An examination of the relationship between air quality and income in Canada

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Abstract

The Environmental Kuznets Curve hypothesis suggests that at high income levels, economic growth is accompanied by decreasing concentrations of air pollutants. We examine the relationship between four common air pollutants and income across Canadian provinces and metropolitan areas. Our study improves upon past studies of the relationship in Canada in two ways. First, our use of panel methods and pollution concentration data from individual monitoring stations allows for a much larger sample size than previous Canadian studies. Furthermore, our econometric modeling approach separates and identifies the relative magnitudes of the scale, composition, and technique effects. Our results are as expected for annual average concentrations of sulphur dioxide, nitrogen dioxide, and carbon monoxide: a positive effect of increases in the scale of the economy was completely offset by improvements in technology and changes in the composition of output. Similar results are found for ground-level ozone when choosing the measure used to assess the Canada-Wide Standard; however, the results when using annual average concentrations of ozone are much different. We attribute this difference to the focus of government policy to reduce short-term, rather than long-term, exposure to ozone. *JEL: Q53, Q56, Q58; Keywords: air quality, environmental Kuznets curve, Canada, panel data;*

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1 Introduction

The Environmental Kuznets Curve (EKC) is an empirical regularity showing that some kinds of pollution tend, at first, to increase as income grows, then apparently to reverse course and decrease. There have been many studies over the years attempting to measure

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this effect, with particular interest in the latter portion of the curve, in which increasing income is associated with lower pollution. Robust identification of such a feature in the data would have interesting and important implications for longstanding debates about "limits to growth", environmental sustainability and so forth.

Most EKC empirical studies focus on examining the income pollution relationship by pooling multi-country data and fitting regression models that include polynomial income variables. However, although this approach describes the overall relationship, it does little to explain why the relationship occurs. Furthermore, several studies (see for example, Stern and Common 2001; Harbaugh et al 2002) find that the results of studies using polynomial regression models may not be robust to the inclusion of time trends.

Few EKC studies have focused on Canada; Day and Grafton (2003), Liang (2007), and He and Richard (2010) are notable exceptions. However, these studies using Canadian data suffer from small sample sizes and/or identification issues. Our paper aims to improve upon past studies examining the income-pollution relationship in Canada in these two respects. First, we take a panel data approach using pollution concentrations from individual monitoring stations and income data from the provincial and metropolitan levels. This approach provides substantially more observations than using data from the national (Day and Grafton 2003; He and Richard 2010) or local (Liang 2007) levels. Second, our econometric modeling approach attempts to separate and identify the relative magnitudes of the scale, composition, and technique effects of income growth. This approach is helpful for explaining the observation of Stern (2004) that the relationship between income and pollution is often found to be positive and monotonic when a time trend (or time fixed effects) is included. In this way, we can identify which effect has contributed most to the long term decline of concentrations of some common air pollutants in Canada.

The results we find are similar for three of the pollutants we examine (sulphur dioxide, nitrogen dioxide, and carbon monoxide), although some differences present themselves. For concentrations of all three pollutants, the relationship with income switches from negative to positive when time fixed effects are accounted for. We interpret the downward trend embodied in the time fixed effects as reflecting the exogenous progress of technology affecting both income and pollution. The downward trend is responsible for most of the observed improvement in air quality for these three pollutants. However, the changing composition of most provincial economies (from goods production towards service production) has also contributed to reduced concentrations of nitrogen dioxide and carbon dioxide, but not of sulphur dioxide. For nitrogen dioxide, our results suggest a composition effect for the 1980s and 1990s, but not the 2000s.

Our results for concentrations of ground-level ozone are mixed. We find no relationship with income when using annual average concentrations of ozone; however, we find similar results as for the other pollutants when using the measure used to assess the Canada-Wide Standard for ozone. This difference may be due to the government focus on reducing short-term high levels of the pollutant, which have larger adverse health impacts, rather than on long-term levels.

Our paper is organized as follows. Section 2 provides a discussion of the formation and possible effects of the pollutants studied, briefly explains the current Canadian regulatory framework, and reviews the EKC literature. Section 3 discusses the data and presents the econometric methodology. Section 4 presents and analyzes the estimation results. Section 5 presents conclusions.

2 Background & Literature Review

2.1 Air Pollution: Criterion Air Contaminants

The air pollutants studied in this paper (sulphur dioxide denoted SO2, nitrogen dioxide denoted NO2, ground-level ozone denoted O3, and carbon monoxide denoted CO) are considered by Environment Canada as criterion air contaminants (CACs)[1]. Sulphur dioxide is released as a result of the combustion or refining of raw materials that contain sulphur (e.g., coal, oil). According to emission data from Environment Canada (2010), smelting and refining accounted for 34% of total SO2 emissions released in Canada in 2008 and utilities (e.g., mainly coal-fired electricity plants) accounted for 24% of total SO2. Therefore, SO2 can be considered a point source pollutant. Traditionally the main concern about sulphur dioxide is that it dissolves in water vapour to produce acid rain. Acid rain may damage ecosystems by increasing the acidity in lakes, rivers and streams. SO2 also can react with air-borne ammonia (NH3) to produce ultra-fine particulate matter (PM2.5) which causes brown haze and may cause serious respiratory problems.

Nitrogen dioxide is emitted into the atmosphere when the nitrogen in the air-fuel mix is released. NO2 forms the largest portion of nitrogen oxides (NOx). In Canada in 2008 approximately 50% of NO2 emissions could be attributed to the transportation sector (Environment Canada 2010). NOx on its own, at high enough levels, can cause lung irritation, brown haze, and acidification of ecosystems. Similar to SO2, NOx reacts with air-borne NH3 to produce ultra-fine particulate matter. NOx also is a key component in the chemical reaction that produces ground-level ozone.

Ground-level ozone (O3) is formed by a chemical reaction involving NOx, volatile organic compounds (VOCs) and intense sunlight. In Canada in 2008 over 90% of VOCs emitted into the atmosphere were from natural sources such as coniferous forests (Environment Canada 2010). Considering only VOC emissions from human sources, 30% of VOCs were emitted by the transportation sector and 27% by the petroleum sector (Environment Canada 2010). O3 can be a lung irritant, especially affecting people with asthma. O3 also decreases the yield of some crops and causes some synthetic materials to deteriorate at an increasing rate. Recent research has also linked increased O3 exposure to the reduced productivity of farm workers in California (Graff-Ziven and Neidell 2012). VOC concentrations are not considered in our

[1]O3 is technically not a CAC, but often is considered a CAC because it is formed by a process involving two CACs

analysis since the vast majority of Canadian sources are natural and ambient concentrations have not been monitored on a systematic basis.

Carbon monoxide is produced by the incomplete combustion of carbon-based fuels and is mainly produced by the transportation sector. The transportation sector in Canada was responsible for 61% of total CO emissions in 2008 (Environment Canada 2010). Forest fires were responsible for 19% of total CO emissions in Canada in 2008 (Environment Canada 2010). Exposure to high concentrations of CO inhibits the oxygen carrying capacity of blood. People with heart disease or respiratory diseases, infants, unborn babies, and the elderly are particularly sensitive to exposure to CO.

2.2 Air Pollution Policy in Canada

Pollution regulation has traditionally fallen under the jurisdiction of the provinces in Canada; however, the federal government has begun to play a much larger role in the last few decades due to issues such as transboundary pollution. Large point sources of air pollution are regulated at the provincial level in most cases by a permitting process. Obtaining a permit to release pollution generally involves a site visit by regulators, possibly resulting in mandated technological recommendations to be fulfilled and/or some prohibitions on emissions. When granting permits, the regulators consult provincial and national ambient air quality objectives for pollutant concentrations over different time scales.[2] The permitting process provides a very flexible regulatory regime for controlling localized pollutants, as regulators have some discretion over which objectives to aim for based on regional economic circumstances. Ontario has also implemented a permit trading market to reduce the cost of emissions abatement (OME (2005)).

At the federal level, the emissions of NOx, CO, and VOCs from motor vehicles are regulated under the *Canadian Environmental Protection Act* (CEPA) instituted in 1999. The On-Road Vehicle and Engine Emission Regulations imposed under CEPA mandates

[2]See Wood (2012) for a description and comparison of the provincial and federal air quality objectives

fleet average grams of NOx 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, NOx, and VOCs. These types of emission standards on new vehicles have been instituted by the federal government since the 1970s in concert with regulations imposed by the Environmental Protection Agency of the United States government due to the highly integrated nature of the North American motor vehicle market. The federal government also has instituted regulations for VOC emissions from other non-point sources, such as paint and solvent use (Environment Canada 2004).

