ECONOMIC GROWTH AND ENVIRONMENTAL DEGRADATION IN CANADA: AN EMPIRICAL ANALYSIS OF THE ENVIRONMENTAL KUZNETS CURVE

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ABSTRACT

The Environmental Kuznets Curve (EKC) hypothesis postulates an inverted U-shaped relationship between measures of environmental degradation and per capita income. This paper empirically tests the validity of the EKC hypothesis in Canada for per capita emissions of green house gases (GHG), CO_2, NO_X, SO_X, CO, and total particulate matter (TPM) emissions. The regression equations estimated are quadratic and cubic functions of per capita GDP. The type of data used are provincial and territorial level cross-sectional panel data and country level time-series data. The study finds that per capita emissions of GHG and CO exhibit inverted-U relationships with per capita GDP. In contrast, per capita SO_X and TPM emissions follow a U-shape curve, In addition, per capita CO_2 emissions may follow either an inverted U or an N shape curve. Furthermore, this study finds insufficient empirical evidence of an EKC for per capita NO_X emissions.

Keywords: Environmental Kuznets Curve, Canada, greenhouse gas, CO_2, NO_X, SO_X, CO, TPM, time-series, cross-section

DEDICATION

To my parents, sister, and Joey

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1: INTRODUCTION

The Environmental Kuznets curve (EKC) is a hypothesized relationship between various indicators of environmental degradation and per capita income. In the early stages of economic growth, environmental degradation increases, but beyond some critical level of per capita income the trend reverses so that at high enough income levels economic growth leads to environmental improvement. The shape described by the EKC hypothesis is therefore an inverted U-shape. Because of its resemblance to the pattern of income and inequality relationship described by Simon Kuznets (1955)[1], this U shape curve is called the EKC.

The theoretical explanations that support the inverted-U shape EKC ground on three effects[2]: 1) the scale of economic activity; 2) the composition or structure of economic activity; 3) the effect of income on the demand and supply of pollution abatement efforts. Figure 1-1 depicts these three effects. Islam and Vincent (1999) and Panayotou (2003) identified the three distinct forces that affect the movement of the environmental degradation with increase in per capita income.

1. Scale Effect (Figure 1-a): At lower levels of income, an economy shifts from agriculture to industry with a subsequent increase of pollution intensity that causes wastes and emissions of the economic activities to increase. The scale of economy is an increasing function of income.

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[1] The EKC is named after the Nobel Laureate Simon Kuznets who had famously hypothesized an inverted ‘U’ income-inequality relationship (Kuznets, 1955). He suggested that as per capita income increases, income inequality also increases at first, but then, after some turning point, starts declining.

[2] An alternative explanation for the EKC hypothesis is from the perspective of international trade. The downward sloping portion of the environment and economic growth may be facilitated by advanced economies exporting their pollution intensive production processes to less-developed countries (Suri and Chapman, 1998).

2. Composition Effect (Figure 1-b): As industry structure progresses further, from heavy energy-intensive industry to service and technology-intensive industries, pollution falls as income grows. In addition, advances in technology make it possible to replace some of the heavily polluting processes with cleaner ones. Hence, the composition effect is probably an inverted- U shape curve.

3. Abatement Effect (Figure 1-c): As an economy grows to a sufficiently high level of per capita income, people tend to have greater preference for cleaner environment. As well as a series of issued and implemented environmental regulations leads to lowering of environmental pollution. As such, pollution is a decreasing function of income.

The existence of the EKC hypothesis has been shown through empirical studies since the middle of 1990's. An empirical approach by Grossman and Krueger (1995) during that period of time popularized EKC studies. They regressed data on ambient air and water quality in cities worldwide on a polynomial function of per capita GDP. They found that economic growth brought an increase in pollution until a certain point where the pollution started to decrease with economic growth, as reflected an inverted-U shape curve known as the EKC. Other early leading EKC studies also confirmed the EKC relationship for some indicators of the environmental performance such as Krueger (1991), Safik and Bandyopadhyay (1992) and Selden and Song (1994).

