia's objective per station with exceedances; despite Ontario's having had its lowest number of exceedances per station with exceedances in 2009. However, additional statistical analysis conducted on data from each province indicates that concentrations of $PM_{2.5}$ have been decreasing between 1995 and 2009, on average, in the three most populous provinces, British Columbia, Ontario, and Quebec. Also, analyzing all Canadian monitoring stations together between 2000 and 2009 produces results that indicate that concentrations of $PM_{2.5}$ have been decreasing, on average, across Canada since the signing of the Canada-wide standard for $PM_{2.5}$. This result further confirms the downward trend apparent in figure 15.

Table 14: Panel-data regression results on average exceedances of $PM_{2.5}$ concentrations per exceeding station

Air quality objective	Time period	Sample size	Common trend coefficient	Standard error	Adj-R^2	F-stat
BC 24-hr objective	1995–2009	(Total Obs. = 94, N = 8)	−0.22328 $^{\text{not sig.}}$	0.1778	0.808	44.86 $^{1\%}$

Notes: The dependent variable is the provincial average number of average 24-hour concentrations exceeding the objective per station with exceeding observations. The independent variable is a common linear trend for all eight provinces. The results are not significant when robust standard errors are used and, therefore, no decrease in exceeding days can be inferred. Superscript $^{1\%}$ denotes statistical significance at the 1% level. More details on the econometric model can be found in the Appendix (p. 54). The fixed-effects model was estimated using Least Squares Dummy Variable estimation. The standard errors are robust to heteroskedasticity and serial correlation using the method proposed by Arellano (1987).

Sources: Environment Canada, 2010b; author's statistical analysis.

Table 15: Panel-data fixed-effects regression results for $PM_{2.5}$ concentrations in each province

Province	Time period	Sample size	Common trend coefficient	Standard error	Adj-R^2	F-stat
Alberta	1998–2009	(Total Obs. = 201, N = 34)	−0.2006	0.1412	0.943	95.07 $^{1\%}$
British Columbia	1995–2008	(Total Obs. = 267, N = 52)	−0.3518 $^{1\%}$	0.0756	0.949	96.22 $^{1\%}$
Saskatchewan	2001–2009	(Total Obs. = 14, N = 3)	−0.8847 $^{10\%}$	0.4357	0.97	112.6 $^{1\%}$
Manitoba	1998–2009	(Total Obs. = 37, N = 4)	−0.2217	0.1381	0.965	204.3 $^{1\%}$
Ontario	1997–2009	(Total Obs. = 343, N = 53)	−1.2776 $^{1\%}$	0.1144	0.969	199.0 $^{1\%}$
Quebec	1998–2009	(Total Obs. = 231, N = 42)	−1.0259 $^{5\%}$	0.4479	0.931	73.18 $^{1\%}$
New Brunswick	1997–2009	(Total Obs. = 48, N = 10)	−0.0794	0.1177	0.953	89.0 $^{1\%}$
Nova Scotia	1998–2009	(Total Obs. = 25, N = 6)	0.1033	0.4512	0.939	56.51 $^{1\%}$

Notes: A panel regression was conducted for each province with individual effects being each monitoring station (N refers to the number of stations). The dependent variable is the annual 98th percentile 24-hour $PM_{2.5}$ concentration. The independent variable is a common linear trend. The results for British Columbia are interpreted as follows: between 1995 and 2008, $PM_{2.5}$ concentrations at monitoring stations in British Columbia decreased on average 0.3518 µg/m^3 annually (a decrease of 4.93 µg/m^3 over 14 years). Superscripts, $^{1\%}$, $^{5\%}$, and $^{10\%}$ denote statistical significance at the 1%, 5%, and 10% levels, respectively. The standard errors are robust to heteroskedasticity and serial correlation using the method proposed by Arellano (1987). Adj-R^2 refers to the Adjusted-R^2, a measure of the goodness-of-fit. The F-stat is a goodness-of-fit test statistic; significance indicates that the model provides non-negligible explanatory power.