The existence of federal environmental regulation does not imply that pollution concentrations are equal across provinces. Different geographies, different industrial compositions, etc. lead to pollution levels that are heterogeneous across the country. Furthermore, most federal regulations are targeted at reducing pollution intensity, rather than absolute pollution levels. For example, with vehicle emission standards, if the number of vehicle miles traveled increases sufficiently, pollution concentrations can still increase. Therefore, the effect of the regulation on pollution levels can differ between provinces depending on their relative levels of vehicle miles traveled.

2.3 The Environmental Kuznets Curve Hypothesis

The Environmental Kuznets Curve (EKC) hypothesis posits that the relationship between income and pollution follows an inverse 'U-shape', i.e., pollution is at first increasing and then decreasing as income increases. The EKC first began to be studied following work by Grossman and Kreuger (1991) who looked at the relationship between various pollution concentrations and income across countries.

The mixed empirical results[3] of the EKC studies have driven a diverse theoretical literature seeking to explain why the effect of income growth on pollution levels may be nonlinear. Lopez (1994) studied a model in which a stock pollutant is a by-product of the production

[3]See Stern (2004) and Carson (2010) for comprehensive literature reviews.

process. Nonlinearities can arise if the stock rises high enough to cause negative productivity effects. Coondoo and Dinda (2002) treats pollution as an input in the production process and as a parameter in consumers utility function. They suggest that pollution changes from a necessary to an inferior good at some threshold income level, implying a turning point. They argue that the correlation between pollution and income should be positive prior to the turning point and negative thereafter. Andreoni and Levinson (2001) consider a model in which pollution is a by-product of production and there are increasing returns to abatement technology, that is, the more pollution is abated, the more effective the abatement becomes at the margin. This induces a turnaround point in abatement effectiveness when income (and therefore pollution) reach a sufficiently high level. Brock and Taylor (2010) argue that increasing returns to abatement are unlikely to occur in reality due to the association of pollution with numerous small sources. They propose instead a “Green Solow” growth model in which pollution is a by-product of output and there is technical progress in abatement. The dynamics imply that the growth rate of emissions eventually becomes negative and an EKC relationship exists.

Most of the empirical EKC studies focus on estimating the relationship between pollution emissions or concentrations and income by estimating a polynomial regression to model the inverse u-shape. However, Stern (2004) has highlighted many shortcomings in this approach and suggests focusing instead on development of appropriate econometric methods to clarify the robustness of the underlying phenomena. He gives as an example Harbaugh et al (2002), who found that including a time trend and a dynamic specification eliminates the EKC result of Grossman and Kreuger (1995) for SO2 concentrations. A useful approach to explaining, rather than describing, the income-pollution relationship was proposed in the original Grossman and Kreuger (1991) study and also notably used by Antweiler et al (2001) to examine the relationship between pollution and trade. They propose that growth in income is related to pollution in three ways: The scale effect, the composition effect, and the technique effect. The technique effect refers to improvements in general technology and knowledge that will lead to reduced pollution being emitted. The composition effect refers to changes in pollution due to the changing composition of the economy. The direction of the composition effect is ambiguous; it can conceivably increase or decrease pollution. For example, at low income levels economic growth may involve the economy shifting towards heavy industry and manufacturing and away from rural agriculture resulting in an increase in pollution. But at higher income levels economic growth may involve the economy shifting from heavy industry and manufacturing to the provision of services resulting in reduced pollution. The scale effect is that the larger an economy is, the more pollution it will produce ceteris paribus. This framework can produce an EKC relationship if at low income levels the scale effect and a positive composition effect (e.g., shift from agriculture to heavy industry) outweigh the technique effect. At some higher level of income, the composition effect becomes negative (e.g.,shift from heavy industry to services) and the scale effect is dominated by the composition effect and the technique effect.

The framework can be used to explain why studies like Harbaugh et al (2002) find a positive monotonic relationship between income and pollution when a time trend (or time fixed effects) are included in the empirical specification. The linear trend could be representing the decreased pollution from the composition and technique effects. Therefore, the positive monotonic relationship can be interpreted as the scale effect after controlling for the composition and technique effects. Ordas Criado et al (2011) use a similar framework, but derived from Brock and Taylor's model, and find a positive relationship between two pollutants (SOx and NOx) and income in a panel of 25 European countries after controlling for a "defensive effect" that could be interpreted as a combination of the composition effect and the technique effect in response to past pollution levels.

Our study applies the scale, composition, and technique framework to examine the relationship between Canadian pollution and income data. This approach is useful as it will help explain, rather than just describe, how observed changes in Canadian pollution concentrations relate to average incomes in Canada.

2.4 Air Pollution & Income in Canada: Empirical Evidence

The majority of the empirical EKC literature has focused on estimating polynomial models using multi-country data sets. There has been surprisingly little research on the relationship between air pollution and income in Canada. He and Richard (2010) estimate parametric and semi-parametric models with Canadian per capita carbon dioxide emissions as the dependent variable. They fail to find an EKC relationship; however, their approach focuses on estimating the relationship without controlling for changes in technique or composition, for example, their parametric models are polynomial regressions. This approach can only describe the overall relationship rather than explain where the relationship is coming from.

Liang (2007) studies the relationship between air pollution concentrations and income for Toronto. She finds that ambient levels of the coefficient of haze and ground-level ozone Granger cause increases in income (measured by monthly real earnings and real average earnings for Ontario). She also finds that nitric oxide Granger causes decreases in income. Looking at causality in the other direction, she finds that real earnings Granger cause decreases in O3, but real average earnings Granger cause increases in O3. However, Liang (2007) notes the limitation of her study in regards to the scale, composition, and technique framework:

> We don't find an income-growth effect on most of the air quality indicators (except O3) in the Toronto area, suggesting that either there is no significant scale effect, or the structure of the economy and the technology level hasn't significantly changed within the period we investigate. The other possibility is that the negative impact on the environment of the scale effect just cancels out the positive impact of the composition and technique effects...

Day and Grafton (2003) also studied the relationship between air pollution and income in Canada, but at the national level. They estimate a vector autoregression model in first differences including per capita gross domestic product, CO2 emissions, and ambient concentrations of carbon monoxide, sulphur dioxide and total suspended particulate matter. They use a joint test of the pollutant variables and find that pollution Granger causes income, but income Granger causes only SO2 (an increase in income leads to an increase in SO2 concentrations). Their data set consists of only 24 time-series observations for the pollution concentrations and 38 observations for CO2, so the results may not be robust due to the small sample size.

We believe our approach is an improvement on the existing Canadian studies. Using provincial and regional data in a panel framework allows us to substantially increase the number of degrees of freedom. Furthermore, incorporating the scale, composition, and technique theoretical framework into our empirical approach allows us to explain the income pollution relationship for Canada in greater detail.

3 Data & Methodology

3.1 Data

The pollution data for the study are annual average concentrations of SO2, CO, NO2, and O3 at monitoring stations across the country from 1984 to 2010. The pollution data are from the National Air Pollution Surveillance (NAPS) database maintained by Environment Canada. The annual averages for each station were calculated by Environment Canada from recorded hourly averages, and only reported to the nearest ppb (or ppm) for monitoring stations with data covering at least 50% of the hours in a year (Environment Canada 2015). The monitoring data is an unbalanced panel with some stations being active for the entire sample period (27 years) and some being active for as little as two years. All stations with only one year of data were omitted from the analysis.

Figure 1 displays the average, 90th percentile, and 10th percentile of concentrations recorded across all of the monitoring stations in the sample between 1984 and 2010. All three indicators for SO2, CO, and NO2 have decreased over the time period. Furthermore, the figure also shows the three indicators becoming more close together over time for the three pollutants. The graph for O3 shows all three indicators increasing over the time period.

We represent scale indirectly using per capita GDP, or income. In all regions population was steady or growing, so the growth of per capita GDP corresponds with growth in total regional GDP. The population growth rates over the sample duration (1984 to 2010) were not equivalent, however, ranging from a low of just under five percent in New Brunswick to just over 180 percent in Alberta. But growth of total GDP within a province may be spread out broadly and thus not impinge on every specific individual monitoring site. Use of per capita GDP approximates a scale change that, on average, applies to all areas in a province, and in most cases, especially to the large urban centres.

Two data series are used to reflect income in our study. First, for the 1984 to 2010 time period we use expenditure-based real Gross Domestic Product (GDP) per capita at the provincial level from the Provincial Economic Accounts published by Statistics Canada (Statistics Canada 2011; Statistics Canada 2015; authors' calculations). Second, for the 2001 to 2009 time period we use a new Statistics Canada data series of GDP per capita at the Census Metropolitan Area (CMA) level (Statistics Canada 2014). There are 34 CMA's in Canada, therefore, using CMA level income data yields a higher amount of variation than provincial data which will hopefully aid in identifying the effects of income on pollution concentrations.