A large number of researchers have since carried out the empirical tests of this relationship. In many cases, the level of environmental degradation, often a type of pollutant, measured in emissions per capita is assumed to be adequately described by a quadratic or a cubic polynomial function of per-capita income. This functional form is empirically tested for whether there would be a decline in environmental degradation for income levels higher than a particular threshold. Most studies are based on multi-countries analysis, which mainly adopt panel data approach. The multi-country analysis assumes that all countries whether underdeveloped, developing or developed follow the same emissions-income path. This assumption may not be valid and may lead to an incorrect country specific income-emission relationship. This is due to the differences in income levels among countries as well as the differences in their economic and political structures, regulations toward the environment, etc

Recently, due to these differences, the single country analyses of an EKC have been gaining increasing recognition. Halicioglu (2008), Cialani (2007), Roca, Padilla, Farré, & Galletto (2001) , and de Bruyn, van den Bergh, & den Opschoor (1998) used individual country's emissions data to test if the EKC hypothesis is supported within a specific country. Additionally, Vincent (1997) claimed, "the EKC that emerges in the cross-section analysis may simply reflect the juxtaposition of a positive relationship between pollution and income in developing countries with a fundamentally different, negative one in developed countries, not a single relationship that applies to both categories of countries". For this reason, he argued that the cross-country analysis of the EKC was just a statistical artifact and should be abandoned. Furthermore, Stern, Common, & and Barbier (1994) stated, "more could be learnt from examining the experiences of individual countries at varying levels of development as they develop over time". All of these researches have given rise to a new perspective of the EKC analysis based on an individual country.

The purpose of this paper is to develop a framework for examining the environmental degradation – income relationship from Canadian perspective. Using the most recent data sets available on the Canadian emissions for various airborne pollutants, GHG, CO_2, $NO_{X,}$ SO_X, CO and TPM, this paper aims to test the applicability of the EKC in Canada. More specifically, I aim to address the following questions for each pollutant: i) is there an inverted-U relationship between environmental degradation and income? ii) if so, at what income level does environmental degradation start declining? The results of the study may have policy implications for Canadian sustainable environmental policies. If the inverted U or an EKC relationship is found to exist, then economic growth could be one of the solutions rather than one of the causes of environmental problems. In other words, an environmentally sustainable development could be achieved congruently with more economic growth resulting in higher per capita GDP and decreasing pollution.

2: A REVIEW OF EKC LITERATURE

In this section, I review some of the leading EKC literature with an attention to the existence of an EKC and the estimated turning points where they exist in these studies.

2.1 Multi-country Analysis

Grossman and Krueger (1995) estimated EKCs for three air quality variables, SO_2, smoke and heavy particles[3] (and several other indicators relating to water quality as well). These data refer to measurements of ambient air quality of many countries during the period of 1977-1988[4]. The regression model employed is a cubic function of per capita GDP. The explanatory variables included were per capita GDP, site-related variables, a time trend, and a trade intensity variable, and the population density of each city. They found that some air and water quality measure appears to improve from economic growth once some critical level of income is reached. The turning points in these inverted U shape relationships varied by pollutants, but in most cases they occurred at an income of less than $8,000 (in 1985 dollars). Namely, the turning points for SO_2 and smoke were found to exist at around $4,053 and $6,151 respectively; and no turning point for heavy particles exists.

Shafik and Bandyopadhyay (1992) estimated EKC's for ten different indicators of environmental degradation. The indicators were lack of clean water, lack of urban sanitation, ambient levels of suspended particulate matter, ambient sulphur oxides, change in forest area, the annual rate of deforestation, dissolved oxygen in rivers, fecal coliforms in rivers, municipal waste per capita, and carbon emissions per capita. The

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[3] Grossman and Krueger divided the sample for suspended particle matters (SPM) into two subsamples, one for "heavy particles" and the other for "smoke".

[4] The sample sizes vary by pollution indicator.

sample included observations of 149 countries over the period of 1960-90. The study used three different functional forms: log-linear, quadratic and cubic polynomial in GDP per capita with a time trend. Of the ten environmental indicators, the two air pollutants, suspended particulate matter and sulphur oxides, conformed to the EKC hypothesis with turning points for SPM and sulfur dioxide to be around $ 3,280 and $ 3,670, respectively (all in 1987 U.S. dollars).

Selden and Song (1994) estimated EKC's for four airborne emissions: SO2, NO2, SPM, and CO. The data used were pooled time-series and cross-sectional data measured at the country level in per capita terms. The sample covered 30 countries from the years1973 to 1984. They estimated a model with a quadratic income, and country specific effect model including a population density variable. Panel data analysis with cross section, fixed and random effects confirmed the validity of the EKC hypothesis that pollution could fall to zero at sufficiently high levels of income. The results of the analysis generally supported the inverted U hypothesis. The estimated turning points are for SO_2 \$8,700 for NO_2 \$11,200 for SPM \$10,300 and for CO \$5,600 (all in 1985 U.S. dollars).