Sources: Environment Canada, 2010b; author's statistical analysis

Table 16: $PM_{2.5}$, Canada-wide panel regression, 2000–2009

Total Observations	1,103
Total Stations	N = 204
Common Trend Coefficient	$-0.8217^{1\%}$
Standard Error (Robust)	0.1076
Adjusted-R^2	0.947

Notes: The dependent variable is the annual 98th percentile 24-hour average concentration. The independent variable is a common linear trend. The results are interpreted as follows: between 2000 and 2009, on average, $PM^{2.5}$ concentrations in Canada decreased by 0.8217 µg/m^3 annually (a decrease of 8.217 µg/m^3 over 10 years). Superscript $^{1\%}$ denotes statistical significance at the 1% level. The estimation was conducted using Least Squares Dummy variable estimation. The method of calculating robust standard errors proposed by Arellano (1987) was used to correct for heteroskedasticity and serial correlation. Adjusted-R^2 is a measure of goodness of fit. Further results from other goodness-of-fit tests and other diagnostic tests can be found in the Appendix. (p. 54)

Sources: Environment Canada, 2010b; author's statistical analysis.

Conclusion

Overall, the results of the statistical analysis suggest that concentrations of $PM_{2.5}$ have been decreasing in the most populated regions of Canada. These results call into question the underlying assumptions made in the Canadian Medical Association's report that O_3 and $PM_{2.5}$ concentrations remain constant into the future. These results alongside the results for O_3 discussed earlier suggest that there is no justification for the assumption that concentrations will not continue to decline in the near future.

In summary, $PM_{2.5}$ concentrations have decreased in the most populated regions of Canada since the mid-1990s. There is no indication that $PM_{2.5}$ concentrations in these regions will not continue to decrease in the future. As with O_3, the Canadian Medical Association's report uses assumptions about future concentrations of $PM_{2.5}$ that are not supported by the most recent Canadian monitoring data. The use of these flawed assumptions results in overestimates of aggregate impacts on human health and health care costs. Also, since industrial $PM_{2.5}$ emissions represent a very small fraction of total $PM_{2.5}$ emissions, future spikes in $PM_{2.5}$ concentrations may be beyond the scope of human control (e.g., $PM_{2.5}$ emitted by forest fires) suggesting that calls for legally binding national standards (e.g., Boyd, 2006) should not be acted upon.

8 Conclusion

This study analyzed Canadian monitoring data for five major air pollutants to assess the true state of air quality in Canada. The results suggest that, in most instances, Canadians currently experience significantly better air quality than at any other time since monitoring of air quality was commenced in the 1970s. The results also suggest that concentrations of two of the pollutants of greatest concern—ground-level ozone and ultrafine particulate matter—have generally decreased across Canada since 2000. Air quality in Canada has improved and is improving.

Concentrations of nitrogen dioxide, carbon monoxide, and sulfur dioxide have decreased significantly over the past 35 years in most locations in Canada. Sulfur dioxide concentrations remain relatively high in only a few sparsely populated locations that rely on emissions-intensive industries such as mineral smelting or oil-sands processing. These relatively higher concentration levels may be acceptable to local residents due to the economic benefits provided by the polluting activities and stricter emission controls in these areas may be unduly costly on the emitters, and lead to layoffs and even closing of the operations. Calls for universal (NRTEE, 2008) and legally binding air pollution standards (Boyd, 2006) ignore the flexibility of the current patchwork policy framework that allows for the consideration of local conditions and preferences.

The results indicate that O_3 and $PM_{2.5}$ concentrations have generally declined in Canada since 2000. This result calls into question the assumption made in a report by the Canadian Medical Association (CMA, 2008) that concentrations of O_3 and $PM_{2.5}$ will remain at current levels in the future; this assumption is not in line with the historical evidence. This suggests that the Canadian Medical Association's report overestimates the future costs of air pollution in Canada.

Improving monitoring of air quality

There are a few instances where improved data would produce a more accurate assessment of the current state of air quality in Canada. The locations like Trail and Flin Flon that continue to record relatively high concentrations of nitrogen dioxide and sulfur dioxide have monitoring data that dates back only around 10 years. Therefore, we have no indication of the air quality in these locations prior to the commencement of monitoring and can only draw conclusions about how air quality in these locations has improved or gotten worse over these ten years. Also, there are locations in Canada with sources of high levels of emissions but no ambient monitoring (e.g., Thompson). It should also be noted that this study considers only the five major pollutants that are available in the National Air Pollution Surveillance database and ignores other pollutants such as benzene. The National Air Pollution Surveillance network should be expanded to collect monitoring data for other air pollutants that may be of concern as the science on the health effects of air pollution continues to develop.