Figure 2 displays the provincial GDP per capita data plotted over time. Provincial incomes are increasing over the sample period, with a slight downward cycle for some provinces in the later years reflecting the recent recession. The CMA income data (not graphed due to the larger number of CMAs) are also increasing over the sample period. Descriptive statistics for the CMA income data are presented in Table 1. The average and the standard deviation are increasing over the time period. There is more than a $20,000 gap between the CMA with the highest income and the CMA with the lowest income for the three years displayed in the table. Abbotsford, British Columbia has the lowest per capita income of the CMAs, while Calgary, Alberta has the highest in 2001 and 2005 and Regina, Saskatchewan has the highest in 2009.

We choose the provincial Services-to-Goods ratio to capture the changing composition of provincial economies in Canada. The Services-to-Goods ratio is calculated from sectoral GDP data at the provincial level (Statistics Canada 2012). The GDP for all services producing sectors is divided by the GDP for all goods producing sectors according to NAICS codes. Figure 2 displays the Services-to-Goods ratio over time for 8 provinces. It is apparent from the graph that all provinces except Alberta and Saskatchewan have experienced a long term shift away from producing goods and towards producing more services. Alberta's economy is always more goods intensive relative to the other provinces over the time period. The composition of Saskatchewan's economy starts out similar to the other provinces excluding Alberta, but displays a major shift towards goods sectors starting in the mid-1990s. From the late-1990s on, the composition of Saskatchewan's economy more closely reflects that of Alberta than the other provinces.

An additional variable of interest related to the technique effect is provincial government environment spending per capita. Provincial spending on "Environment" using a standardized accounting framework (Financial Management System) is obtained from Statistics Canada for the period 2001 to 2009 (Statistics Canada 2009). The category of "Environment" includes provincial government expenditures on water treatment and control and air pollution control. These expenditures are divided by provincial population and displayed in Figure 2. Environment spending per capita is slightly increasing for most provinces except for Alberta which has experienced a very large increase.

3.2 Methodology

Our strategy to examine the relationship between air pollution and income in Canada uses data on local pollution concentrations and provincial level and metropolitan level macroeconomic variables to identify the scale effect, composition effect, and technique effect while controlling for unidentified characteristics of individual monitoring stations. For each of the four pollutants studied, we estimate two main regression model specifications for two time periods: 1984-2010 and 2001-2009. For the 1984-2010 time period we regress average annual concentrations of a pollutant at each monitoring station (p_{it}) on provincial per capita GDP (y_{kt}) and the provincial Services-to-Goods ratio (c_{kt}). For the 2001-2009 time period we increase the variation in the income variable by using CMA level per capita GDP instead of the provincial level income data. When using the CMA level income data we restrict our sample of monitoring stations to only include those that fall within the boundaries of a CMA; although we do add monitoring stations from St. John's, NL and Prince Edward Island (PEI as a whole is counted by Statistics Canada as a CMA). We also run regressions with and without provincial environment spending per capita (e_{kt}) for the 2001-2009 period.

We control for the heterogeneous characteristics of individual monitoring stations by using fixed effects at the station level, η_i. The following is our Model (1) specification that includes only station level fixed effects:

$$p_{it} = \delta_y y_{jt} + \delta_c c_{kt} + \delta_e e_{kt} + \eta_i + \epsilon_{it}, \tag{1}$$

where p_{it} is the annual average concentration of the selected pollutant at station i in year t, y_{jt} is the per capita GDP for province or CMA j in year t, c_{kt} is the Services-to-Goods ratio for province k[4] in year t, and e_{kt} is government environment spending per capita for province k in year t, and η_i is the intercept for station i. Model (1) is insufficient to separate the scale and technique effects, as they will both be embodied in δ_y. Therefore, to identify the scale effect while controlling for the technique effect we propose the following Model (2):

$$p_{it} = \delta_y y_{jt} + \delta_c c_{kt} + \delta_e e_{kt} + \eta_i + \gamma_t + \epsilon_{it}, \tag{2}$$

where γ_t is the fixed effect for year t.

[4]When using Provincial GDP, $j = k$.

When conducting hypothesis tests on the estimated coefficients, we use the method proposed by Arellano (1987) to obtain standard errors that are robust to heteroskedasticity and cross-sectional dependence.

4 Results & Analysis

Sulphur Dioxide

Table 2 contains the results from the regressions with SO2 as the dependent variable. The estimated coefficients for the income variable in the Model (1) specification (station level fixed effects) are negative and statistically significant. However, the sign of the coefficients become positive when year fixed effects are included (Model (2)). This is consistent with the results of some multi-country EKC studies. Stern and Common (2001) and Maddison (2006) both find positive monotonic relationships between income and emissions per capita when time fixed effects are included, and in both these cases the time effects are negative. Harbaugh et al (2002) report a similar result for SO2 concentrations when including a linear time trend. This leads them to comment:

> This may seem counterintuitive. SO2 concentrations in Canada and the United States have declined over time at ever decreasing rates...the regressions...include...a linear time trend...after detrending the data with the time function, pollution appears to increase as a function of GDP (p. 548)

Furthermore, Ordas Criado et al (2011) find a positive relationship between income and SOx emissions for a panel of European countries after controlling for the "defensive effect". A positive relationship between income and SO2 concentrations is consistent with the scale effect.Our results from model (2) suggest $1,000 higher income is associated with SO2 concentrations that are higher by between 0.054 ppb (2001-2009) and 0.305 ppb (1984-2010).

The estimated coefficient for the Services-to-Goods ratio is statistically significant in all Model (1) specifications in the 1984-2010 time period. The sign of the estimated coefficients are negative suggesting a shift from goods to services leads to reduced SO2 concentrations. SO2 is mainly emitted in Canada by goods producing industries, therefore, a negative coefficient is consistent with the composition effect. However, when year fixed effects are added, we can no longer conclude that the estimated coefficients are statistically significantly different from zero.

The coefficient for provincial environment spending per capita is only statistically significant (and only at the 15% confidence level) in the Model (2) specification. The estimate suggests that $1 higher environment spending per capita is associated with SO2 concentrations that are 0.005ppb lower. This effect is very small in magnitude. To decrease SO2 concentrations by one ppb, environment spending per capita would need to increase by $200; however, environment spending per capita is less than this in all provinces.

Figure 3 plots the year fixed effects over time for the 1984-2010 time period. The year fixed effects estimated in Model (2) show a clear downward trend reflecting a 9 ppb decrease in SO2 concentrations across the time period. Regressing the estimated year fixed effects on a linear time trend suggests an annual decrease of 0.371 ppb (reported in Table 2). This downward trend more than offsets the increases from the estimated scale effect (0.305); it would take an increase in real GDP per capita of $29,508 for the scale effect to offset the 9 ppb decrease. Similar results are identified when using the CMA level income data in the 2001-2009 time period. The year fixed effects are displayed in Figure 4. The estimated year fixed effects in Model (2) show a clear downward trend corresponding to a decline of SO2 concentrations of 2.4 ppb over the 9 years.

Carbon Monoxide

The results from the regressions with concentrations of CO as the dependent variable are presented in Table 3. The estimated coefficient on the income variable is negative and significant in Model (1) for both time periods. A negative coefficient is inconsistent with the scale effect. When year fixed effects are added (Model (2)), the estimated coefficient on the income variable is no longer statistically significant. Unlike with SO2, we fail to identify a scale effect for CO.

The coefficient for the Services-to-Goods ratio is negative and significant in the 1984-2010 period, but becomes insignificant when year fixed effects are added to the model. However, for the 2001-2009 time period the coefficient remains negative and significant in all model specifications. This suggests a composition effect in which a one point increase in the Services-to-Goods ratio is associated with a 0.074 ppm decrease in CO concentrations.

The coefficient for provincial environment spending per capita is not significant in either Model (1) or Model (2).

Figure 3 displays the estimated year fixed effects over the 1984 to 2010 period. The year fixed effects in Model (2) show a clear downward trend in CO concentrations between 1984 and 2010 (an overall decrease of 0.7 ppm). The effects are displayed for 2001 to 2009 in Figure 4. The year fixed effects in this period also show a clear downward trend over the 9 year period; consistent with the technique effect.

We conclude that CO concentrations have decreased in Canada due to changes in composition and technique, without identifiable upward pressure due to the increased scale of the economy.