2.2 Single-country Analysis

Taking into account the fact that it may not be right to treat developing and developed countries in the same way, a single country analysis of EKC has been gaining an increasing attention in EKC literature. Especially, two studies looked at the EKC relationship in Canada. First, He and Richard (2009) examined the CO_2 emissions in Canada with the time series emissions data over the years from 1948 to 2004. They modified the basic polynomial EKC models to use models that are more flexible namely, semi-parametric and flexible nonlinear parametric models. Results obtained from parametric cubic models were found to be somewhat ambiguous though they indicated that there probably was no EKC relationship. Moreover, there was no evidence found for an EKC using the flexible nonlinear parametric models.

Second, Lantz and Feng (2006) also examined the applicability of the EKC relationship between per capita GDP and per capita CO_2 emissions to Canada. They tested two versions of a quadratic model specification, one with and one without the additional variables - population density and technology. The data set used contained a five-region provincial panel data set of per capita CO_2 emissions from the years of 1970 to 2000. Their findings contrasted the known EKC relationship in that the estimated coefficients of the two versions supported a U shape relationship rather than an inverted U shape. However, the estimates were not strong enough to conclude that the CO_2 emissions follow a U shape curve.

De Bruyn *et al.* (1998) took a different approach to a common polynomial specification of an EKC. They constructed a dynamic model incorporating technological and structural change, and energy intensity as well as level of GDP. The three types of emissions (CO2, NOX, and SO2) in four OECD countries (Netherlands, West Germany, UK and USA) were tested with the annual data of 34 years between the years of 1960 and 1993 by each country. The estimation result of their model found that the economic growth had a direct positive influence on emissions in all cases except for SO2 emissions, and the technological and structural changes had a negative impact on the emissions.

Roca *et al*. (2001) examined the validity of the EKC hypothesis for Spain. The authors tested six airborne pollutants, carbon dioxide (CO_2), methane (NH_4), nitrous oxide (N_2O), sulfur dioxide (SO_2), nitrogen oxide (NO_x), and non-methanic volatile organic compounds (NMVOC), using the annual emission data for the each pollutant covering the years 1972 to 1996 for CO2 and 1980 to 1996 for all the other pollutants. The regression equation estimated was a basic cubic function of per capita GDP. The result confirmed the validity of the EKC hypothesis only in the case of SO2 emissions; the SO2 emissions decreased as income increased. However, the authors argued that the decrease in these emissions could have been caused by an unobserved factor - the EU's protocol on sulfur emissions - which targeted SO2 reduction of 30% to 35%. No other pollutants confirmed to the EKC hypothesis that an increase in income led to a decrease in emissions.

Cialani (2007) tested the EKC hypothesis to study the relationship between per capita CO_2 emissions and per capita income over the period from 1861 to 2002 using the time series data in Italy. The authors adopted a cubic specification with a time fixed effect. The findings suggested that there was a positive relationship between economic growth and CO_2 emissions; the typical inverted U shape pattern of EKC was not confirmed. However, they found econometric evidence that by following the trend, the maximum per capita CO_2 emissions would be reached at $29,600 (U.S. dollar).

Halicioglu (2008) examined the dynamic causal relationships between carbon dioxide emissions and income (as well as energy consumption and foreign trade) in the case of Turkey using the time-series data over the period of 1960 to 2005. The study concluded that there is not enough evidence to support the existence of an EKC for Turkey. He reported that the elasticity of CO_2 emissions with respect to income in the long-run was greater than one indicating that 1 per cent increase in income was associated with a greater than 1 per cent increase in CO_2 emissions.

The two different groups (multi-country and single country) of the EKC literature reviewed in this section led to somewhat similar outcomes about the EKC hypothesis within each group but to total contrast when compared to each other. The multi-country analyses generally conformed to the EKC and the turning points seemed to have passed at low levels of income of below $10,000. Most of the single country analyses, however found only a positive relationship between emissions and income, therefore, not supporting the EKC hypothesis. Table 2-1 presents a summary of the estimation results for the single country analyses reviewed above.