Technical appendix

This study employs panel-data regression analysis to estimate common trend slopes (trend coefficients) for various dependent variables. Panel data refers to data that uses both a cross-sectional dimension and a time-series dimension. The pollution monitoring data studied generally has a cross-section of monitoring stations each with pollution concentrations observed over time. The panel data is considered unbalanced since some monitoring stations have more observations over time than others. Arellano (2003) provides an excellent introduction to panel data for readers with an intermediate background in statistics or econometrics. Wooldridge (2009) is an introductory text on econometrics that provides a good treatment of panel-data statistical methods.

The regression analysis applied in this study estimates a panel data fixed-effects model with a common, linear time-trend as the explanatory variable. Fixed effects refer to allowing the intercepts to differ between cross-sectional units. Fixed effects allow the model to take into account unobserved individual effects between cross-sectional units. The model is estimated using ordinary least squares and includes dummy variables identifying each cross-sectional unit (each province for the regressions listed in tables 2 and 6, and each monitoring station for the regressions listed in tables 3, 4, 7, and 8). This estimation approach is referred to as Least Squares Dummy Variable estimation. The dependent variable for the regressions listed in tables 2 and 6 is the average number of exceedances per station with exceeding observations for each province. Each province has one observation per year. This variable was calculated by dividing the total number of exceeding observations for a province in a year by the number of monitoring stations that recorded exceeding observations in that province in that year. The dependent variable for the regressions listed in tables 3, 4, 7, and 8 are pollution concentrations at individual monitoring stations. For O_3, each observation is the annual Canada-wide standard unit of measurement for each monitoring station (the annual 4th-highest daily maximum 8-hour average O_3 concentration). For $PM_{2.5}$, each observation is the annual Canada-wide standard unit of measurement for each monitoring station (the annual 98th percentile 24-hour average $PM_{2.5}$ concentration).

Several diagnostic tests were undertaken. An F-test of the goodness-of-fit was used to test whether all estimates for a regression are unimportant (the trend coefficient and the individual fixed effects are jointly zero). The results of the F-test for each regression are listed in tables 2, 4, 6, 7, A.1, and A.2. A second F-test was used to test whether the proposed common linear time-trend specification is just as good at explaining the dependent variable as a model with individual linear time-trends that differ among monitoring stations. The results for this test are displayed for the Canada-wide regressions for O_3 and $PM_{2.5}$ in tables A.1 and A.2. The test results suggest that the common linear trend explains the data just as well as differing linear trends. The Hausman test is applied to identify whether the unobserved individual effects are best represented as fixed or as random. The test results listed in tables A.1 and A.2 suggest that the fixed effects specification is as good of a representation as the random effects specification.

A modified Wald test was used to test for differences in error variance (heteroskedasticity). The resulting statistics in tables A.1 and A.2 suggest that the constant variance assumption (homoskedasticity) is violated for both regressions. The Breusch-Godfrey test is used to test for serial correlation in the regression residuals. The resulting statistics are listed in tables A.1 and A.2. The results suggest that the residuals from the Canada-wide regression for O_3 are serially correlated but the residuals from the Canada-wide regression for $PM_{2.5}$ are not. To correct for serial correlation and heteroskedasticity, the robust standard errors proposed by Arellano (1987) are used to conduct simple t-tests of whether the estimated trend coefficients are different than zero for all of the estimated regressions.

All statistical analysis was conducted using *R version 2.9.2* (R Development Core Team, 2011). The Hausman test, the Breusch-Godfrey test, and the robust standard errors were calculated using the PLM package developed by Croissant and Millo (2008).

Table A1: O_3, Canada-wide panel regression diagnostic tests

Goodness-of-fit F-test	54.078 $^{1\%}$
F-test for heterogeneous trends	1.073
Modified Wald test for heteroskedasticity	8,261.76 $^{1\%}$
Hausman test for fixed effects	1.4437
Breusch-Godfrey test for serial correlation	8.1037 $^{1\%}$

Note: Superscript $^{1\%}$ denotes statistical significance at the 1% level.

Table A2: $PM_{2.5}$, Canada-wide Panel Regression diagnostic tests

Goodness-of-fit F-test	96.99 $^{1\%}$
F-test for heterogeneous trends	1.656
Modified Wald test for heteroskedasticity	50,337.48 $^{1\%}$
Hausman test for fixed effects	0.3316
Breusch-Godfrey test for serial correlation	2.0851

Notes: Superscript $^{1\%}$ denotes statistical significance at the 1% level.