Nitrogen Dioxide

The results from the regressions with NO2 as the dependent variable are displayed in Table 4. The estimated coefficient on the income variable is statistically significant in all of the regressions. Similar to the results for SO2, the coefficient is negative in Model (1), but positive in Model (2). For the 1984-2010 time period, the results from Model (2) suggest that a $1,000 higher income per capita is associated with NO2 concentrations that are 0.17 ppb higher after controlling for differences in composition and technique. For the 2001-2009 time period, a $1,000 higher income per capita is associated with 0.12 ppb lower concentrations.

We identify a large composition effect in Model (1) for all three time periods. A one point increase in the Services-to-Goods ratio results in over a 2 ppb decrease in concentrations. However, this effect is smaller for the 1984-2010 time period using Model (2) and not statistically significant for the 2001-2009 time period using Model (2). For the 1984-2010 time period, Model (2) suggests that a one point higher Services-to-Goods ratio is associated with NO2 concentrations that are 0.889 ppb lower.

The coefficient for provincial government environment spending is only statistically significant in Model (1); a 0.018 ppb increase in NO2 concentrations for a $1 increase in environment spending. This is counter-intuitive, and is probably reflective of endogeneity between environment spending and pollution concentrations (i.e., provinces with higher initial pollution concentrations probably would spend more on pollution monitoring and control). However, the effect is no longer identified when year fixed effects are added to the model specification.

The year fixed effects for the 1984-2010 period are displayed in Figure 3. In the 1984-2010 time period, the year fixed effects show a clear downward trend suggesting an overall decrease in concentrations of 10ppb. Similarly, the year fixed effects for the 2001 to 2009 time period displayed in Figure 4 show a clear downward trend. The year fixed effects suggest decreases in NO2 concentrations from the technique effect of 5 ppb over the time period. The decreases from the technique effect alone have clearly dominated the increases from the scale effect. For example, taking the coefficient of 0.12 estimated for the income variable in Model (2), a 5 ppb increase in concentrations would require an increase in income of more than $42,000 over the 9 years. Furthermore, a 10 ppb increase in NO2 concentrations would require an increase in income of more than $58,000 over the 1984 to 2010 period.

We conclude that for NO2 the technique effect and a shift to services production outpaced the scale effect. Furthermore, the technique effect by itself was sufficient to outweigh the increased NO2 concentrations from the increased scale of economic activity. The composition effect is identified in the 1984-2010 time period, but not in the 2000-2009 time period, suggesting that the shift to services in the 1980s and 1990s led to large reductions in NO2, but possibly not in the 2000s.

Ground-level Ozone

The regression results with O3 as the dependent variable are displayed in Table 5. Unlike for the other pollutants, the scale effect is only identified in Model (1) where the estimated coefficients for the income variable are positive and statistically significant.The coefficient is no longer significant when year fixed effects are added to the model specification (Model (2)). We do identify the composition effect as the coefficient for the Services-to-Goods ratio is positive and statistically significant in Model (1) for both periods and for Model (2) in the 1984-2010 period. A 1 point higher ratio is associated with O3 concentrations that are 1.405 ppb higher in Model (2). This suggests that the transition to a more service based economy may also result in higher concentrations of O3. This is contrary to what we found for NO2, a precursor component to O3.

We fail to identify the technique effect for O3. The estimated coefficients for provincial environmental spending are not statistically significant. Furthermore, the year fixed effects shown in Figures 3 and 4 display substantial annual fluctuation and slight upward trends. The presence of an upward trend suggests that the year fixed effects are not capturing only the technique effect in this instance, but some other variable as well. O3, as mentioned earlier, is not a directly emitted pollutant. It is formed by a reaction of nitrogen oxides (NOx), airborne volatile organic compounds (VOCs) and sunlight. VOCs were not considered in this study because of limited monitoring data and the dominance of natural sources of emissions. NO2 represents the largest portion of airborne concentrations of NOx, therefore, it may be strange that we identified a negative composition effect and a downward temporal trend for NO2 concentrations, but a positive composition effect and an upward temporal trend for O3 concentrations. However, the O3 formation process is nonlinear and depending on VOC levels and the intensity of sunlight, O3 may go up or down as NOx decreases (Adamowicz et al 2001). The upward trend displayed by the year fixed effects is likely capturing the technique effect as well as an upward trend and annual fluctuations in one of these unobserved variables.

Due to the failure to identify a relationship between annual average concentrations of O3 and income, we consider another measure of O3 pollution. In 2000, most Canadian provinces agreed to meet a voluntary Canada-Wide Standard (CWS) of 65ppb for O3 by 2010.[5] Compliance with the CWS is based on a specific measurement of O3 concentrations: the three year average of the annual fourth highest daily maximum 8-hour moving average. This measure is aimed at reflecting exposure to short-term, extreme levels of O3, whereas the annual average reflects long-term exposure. Many provinces in Canada do not have air quality objectives for annual average concentrations of O3; for example, Ontario only uses the CWS objective and a 1-hour objective. We use hourly average concentration data from the NAPS database (Environment Canada 2015) to calculate the annual fourth highest daily maximum 8-hour average concentrations at monitoring stations across the country.[6] We use this new measure as the dependent variable in our Model (1) and Model (2) regressions. The CWS measure and the annual average are positively correlated in our data set, but this is to be expected as a high peak value will increase the average all else equal. For the CWS measure of O3 concentrations, the average, 90th percentile, and 10th percentile are plotted over time in Figure 5. Visual inspection suggests the average and 90th percentile appear to be slightly declining over time, but the 10th percentile is slightly increasing. In contrast, for the annual average O3 concentrations displayed in Figure 1, the average, 90th percentile, and 10th percentile are all increasing. The CWS measure also has a standard deviation (13.91) that is double that of the annual average (6.21).

[5] Quebec did not sign the agreement.

[6] We restrict our calculation to only calculate a daily maximum 8-hour moving average on days for which a station has data for 18 out of 24 hours. We then also restrict our calculation of the annual measure to only calculate if a station has a daily maximum 8-hour moving average for at least 50% of the days between May and September. The R code used is available from the authors upon request.

The results from the regressions using the CWS measure are displayed in Table 6. The results using the CWS measure for O3 are exactly as predicted by the scale, composition, and technique framework and are similar to the results found for SO2, NO2, and CO. The coefficient on income is always negative in Model (1), but becomes positive in Model (2) when year fixed effects are added to control for the technique effect. For the 1984-2010 period the coefficient on the income variable in Model (2) implies a scale effect in which a $10,000 increase in income is associated with an increase in O3 concentrations of 8.57ppb. In the 2001-2009 period, a $10,000 increase in income is associated with O3 concentrations that are higher by between 3.85ppb to 4.86ppb.

We identify a composition effect that is statistically significant in all cases. Adding year fixed effects lowers the magnitude of the composition effect. For the 1984-2010 period, a one point increase in the Services-to-Goods ratio is associated with a 1.647ppb decrease in O3. Unlike with NO2, the composition effect is stronger in the 2001-2009 period. A one point increase in the Services-to-Goods ratio is associated with a decrease in O3 of just over 5ppb.

Unlike when we used annual average O3 concentrations as the dependent variable, the year fixed effects when using the CWS O3 measure show a downward trend. Over the 1984-2010 period, a regression fitting a linear trend to the year fixed effects coefficients estimates an annual decrease of 0.65ppb. A similar trend regression for the 2001-2009 period estimates an annual decrease of 1.6ppb. A downward trend in the year fixed effects is consistent with the technique effect. Although, as can be seen in Figure 5 that the year fixed effects display more annual fluctuation than for the other pollutants.

It may seem surprising that the CWS measure produces results consistent with the results for the other pollutants, but that the annual average does not. This is probably reflective of higher levels of concern in regards to the health effects of short-term exposure to high levels. Government control of pollution permits results in the adoption of cleaner techniques. If provincial governments are issuing permits for NOx and VOCs in a manner to reduce the CWS measure of concentrations, but not average annual concentrations, it could partially explain the differing results. This in itself is probably not cause for concern given that the World Health Organization reviewed the scientific evidence surrounding the health impacts of exposure to O3 and concluded “there is some evidence that long-term exposure to ozone may have chronic effects but it is not sufficient to recommend an annual guideline” (WHO, 2006; p. 14). Therefore, it is entirely appropriate for governments to focus on controlling the high levels where the major health damages occur.

5 Conclusion

Our approach improved upon past Canada-focused studies of the pollution-income relationship in two main respects. First, using panel data at the monitoring station level provides substantially more observations. Second, interpreting our econometric results using the scale, composition, and technique framework helps us identify why some pollutants decreased.