3: PANEL DATA ANALYSIS OF CANADIAN GREEN HOUSE GAS EMISSIONS

3.1 Data Sources and Description

To examine the empirical EKC analysis for Canada, I use the provincial and territorial panel data on annual total Canadian GHG emissions from 1990 to 2008. These data are collected from the Environment Canada's Greenhouse Gas Inventory[5]. It reports GHG emissions data as CO2 emission equivalents at the national and at the provincial and territorial levels. The descriptive statistics of this variable are provided in Table 3-1. According to the 2008 National Inventory Report[6], since 1990, the overall total greenhouse gas emissions have risen by 24%, however, the rate of increase in emissions has been declining. The provincial/territorial GDP data are collected from the Statistics Canada (CANSIM Table 384-0002[7]). All dollar amounts recorded in this study are in 2002 constant prices. The regional population data collected from the Statistics Canada (CANSIM Table 051-0001[8])

Figure 3-1 presents the annual provincial/territorial per-capita GHG emissions trend from 1990 to 2008. It shows that the regional emission plots are rather similar across the regions except for Alberta and Saskatchewan. These two provinces' per capita emissions are notably higher than that of the rest of the regions. Alberta's per-capita emissions look steadily high at around 70 metric tonnes per person. Saskatchewan's emissions have kept increasing and the province ranked as having the highest GHG emissions per capita in 2008. The differences in the emissions trends may result from several factors including differences in the nature of manufacturing activities (some

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[5] http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1 (last accessed Sept. 27, 2010)

[6] http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=0590640B-1 (last accessed Sept. 27, 2010)

[7] SOURCE: Statistics Canada, CANSIM 384-0002 - Gross domestic product (GDP), expenditure-based, provincial economic accounts, annual (dollars); Note: Dollar amounts in constant 2002 prices.

[8] SOURCE: Statistics Canada, CANSIM Table 051-0001, Estimates of population, by age group and sex for July 1, Canada, provinces and territories, annual (persons), 1971 to 2009

provinces have significant fossil fuel industries), in energy generating technologies (some provinces rely on hydropower, others on coal), and in population growth in each region.

As shown in Figure 3-2, in general, the patterns of GDP per-capita growth follow an upward trend in all the regions with Northwest Territories and Nunavut, Newfoundland and Labrador, Saskatchewan, and Alberta regions leading the rest of the regions in percentage growth over the period at 104%, 88%, 50%and 40% respectively.

3.1.1 Graphical Representation of GHG Emissions and GDP

Each province's graphical relationship of its emissions per capita and GDP per capita are presented in Figures 3-3 to 3-6. The horizontal axis represents the economic growth measured in per capita GDP and the vertical axis represents the level of environmental degradation measured in per capita GHG emissions. Out of the 12 regions, the presumed relationship of an inverted U EKC seems to exist in the five regions, namely Quebec, Saskatchewan, Alberta, Northwest Territories and Nunavut, Yukon. Each of these regions seems to have its own estimated turning point.

3.2 Econometric Methods

The goal is to empirically test for the existence of the EKC relationship between province/territory-level of per capita GHG emissions and per capita GDP. To maintain consistency with existing EKC studies, I employ the basic polynomial specifications of per capita emissions as a function of per capita GDP. The quadratic and cubic regression specifications take the following forms:

$$GHG_{it} = b_0 + b_1 y_{it} + b_2 \, {y_{it}}^2 + a_i + e_{it} \qquad \text{(Equation 1)}$$

$$GHG_{it} = b_0 + b_1 y_{it} + b_2 \, {y_{it}}^2 + b_3 \, {y_{it}}^3 + a_i + e_{it} \qquad \text{(Equation 2)}$$

, where *i* denotes the province, and *t* denotes the year, GHG_{it} represents per-capita GHG emissions in the region i in year t, y_{it} represents per capita GDP, a_i is a provincial or territorial dummy variable that captures all unobserved, time-constant factors that affect. e_{it} is an error term often called idiosyncratic error. The bi's are parameters to be estimated. An EKC relationship can be said to exist if $\widehat{b_1}$ is significantly positive, $\widehat{b_2}$ is significantly negative, and $\widehat{b_3}$ is zero for the cubic model. That is, $\widehat{b_1} > 0$, $\widehat{b_2} < 0$, and $\widehat{b_3} = 0$. Additionally, there is a special case for the cubic model of which it can be said to have an EKC. When $\widehat{b_3} < 0$ in the model, the emissions path is an inverted N shape curve. If the range of per capita GDP lies beyond the first half of this curve, then the emissions path for this range of per capita GDP is an inverted U shape.

Referring to Wooldridge (2003)'s panel data methods, the type of data set used in this study is a panel data set which has both a cross-sectional dimension and a time series dimension of annual provincial emissions data in per capita terms from the years 1990 to 2008. For an econometric analysis of such a panel data set, each observation may not be independently distributed over time. For example, unobserved factors such as climate, geography, industry structure, and government policies that affect per capita GHG emissions in a year in a province could also affect the emissions in the subsequent year in that province. All these factors are hard to control for and the regression without these factors is likely to suffer from omitted variable problems. In using panel data, there is a common way to view these time constant unobserved factors affecting the dependant variables as consisting of two types: those that are constant and those that vary over time. Therefore, I include the provincial/territorial unobserved factor, a_i, into the regression equation (1) and (2) to account for all these factors affecting per capita GHG emissions that do not change over time. The e_{it} term is the time varying error term that represents the unobserved factors that change over time.