References

Alberta Environment (2009). *Alberta Ambient Air Quality Objectives and Guidelines.* <http://environment.gov.ab.ca/info/library/5726.pdf>, as of March 9, 2011.

Alberta Environment (2011). Alberta Ambient Air Quality Objectives Sulphur Dioxide. <http://environment.gov.ab.ca/info/library/8304.pdf>, as of March 9, 2011.

Arellano, Manuel (1987). Computing Robust Standard Errors for Within Group Estimators. *Oxford Bulletin of Economics and Statistics* 49,4: 431–434.

Arellano, Manuel (2003). *Panel Data Econometrics.* Oxford University Press.

Australia, Department of Sustainability, Environment, Water, Population and Communities [AUS-DSEWPC] (2009). *National Standards for Criteria Air Pollutants in Australia.* <http://www.environment.gov.au/atmosphere/airquality/publications/standards.html>, as of March 9, 2011.

Barn, Prabjit, and Tom Kosatsky (2010). *An Introduction to Air Quality Advisories.* National Collaborating Centre for Environmental Health. <http://www.ncceh.ca/sites/default/files/Air_Quality_Advisories_Sept_2010.pdf>, as of March 10, 2011.

Bell, Michelle L., Aiden McDermott, Scott L. Zeger, Jonathan M. Samet, and Francesca Dominici (2004). Ozone and Short-term Mortality in 95 US Urban Communities, 1987-2000. *Journal of the American Medical Association* 292, 19: 2372–2378.

British Columbia Ministry of the Environment [BCME] (no date). *Permits, Approvals and Codes of Practice.* <http://www.env.gov.bc.ca/epd/bcairquality/regulatory/permits-approvals-codes.html>, as of March 17, 2011.

British Columbia Ministry of the Environment [BCME] (2009). *Air Quality Objectives and Standards.* <http://www.env.gov.bc.ca/epd/bcairquality/reports/pdfs/aqotable.pdf>, as of March 9, 2011.

Brown, Jeremy S., Kenneth Green, Steven Hansen, and Liv Fredricksen (2004). *Environmental Indicators (Sixth Edition)*. Fraser Institute. <http://www.fraserinstitute.org/research-news/display.aspx?id=13017>, as of March 22, 2011.

Boyd, David R. (2006). *The Air We Breathe: An International Comparison of Air Quality Standards and Guidelines*. David Suzuki Foundation. <http://www.davidsuzuki.org/publications/reports/2006/the-air-we-breathe-an-international-comparison-of-air-quality-standards-and-guid/>, as of February 4, 2011.

Buringh, E., P. Fischer, and G. Hoek (2000). Is SO_2 a Causative Factor for PM-Associated Mortality Risks in the Netherlands? *Inhalation Toxicology* 12 (Suppl.): S55–S60.

Burnett, Richard T., Dave Stieb, Jeffrey R. Brook, Sabit Cakmak, Robert Dales, Mark Raizenne, Renaud Vincent, and Tom Dann (2004). Associations between Short-Term Changes in Nitrogen Dioxide and Mortality in Canadian Cities. *Archives of Environmental Health* 59, 5: 228–236.

Canadian Broadcasting Corporation [CBC] (2005, May 2). Air Pollution Kills Thousands Each Year: Health Canada. *CBC News*. <http://www.cbc.ca/news/health/story/2005/05/02/air-pollution050502.html>, as of March 22, 2010.

Canadian Council of Ministers of the Environment [CCME] (2006). *Canada-wide Standards for Particulate Matter and Ozone: Five Year Report: 2000-2005*. <http://www.ccme.ca/assets/pdf/pm_oz_2000_2005_rpt_e.pdf>, as of March 9, 2011.

Canadian Medical Association [CMA] (2008). *No Breathing Room: National Illness Costs of Air Pollution Summary Report*. <http://www.cma.ca/multimedia/CMA/Content_Images/Inside_cma/Office_Public_Health/ICAP/CMA_ICAP_sum_e.pdf>, as of March 10, 2011.

Croissant, Yves, and Giovanni Millo (2008). Panel Data Econometrics in R: The PLM Package. *Journal of Statistical Software* 27, 2. <http://www.jstatsoft.org/v27/i02>, as of March 29, 2011.