We find many similarities in the income-pollution relationship for concentrations of three common pollutants: sulphur dioxide, nitrogen dioxide, and carbon monoxide. For all three pollutants, the coefficient on income switches from negative to positive when year fixed effects are added to the model. The switch in sign occurs due to the coefficient at first capturing both the scale and technique effects. When added to the model, the year fixed effects reflect the improvement in technique over time, and once this is controlled for the coefficient on the income variable is now positive reflecting solely the scale effect. We also find that the pollution reductions attributed to the year fixed effects, reflecting the technique effect, were more than sufficient to offset any upward pressure to pollution due to the increased scale of the economy.

Despite this similarity for the three pollutants, some differences are identified. We can detect no scale effect for carbon monoxide after controlling for changes in composition and technique. This may help explain why concentrations of carbon monoxide have decreased relatively more compared to other pollutants. We also cannot identify a composition effect for sulphur dioxide, whereas we do identify composition effects for carbon monoxide and nitrogen dioxide. Interestingly though, we only identify a composition effect for nitrogen dioxide when looking at the 1984 to 2010 time period, but not for the 2001 to 2009 time period. This is suggestive that there are limits to the composition effect, i.e., the changing composition of the economy contributed to nitrogen dioxide reductions in the 1980s and 1990s, but not in the 2000s despite a long term shift from goods production to service production in most provincial economies in Canada.

We find mixed results for the fourth pollutant studied. No relationship with income is identified when looking at annual average concentrations of ground-level ozone. Furthermore, we find a positive composition effect in the 1984 to 2010 period and the year fixed effects show annual fluctuation and a slight upward trend. These results are surprisingly contrary to the results found for nitrogen dioxide which is a precursor to ground-level ozone. However, when we instead use the Canada-Wide Standard measurement of ozone concentrations, we find results in-line with what we found for the other three pollutants. We find a positive scale effect, a negative composition effect, and a negative technique effect. The difference in results for the two ozone measures may reflect government focus on reducing short-term high levels of ozone rather than long-term levels. The existence of a Canada-Wide Standard and a WHO guideline for short-term levels, but not annual average levels supports this conclusion.

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Table 1: Descriptive Statistics: CMA Income

	2001	2005	2009
Mean	31,549	36,876	41,837
Standard Deviation	5,848	6,821	9,020
Maximum	44,438	52,681	65,403
Minimum	21,282	25,231	28,751

Notes:

Table 2: Results, Sulphur Dioxide

Explanatory Variables	SO2: 1984-2010 (1)	SO2: 1984-2010 (2)	SO2: 2001-2009 (1)	SO2: 2001-2009 (2)	SO2: 2001-2009 (1)	SO2: 2001-2009 (2)
GDP per capita, y_{jt}	**-0.229**[a]	**0.305**[a]	**-0.071**[a]	**0.054**[b]	**-0.071**[a]	**0.073**[a]
	(0.037)	(0.066)	(0.013)	(0.021)	(0.014)	(0.027)
Services-to-Goods Ratio, c_{kt}	**-1.424**[a]	0.563	**-0.857**[a]	-0.128	**-0.857**[a]	-0.124
	(0.182)	(0.411)	(0.228)	(0.278)	(0.237)	(0.272)
Environment Spending per capita, e_{kt}	-	-	-	-	0.00009	**-0.005**[d]
					(0.003)	(0.003)
Linear trend of year fixed effects	-	**-0.371**[a]	-	**-0.292**[a]	-	**-0.303**[a]
		(0.013)		(0.012)		(0.013)
F Statistic	190.2[a]	21.6[a]	60.6[a]	5.4[a]	40.3[a]	4.5[a]
Degrees of Freedom	1766	1740	403	395	402	394
	n=201, T_i=2-27, N= 1969		n=74, T_i=2-9, N=479		n=74, T_i=2-9, N=479	

Notes: Results are for regressions with monitoring station level average annual concentrations of sulphur dioxide (SO2) as the dependent variable. The explanatory variables are (Y) GDP per capita (at the provincial level for the 1984-2010 regressions, and at the Census Metropolitan Area level for the 2001-2009 regressions), the Service GDP to Goods GDP ratio at the provincial level (C), and environment spending per capita by provincial governments (E). Model (1) refers to a specification with station level fixed effects. Model (2) refers to a specification with station level and year fixed effects. Superscripts a, b, c, and d refer to significance at the 1%, 5%, 10%, and 15% levels respectively. In an effort to be concise, a linear trend coefficient from regressing the estimated time fixed effects from Model (2) on $t \in [1, 26]$ (or $t \in [1, 8]$) is reported rather than reporting each of the estimated year fixed effects. The standard errors are in parentheses and are robust to heteroskedasticity and cross-sectional correlation. n is the number of monitoring stations and N is the total number of observations.

Table 3: Results, Carbon Monoxide

Explanatory Variables	CO: 1984-2010 (1)	CO: 1984-2010 (2)	CO: 2001-2009 (1)	CO: 2001-2009 (2)	CO: 2001-2009 (1)	CO: 2001-2009 (2)
GDP per capita, y_{jt}	**-0.037**[a]	-0.011	**-0.012**[a]	0.0009	**-0.014**[a]	0.0004
	(0.005)	(0.016)	(0.001)	(0.003)	(0.002)	(0.003)
Services-to-Goods Ratio, c_{kt}	**-0.224**[a]	-0.058	**-0.109**[a]	**-0.074**[c]	**-0.113**[a]	**-0.073**[c]
	(0.054)	(0.057)	(0.020)	(0.042)	(0.020)	(0.042)
Environment Spending per capita, e_{kt}	-	-	-	-	0.0003	-0.0002
					(0.0003)	(0.0003)
Linear trend of year fixed effects	-	**-0.023**[a]	-	**-0.026**[a]	-	**-0.028**[a]
		(0.001)		(0.0009)		(0.001)
F Statistic	423.4[a]	2.5[c]	107[a]	2.8[c]	71.7[a]	2.1[c]
Degrees of Freedom	1246	1220	384	396	383	375
	n=116, T_i=2-27, N=1364		n=67, T_i=2-9, N=453		n=67, T_i=2-9, N=453	

Notes: Results are for regressions with average annual concentrations of carbon monoxide (CO) as the dependent variable. The explanatory variables are (Y) GDP per capita (at the provincial level for the 1984-2010 regressions, and at the Census Metropolitan Area level for the 2001-2009 regressions), the Service GDP to Goods GDP ratio at the provincial level (C), and environment spending per capita by provincial governments (E). Model (1) refers to a specification with station level fixed effects. Model (2) refers to a specification with station level and year fixed effects. a, b, and c refer to significance at the 1%, 5%, and 10% levels respectively. In an effort to be concise, a linear trend coefficient from regressing the estimated time fixed effects from Model (2) on $t \in [1, 26]$ (or $t \in [1, 8]$) is reported rather than reporting each of the estimated year fixed effects. The F Statistic is a test that the coefficients on the explanatory variables are jointly zero. The standard errors are in parentheses and are robust to heteroskedasticity and cross-sectional correlation.

Table 4: Results, Nitrogen Dioxide

Explanatory Variables	NO2: 1984-2010 (1)	NO2: 1984-2010 (2)	NO2: 2001-2009 (1)	NO2: 2001-2009 (2)	NO2: 2001-2009 (1)	NO2: 2001-2009 (2)
GDP per capita, y_{jt}	**-0.335**^{a}	**0.170**^{d}	**-0.215**^{a}	**0.118**^{a}	**-0.273**^{a}	**0.121**^{b}
	(0.037)	(0.113)	(0.020)	(0.040)	(0.027)	(0.049)
Services-to-Goods Ratio, c_{kt}	**-2.894**^{a}	**-0.889**^{c}	**-2.161**^{a}	-0.364	**-2.253**^{a}	-0.362
	(0.284)	(0.457)	(0.336)	(0.384)	(0.337)	(0.384)
Environment Spending per capita, e_{kt}	-	-	-	-	**0.018**^{a}	-0.0007
					(0.006)	(0.004)
Linear trend of year fixed effects	-	**-0.351**^{a}	-	**-0.761**^{a}	-	**-0.763**^{a}
		(0.017)		(0.058)		(0.058)
F Statistic	673.2^{a}	22.6^{a}	253.3^{a}	18.8^{a}	180.3^{a}	12.5^{a}
Degrees of Freedom	1978	1952	548	540	547	539
	n=196, T_i=2-27, N=2176		n=96, T_i=2-9, N=646		n=96, T_i=2-9, N=453	

Notes: Results are for regressions with average annual concentrations of nitrogen dioxide (NO2) as the dependent variable. The explanatory variables are (Y) GDP per capita (at the provincial level for the 1984-2010 regressions, and at the Census Metropolitan Area level for the 2001-2009 regressions), the Service GDP to Goods GDP ratio at the provincial level (C), and environment spending per capita by provincial governments (E). Model (1) refers to a specification with station level fixed effects. Model (2) refers to a specification with station level and year fixed effects. Superscripts a, b, c, and d refer to significance at the 1%, 5%, 10%, and 15% levels respectively. In an effort to be concise, a linear trend coefficient from regressing the estimated time fixed effects from Model (2) on $t \in [1, 26]$ (or $t \in [1, 8]$) is reported rather than reporting each of the estimated year fixed effects. The F Statistic is a test that the coefficients on the explanatory variables are jointly zero. The standard errors are in parentheses and are robust to heteroskedasticity and cross-sectional correlation.