Dominici, Francesca, Aiden McDermott, Scott L. Zeger, and Jonathan M. Samet (2003). Airborne Particulate Matter and Mortality: Timescale Effects in Four US Cities. *American Journal of Epidemiology* 157, 12: 1055–1065.

Dominici, Francesca, Roger D. Peng, and Michelle L. Bell (2006). Fine Particulate Air Pollution and Hospital Admission for Cardiovascular and Respiratory Diseases. *Journal of the American Medical Association* 295, 10: 1127–1134.

DSS Management Consultants Inc. (2005). *Ontario ICAP Model Version 2.0: Software Refinements and Revised Provincial Damage Estimates*. Ontario Medical Association. <https://www.oma.org/Resources/Documents/2005OntarioICAPModelVersion2.0.pdf>, as of March 10, 2011.

Eisen, Ben, and Kenneth P. Green (2009). *The Environmental State of Canada—30 Years of Progress*. FCPP Policy Series No. 63. Frontier Centre for Public Policy. <http://www.fcpp.org/images/publications/63.%20The%20Environmental%20State%20of%20Canada.pdf>, as of March 10, 2011.

Environics Research Group [ERG] (2002). *Air Pollution: Information Needs and the Knowledge, Attitudes and Behavior of Canadians*. <http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/air/pollution/environics_air_pollution_survey-eng.pdf>, as of November 7, 2011.

Environment Canada (2001). *Smog Advisory Programs*. <http://www.ec.gc.ca/media_archive/press/2001/010503_b_e.htm>, as of February 16, 2011.

Environment Canada (2004). *Federal Agenda for Reduction of Emissions of Volatile Organic Compounds from Consumer and Commercial Products*. <http://www.ec.gc.ca/cov-voc/Default.asp?lang=En&n=A6586DEE-1>, as of March 17, 2011.

Environment Canada (2007). *National Ambient Air Quality Objectives*. <http://www.ec.gc.ca/rnspa-naps/default.asp?lang=En&n=24441DC4-1>, as of March 9, 2011.

Environment Canada (2010a). *Air Quality Indicators: Data Sources and Methods*. Canadian Environmental Sustainability Indicators. <http://www.ec.gc.ca/indicateurs-indicators/59820E45-19C5-4368-AF63-F8B9BAC7C7B6/AQ-DSM-EN.pdf>, as of November 26, 2010.

Environment Canada (2010b). National Air Pollution Surveillance (NAPS) Network. <http://www.etc-cte.ec.gc.ca/napsdata/Default.aspx>, as of October 21, 2010.

Environment Canada (2010c). *2008 National and Provincial Emission Summaries*. <http://www.ec.gc.ca/inrp-npri/default.asp?lang=en&n=0EC58C98-1>, as of March 10, 2011.

Environment Canada (2010d). *National Pollutant Release Inventory*. <http://www.ec.gc.ca/pdb/websol/querysite/query_e.cfm>, as of March 31, 2011.

Environment Canada (2011). *Criteria Air Contaminants and Related Pollutants*. <http://www.ec.gc.ca/Air/default.asp?lang=En&n=7C43740B-1>, as of March 10, 2011.

European Commission (no date). *Air Quality Standards*. <http://ec.europa.eu/environment/air/quality/standards.htm>, as of March 7, 2011.

Government of Canada (2003). On-Road Vehicle and Engine Emission Regulations. *Canada Gazette* 137, 1, SOR/2003-2. <http://canadagazette.gc.ca/archives/p2/2003/2003-01-01/html/sor-dors2-eng.html>, as of March 17, 2011

Graff Ziven, Joshua S., and Matthew J. Neidell (2011). *The Impact of Pollution on Worker Productivity*. NBER Working Paper No. 17004. National Bureau of Economic Research.

Judek, Stan, Barry Jessiman, Dave Stieb, and Robert Vet (2004). *Estimated Number of Excess Deaths in Canada Due to Air Pollution*. Health Canada. <www.metrovancouver.org/about/publications/Publications/AirPollutionDeaths.pdf>, as of March 10, 2011.

Koop, Gary, Ross McKitrick, and Lise Tole (2010). Air Pollution, Economic Activity and Respiratory Illness: Evidence from Canadian Cities, 1974–1994. *Environmental Modeling and Software* 25, 7: 873–885.

Manitoba Conservation (2005). *Manitoba Ambient Air Quality Criteria*. <http://www.gov.mb.ca/conservation/pollutionprevention/airquality/pdf/criteria_table_update_july_2005.pdf>, as of January 4, 2011.

McKitrick, Ross (2008). Air Pollution Policy in Canada: Improving on Success. In Nicholas Schnieder (ed.), *A Breath of Fresh Air: The State of Environmental Policy in Canada* (Fraser Institute): 13–47.

National Round Table on the Environment and the Economy [NRTEE] (2008). *Developing Ambient Air Quality Objectives For Canada: Advice to the Minister of the Environment*. <http://www.nrtee-trnee.com/eng/publications/ambient-air-report/ambient-air.pdf>, as of January 4, 2011.

New Brunswick, Ministry of the Environment and Local Government (2002). *Order Establishing Objectives under Section 8 of the Clean Air Act*. <http://www.gnb.ca/0009/0355/0005/0001-e.pdf>, as of January 4, 2011.

Nova Scotia, Department of Justice, Legal Services Division (2011). *Air Quality Regulations*, made under Section 112 of the Environment Act S.N.S. 1994-95, c. 1 O.I.C. 2005-87 (February 25, 2005, effective March 1, 2005), N.S. Reg. 28/2005 as amended up to O.I.C. 2010-444 (December 7, 2010), N.S. Reg. 187/2010 N.S. Reg. 28/2005 as amended by N.S. Reg. 261/2009. <http://www.gov.ns.ca/just/regulations/regs/envairqt.htm>, as of January 6, 2011.

Ontario Medical Association (2008). *Local Premature Smog Deaths in Ontario*. <https://www.oma.org/Resources/Documents/2008LocalPrematureSmogDeaths.pdf>, as of March 10, 2011.

Ontario, Ministry of the Environment [ON-MEnv] (2005). *Emissions Trading Fact Sheet*. <http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079108.pdf>, as of March 17, 2011.

Ontario, Ministry of the Environment [ON-MEnv] (2008). *Ontario's Ambient Air Quality Criteria*. <http://www.ene.gov.on.ca/publications/6570e-chem.pdf>, as of January 6, 2011.

Ontario, Ministry of the Environment [ON-MEnv] (2010a). *Air Quality in Ontario: 2009 Report*. <http://www.ene.gov.on.ca/environment/en/resources/STDPROD_081227.html>, as of March 10, 2011.

Ontario, Ministry of the Environment [ON-MEnv] (2010b). *Environmental Approvals*. <http://www.env.gov.bc.ca/epd/bcairquality/regulatory/permits-approvals-codes.html>, as of March 18, 2011.

Peng, Roger D., Howard H. Chang, Michelle L. Bell, Aiden McDermott, Scott L. Zeger, Jonathan M. Samet, and Francesca Dominici (2008). Coarse Particulate Matter Air Pollution and Hospital Admissions for Cardiovascular and Respiratory Diseases among Medicare Patients. *Journal of the American Medical Association* 299, 18: 2172–2179.

Pope, C. Arden, Richard T. Burnett, Michael J. Thun, Eugenia E. Calle, Daniel Krewski, Kazuhiko Ito, and George D. Thurston (2002). Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. *Journal of the American Medical Association* 287, 9: 1132–1141.

Pope, C. Arden, Richard T. Burnett, Daniel Krewski, Michael Jerrett, Yuanli Shi, Eugenia E. Calle, and Michael J. Thun (2009). Cardiovascular Mortality and Exposure to Airborne Fine Particulate Matter and Cigarette Smoke. *Circulation* 120: 941–948.

Québec, Ministère du Développement durable, de l'Environnement et des Parcs [QUE-MDDEP] (2010). Mise à jour des critères québécois de qualité de l'air : Direction du suivi de l'état de l'environnement. <http://www.mddep.gouv.qc.ca/air/criteres/fiches.pdf>, as of March 9, 2011.

R Development Core Team (2011). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. <http://www.R-project.org>, as of March 29, 2011.

Saskatchewan, Ministry of the Envrionment [SME] (1996). *Ambient Air Quality Standards*. <http://www.environment.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=6b1f40c1-7d4a-499b-a366-e5ffa76324d5&MediaID=1539&Filename=Saskatchewan+Ambient+Air+Quality+Standards.pdf&l=English>, as of January 4, 2011.