Table 5: Results, Ground-level Ozone Annual Average

Explanatory Variables	O3: 1984-2010 (1)	(2)	O3: 2001-2009 (1)	(2)	O3: 2001-2009 (1)	(2)
GDP per capita, y_{jt}	**0.175**[a]	0.036	**0.055**[c]	-0.007	**0.075**[c]	-0.016
	(0.025)	(0.072)	(0.028)	(0.065)	(0.043)	(0.075)
Services-to-Goods Ratio, c_{kt}	**1.520**[a]	**1.405**[a]	**0.582**[c]	0.434	**0.607**[c]	0.368
	(0.203)	(0.431)	(0.327)	(0.405)	(0.325)	(0.413)
Environment Spending per capita, e_{kt}	-	-	-	-	-0.007	-0.008
					(0.014)	(0.014)
Linear trend of year fixed effects	-	**0.081**[a]	-	**0.167**[c]	-	**0.168**[c]
		(0.019)		(0.069)		(0.071)
F Statistic	330.9[a]	25.1[a]	12.8[a]	0.91	9.1[a]	1.4
Degrees of Freedom	3109	3083	698	690	697	689
	n=275, T_i=2-27, N=3386		n=113, T_i=2-9, N=813		n=113, T_i=2-9, N=813	

Notes: Results are for regressions with average annual concentrations of ground-level ozone (O3) as the dependent variable. The explanatory variables are (Y) GDP per capita (at the provincial level for the 1984-2010 regressions, and at the Census Metropolitan Area level for the 2001-2009 regressions), the Service GDP to Goods GDP ratio at the provincial level (C), and environment spending per capita by provincial governments (E). Model (1) refers to a specification with station level fixed effects. Model (2) refers to a specification with station level and year fixed effects. In an effort to be concise, a linear trend coefficient from regressing the estimated time fixed effects from Model (2) on $t \in [1, 26]$ (or $t \in [1, 8]$) is reported rather than reporting each of the estimated year fixed effects. The F Statistic is a test that the coefficients on the explanatory variables are jointly zero. The standard errors are in parentheses and are robust to heteroskedasticity and cross-sectional correlation

Table 6: Results, Ground-level Ozone CWS Measure

Explanatory Variables	O3: 1984-2010 (1)	O3: 1984-2010 (2)	O3: 2001-2009 (1)	O3: 2001-2009 (2)	O3: 2001-2009 (1)	O3: 2001-2009 (2)
GDP per capita, y_{jt}	-0.037	**0.857**[a]	**-0.275**[a]	**0.486**[a]	**-0.503**[a]	**0.385**[a]
	(0.066)	(0.200)	(0.064)	(0.105)	(0.118)	(0.145)
Services-to-Goods Ratio, c_{kt}	**-5.073**[a]	**-1.647**[d]	**-8.98**[a]	**-5.389**[a]	**-9.19**[a]	**-5.276**[a]
	(0.609)	(1.11)	(1.03)	(1.17)	(0.021)	(0.016)
Environment Spending per capita, e_{kt}	-	-	-	-	**0.076**[a]	**0.029**[c]
					(0.021)	(0.016)
Linear trend of year fixed effects	-	**-0.645**[a]	-	**-1.68**[a]	-	**-1.65**[a]
		(0.104)		(0.445)		(0.435)
F Statistic	87[a]	37.4[a]	87.7[a]	35.6[a]	65[a]	24.8[a]
Degrees of Freedom	3434	3408	727	719	726	718
	n=288, T_i=2-27, N=3722		n=113, T_i=2-9, N=842		n=113, T_i=2-9, N=842	

Notes: Results are for regressions with annual 4th highest daily maximum 8-hour moving average concentrations of ground-level ozone (O3) as the dependent variable; the measurement used to assess compliance with the Canada-Wide Standard (CWS) for ozone. The explanatory variables are (y) GDP per capita (at the provincial level for the 1984-2010 regressions, and at the Census Metropolitan Area level for the 2001-2009 regressions), the Service GDP to Goods GDP ratio at the provincial level (c), and environment spending per capita by provincial governments (e). Model (1) refers to a specification with station level fixed effects. Model (2) refers to a specification with station level and year fixed effects. Superscripts a, b, c, and d refer to significance at the 1%, 5%, 10%, and 15% levels respectively. In an effort to be concise, a linear trend coefficient from regressing the estimated time fixed effects from Model (2) on $t \in [1, 26]$ (or $t \in [1, 8]$) is reported rather than reporting each of the estimated year fixed effects. The F Statistic is a test that the coefficients on the explanatory variables are jointly zero. The standard errors are in parentheses and are robust to heteroskedasticity and cross-sectional correlation

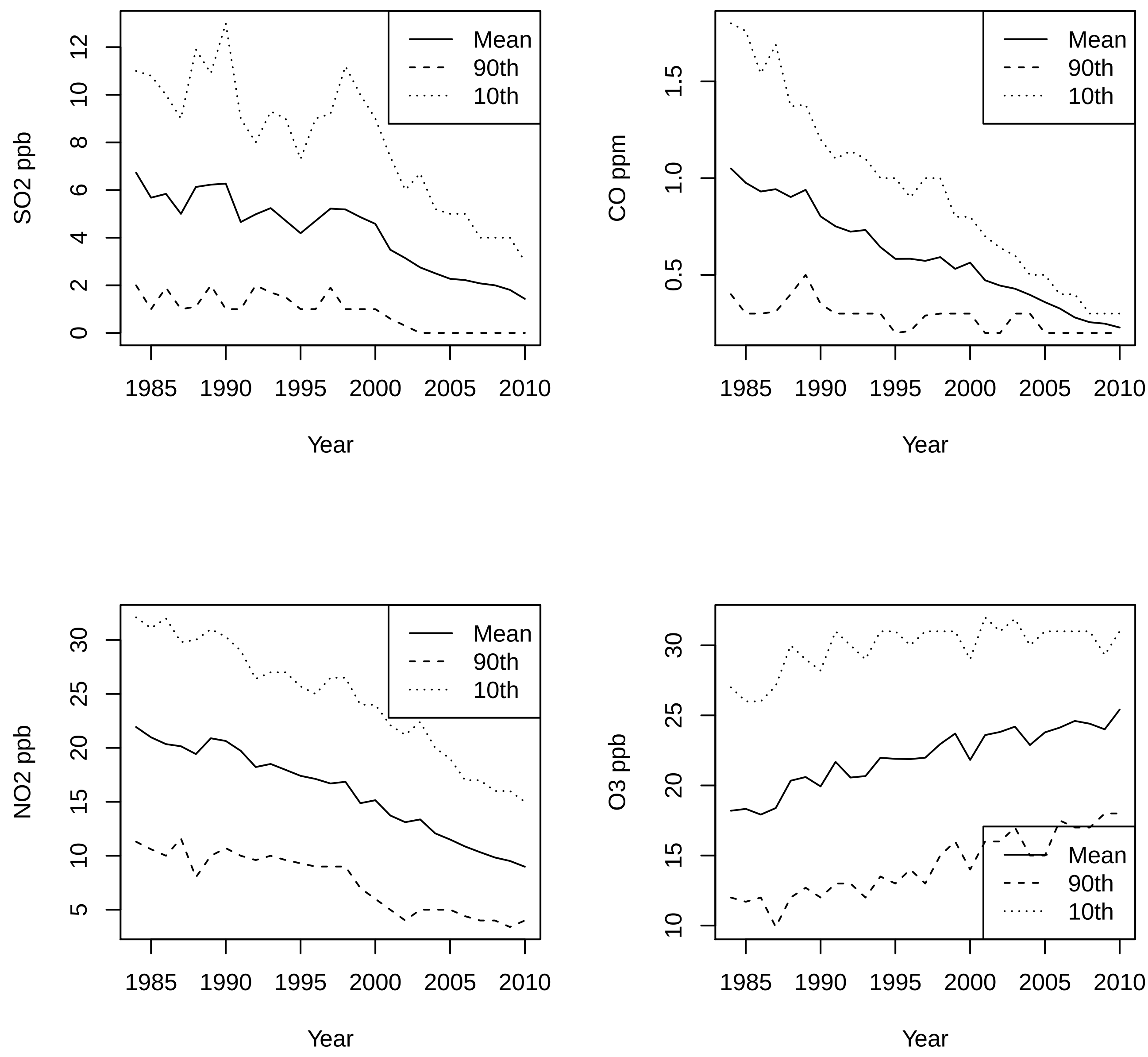

Figure 1: Pollution concentrations, 1984-2010

Notes: Each subfigure plots the average, 90th percentile, 10th percentile of annual average concentrations recorded at monitoring stations across the country over the time period 1984-2010.

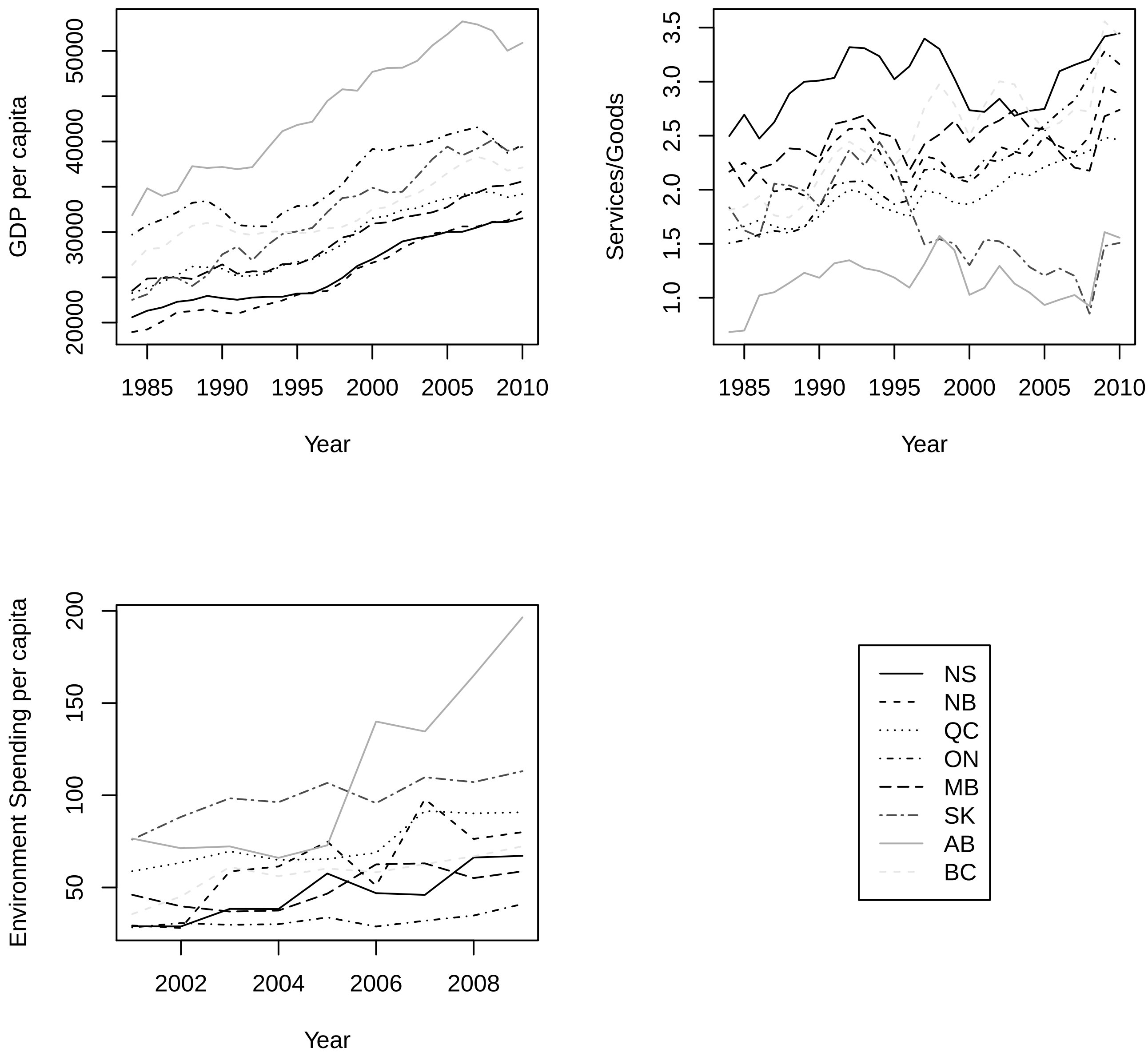

Figure 2: Provincial Macroeconomics Variables

Notes: The sub-figure in the upper left corner plots provincial real GDP per capita between 1984 and 2010 for Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan, Alberta, and British Columbia. The sub-figure in the upper right corner plots the Services GDP to Goods GDP ratio between 1984 and 2010. The remaining sub-figure plots per capita environment spending by provincial governments between 2001 and 2009.