Shin, Hwashin Hyun, David M. Stieb, Barry Jessiman, Mark S. Goldberg, Orly Brion, Jeff Brook, Tim Ramsay, and Richard T. Burnett (2008). A Temporal, Multicity Model to Estimate the Effects of Short-Term Exposure to Ambient Air Pollution on Health. *Environmental Health Perspectives* 116, 9: 1147–1153.

United States, Environmental Protection Agency [US-EPA] (2010). *National Ambient Air Quality Standards (NAAQS)*. <httpwww.epa.gov/air/criteria.html>, as of January 5, 2011.

Wichmann, H. Erich, Claudia Spix, Thomas Tuch, Gabriele Wolke, Annette Peters, Joachim Heinrich, Wolfgang G. Kreyling, and Joachim Heyder (2000). *Daily Mortality and Fine and Ultrafine Particles in Erfurt, Germany. Part 1: Role of Particle Number and Particle Mass*. Health Effects Institute Research Report No. 98.

Wong, Chit-Ming, Richard W. Atkinson, H. Ross Anderson, Anthony Johnson Hedley, Stefan Ma, Patsy Yuen-Kwan Chau, and Tai-Hing Lam (2002). A Tale of Two Cities: Effects of Air Pollution on Hospital Admissions in Hong Kong and London Compared. *Environmental Health Perspectives* 110: 67–77.

Wood, Joel (2010). Air Quality and Income in Canada: A Panel VAR Analysis. In *Selected Topics on the Economics of Air Pollution* (unpublished thesis). University of Guelph.

Wooldridge, Jeffrey (2009). *Introductory Econometrics: A Modern Approach* (Fourth Edition). South-Western College Publishing.

World Health Organization [WHO] (2006). *WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global update 2005, Summary of Risk Assessment*. <http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf>, as of March 9, 2011.

About the author

Joel Wood

Joel Wood is a Senior Research Economist with the Centre for Environmental Studies at the Fraser Institute. He holds a Ph.D. in economics from the University of Guelph. Dr Wood also holds a B.A. from the University of British Columbia and an M.A. from the University of Guelph. He has been published in the *Vancouver Sun*, *National Post*, *Province*, *Winnipeg Free Press*, and other newspapers across Canada.

Acknowledgments

The author would like to thank Niels Veldhuis, Dr Ross McKitrick and Dr Andrew Leach for their helpful comments on earlier drafts of this paper.

Any remaining errors, omissions, or mistakes are the sole responsibility of the author. As the author has worked independently, the views and analysis expressed in this document are his own, and do not necessarily represent the views of the supporters, trustees, or other staff of the Fraser Institute.

Publishing information

Distribution

These publications are available from <http://www.fraserinstitute.org> in Portable Document Format (PDF) and can be read with Adobe Acrobat® 7 or Adobe Reader®, versions 7 or later. Adobe Reader® X, the most recent version, is available free of charge from Adobe Systems Inc. at <http://get.adobe.com/reader/>. Readers who have trouble viewing or printing our PDF files using applications from other manufacturers (e.g., Apple's Preview) should use Reader® or Acrobat®.

Ordering publications

For information about ordering the printed publications of the Fraser Institute, please contact the publications coordinator:

- e-mail: sales@fraserinstitute.org
- telephone: 604.688.0221 ext. 580 or, toll free, 1.800.665.3558 ext. 580
- fax: 604.688.8539.

Media

For media enquiries, please contact our Communications Department:

- 604.714.4582
- e-mail: communications@fraserinstitute.org.

Copyright

Copyright © 2012 by the Fraser Institute. All rights reserved. No part of this publication may be reproduced in any manner whatsoever without written permission except in the case of brief passages quoted in critical articles and reviews.

Date of issue

January 2012

ISSN

ISSN 1927-8756 (Print)
ISSN 1927-8764 (Online)

Citation

Wood, Joel (2012). *Canadian Environmental Indicators—Air Quality*. Fraser Institute. <http://www.fraserinstitute.org>.