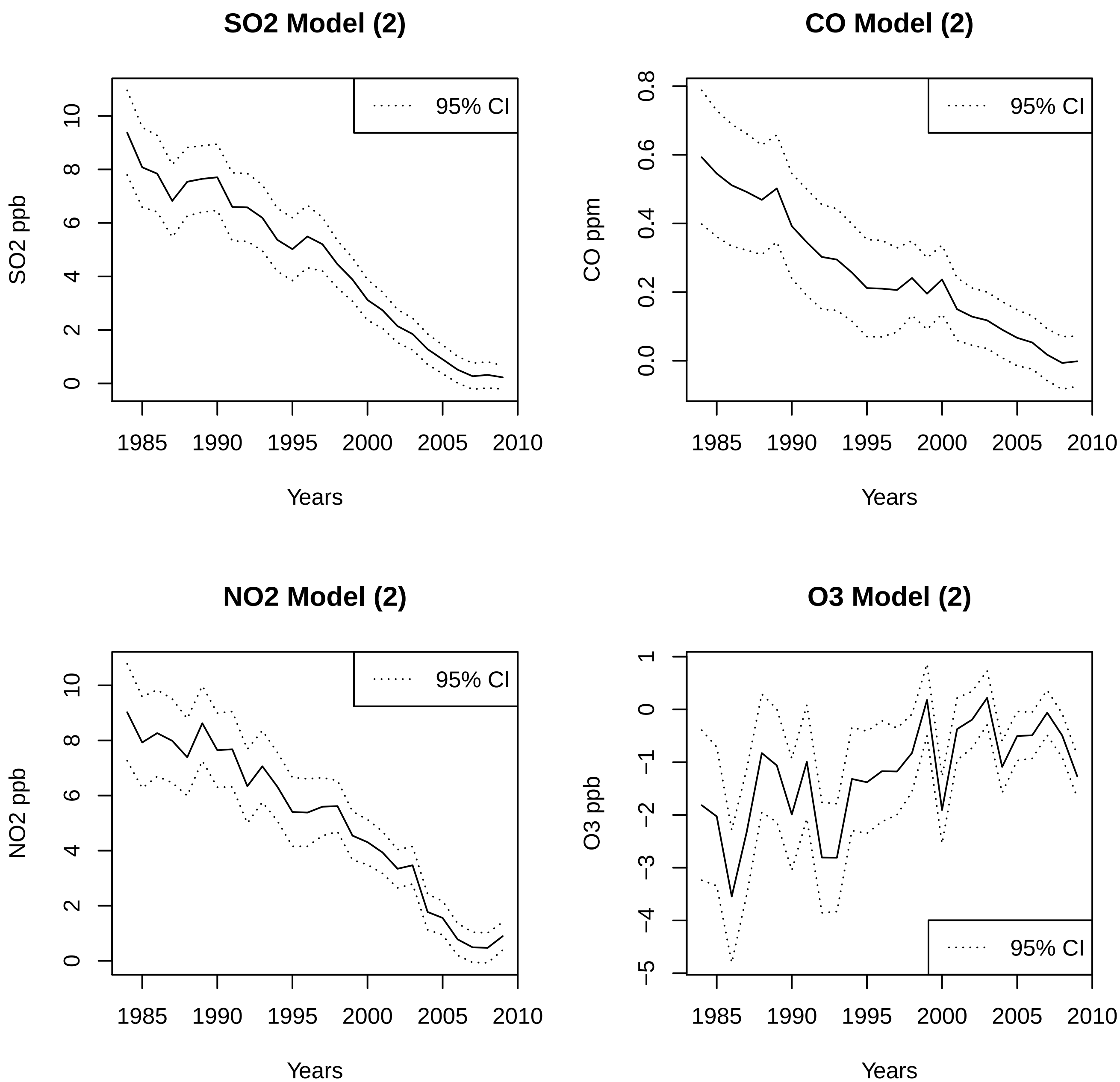

Figure 3: Year Fixed Effects, 1984-2010

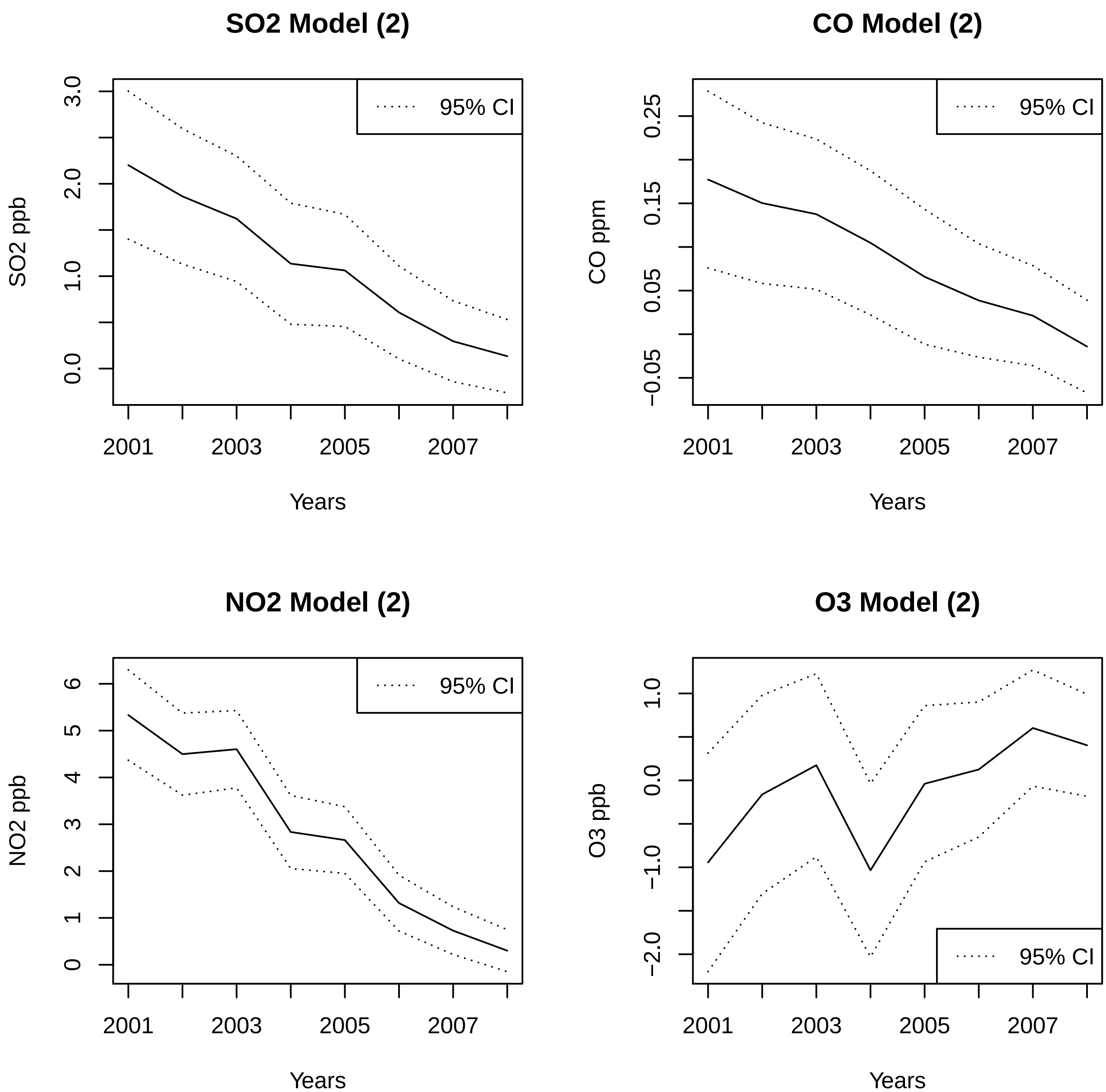

Figure 4: Year Fixed Effects, 2001-2009

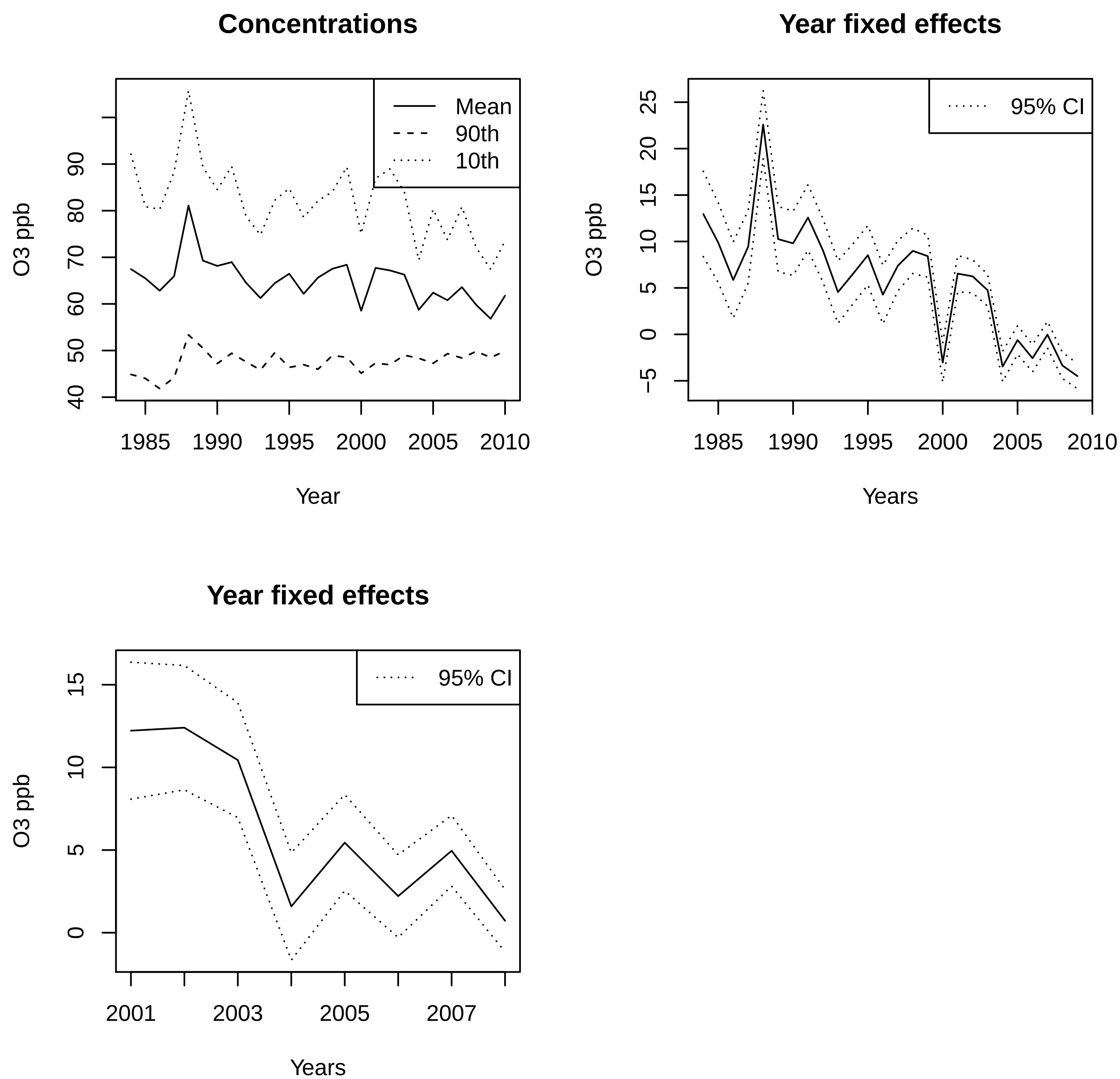

Figure 5: O3 Canada-Wide Standard Measure

Notes: The top-left sub-figure displays the average, 90th percentile, and 10th percentile CWS concentrations of O3 over time from station across the country. The CWS measure is the annual fourth highest daily maximum 8-hour average concentration at a monitoring station. The top-right sub-figure plots the year fixed effects from the Model (2) regression over time for the period 1984-2010. The third figure plots the year fixed effects from the Model (2) regression for the 2001-2009 period when environment spending is included in the model.