Editing, typesetting, and design

Lindsey Thomas Martin

Cover design

Bill Ray

Supporting the Fraser Institute

To learn how to support the Fraser Institute, please contact

- Development Department, Fraser Institute
  Fourth Floor, 1770 Burrard Street
  Vancouver, British Columbia, V6J 3G7 Canada
- telephone, toll-free: 1.800.665.3558 ext. 586
- e-mail: development@fraserinstitute.org

Lifetime patrons

For their long-standing and valuable support contributing to the success of the Fraser Institute, the following people have been recognized and inducted as Lifetime Patrons of the Fraser Institute.

Sonja Bata
Charles Barlow
Ev Berg
Art Grunder
Jim Chaplin
Serge Darkazanli
John Dobson
Raymond Heung
Bill Korol
Bill Mackness
Fred Mannix
Con Riley
Catherine Windels

Purpose, funding, & independence

The Fraser Institute provides a useful public service. We report objective information about the economic and social effects of current public policies, and we offer evidence-based research and education about policy options that can improve the quality of life.

The Institute is a non-profit organization. Our activities are funded by charitable donations, unrestricted grants, ticket sales, and sponsorships from events, the licensing of products for public distribution, and the sale of publications.

All research is subject to rigorous review by external experts, and is conducted and published separately from the Institute's Board of Trustees and its donors.

The opinions expressed by the authors are those of the individuals themselves, and do not necessarily reflect those of the Institute, its Board of Trustees, its donors and supporters, or its staff. This publication in no way implies that the Fraser Institute, its trustees, or staff are in favour of, or oppose the passage of, any bill; or that they support or oppose any particular political party or candidate.

As a healthy part of public discussion among fellow citizens who desire to improve the lives of people through better public policy, the Institute welcomes evidence-focused scrutiny of the research we publish, including verification of data sources, replication of analytical methods, and intelligent debate about the practical effects of policy recommendations.

About the Fraser Institute

Our vision is a free and prosperous world where individuals benefit from greater choice, competitive markets, and personal responsibility. Our mission is to measure, study, and communicate the impact of competitive markets and government interventions on the welfare of individuals.

Founded in 1974, we are an independent Canadian research and educational organization with locations throughout North America and international partners in over 85 countries. Our work is financed by tax-deductible contributions from thousands of individuals, organizations, and foundations. In order to protect its independence, the Institute does not accept grants from government or contracts for research.

Nous envisageons un monde libre et prospère, où chaque personne bénéficie d'un plus grand choix, de marchés concurrentiels et de responsabilités individuelles. Notre mission consiste à mesurer, à étudier et à communiquer l'effet des marchés concurrentiels et des interventions gouvernementales sur le bien-être des individus.

Peer review—validating the accuracy of our research

The Fraser Institute maintains a rigorous peer review process for its research. New research, major research projects, and substantively modified research conducted by the Fraser Institute are reviewed by a minimum of one internal expert and two external experts. Reviewers are expected to have a recognized expertise in the topic area being addressed. Whenever possible, external review is a blind process.

Commentaries and conference papers are reviewed by internal experts. Updates to previously reviewed research or new editions of previously reviewed research are not reviewed unless the update includes substantive or material changes in the methodology.

The review process is overseen by the directors of the Institute's research departments who are responsible for ensuring all research published by the Institute passes through the appropriate peer review. If a dispute about the recommendations of the reviewers should arise during the Institute's peer review process, the Institute has an Editorial Advisory Board, a panel of scholars from Canada, the United States, and Europe to whom it can turn for help in resolving the dispute.

Editorial Advisory Board

Members

Prof. Armen Alchian
Prof. Terry L. Anderson
Prof. Robert Barro
Prof. Michael Bliss
Prof. James M. Buchanan[†]
Prof. Jean-Pierre Centi
Prof. John Chant
Prof. Bev Dahlby
Prof. Erwin Diewert
Prof. Stephen Easton
Prof. J.C. Herbert Emery
Prof. Jack L. Granatstein
Prof. Herbert G. Grubel
Prof. James Gwartney
Prof. Ronald W. Jones
Dr. Jerry Jordan
Prof. Ross McKitrick
Prof. Michael Parkin
Prof. Friedrich Schneider
Prof. Lawrence B. Smith
Mr. Vito Tanzi

Past members

Prof. Friedrich A. Hayek*[†]
Prof. H.G. Johnson*
Prof. F.G. Pennance*
Prof. George Stigler*[†]
Sir Alan Walters*
Prof. Edwin G. West*

* deceased; [†] Nobel Laureate