One way of estimating the parameters of interest is to pool all the regions and use OLS estimation. However each province or territory may have different industry structures, population growth, policy toward environment, etc. that contribute to their per capita GHG emissions. If such regional specific factors are correlated with per capita GDP even if per capita GDP is uncorrelated with e_{it}, the OLS estimators will be inconsistent. For example, an expansion in Alberta's oil industry may cause the province's per capita GDP and per capita GHG emissions to grow. To account for the possible unobserved factors in the model, I will also perform both fixed effects and random effects estimation. Moreover, to account for possible autocorrelation within each province, robust standard errors will be computed to allow the cluster correlation.

The fixed effects model assumes for arbitrary correlation between the unobserved effect a_i and the explanatory variables y_i's in any time period and uses a transformation[9] to remove any time constant unobserved effects prior to OLS estimation. The model allows for a separate intercept for each province and permits cross-provincial differences. As the data used in this study are data on provinces, it may make sense to think that the regions do not share the same intercept.

Along with the fixed effects model, a random effects model is also applied to the panel data set. When the unobserved factors are thought to be independent of all explanatory variables in all time periods, the random effects estimator is more appropriate than the fixed effects estimators. In addition, because the term a_i is in the composite error term in each period, the error terms are seriall correlated.

In addition to estimating fixed effects and random effects estimators of the parameters, I perform several empirical tests to choose an appropriate estimator for the model. In order to choose between the pooled OLS and the fixed effects model, an F-test is performed under the null hypothesis that all regional specific intercepts are equal. If the null is accepted, the pooled OLS is the appropriate estimation method to employ, and if not, I re-estimate the model with fixed effects. To check for the validity of the random effects in the model I use the Breusch and Pagan test. The null hypothesis of the random group effect model is that variances of groups are zero. If the null hypothesis is not rejected, the pooled OLS regression model is more appropriate, and if the null is rejected, random effects are present in the model. Finally, a Hausman test is used to ascertain whether fixed effects or random effects estimation is preferred. The test compares the

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[9] The fixed effect transformation (or within transformation) removes the provincial/terriitorial effect αi by subtracting the within-provincial/territorial average of each variable in the model equations (equation 1 and 2) so that OLS estimation can be applied to the transformed time-demeaned data. (Wooldridge 2003)

fixed versus random effects under the null hypothesis that the individual effects are uncorrelated with the other regressors in the model and if the null is rejected, the fixed-effects model is superior to the random-effects model.

3.3 Estimation Results

The quadratic estimation results of the regression equation (1) and equation (2) are presented in Table 3-2. The first column shows the pooled OLS results and all the coefficient estimates are statistically significant at 1% and their signs are what we expect to see of an EKC.

The F-test and the Breusch-Pagan Lagrangian multiplier test show that the fixed effects and the random effects model are more efficient estimators than the pooled OLS for both quadratic and cubic specifications. The F-test for fixed effects model clearly rejects the null hypothesis of homogeneous cross-sections suggesting that there are statistically significant regional fixed effects in the model. Also the Breusch-Pagan Lagrangian multiplier test for random effects rejects the null hypothesis of no correlation in between the regional fixed effects and the per-capita GDP term in favour of the random effects.

Finally, in choosing between the fixed effects and the random effects estimation, the Hausman test is performed. The test statistic fails to reject the null hypothesis of no correlation between the regressors and the provincial/territorial effects in both quadratic and cubic models. Hence the random effects estimation is chosen as the most appropriate method to be adapted to the model.

In the column 2 and 3 of Table 3-2, I report the fixed effects and the random effects estimators of the quadratic model. The coefficient estimates are almost identical for the two estimators. Both parameters $\widehat{b_1}$ and $\widehat{b_2}$ are statistically significant at high level of significance and have expected signs of an EKC. Thus, there appears to be a sufficient evidence to conclude that an EKC exists for the GHG emissions. The turning point is estimated to be \$48,877[10] for the fixed effects model and \$48,673 for the random effects model.

The regression results of the cubic model are presented in Table 3-3. As in the quadratic model, the F-test for fixed effects and the Breusch-Pagan Lagrangian multiplier test for random effects reject the null the hypothesis in favour of fixed effects and random effects over the pooled OLS. The signs of $\widehat{b_1}$, $\widehat{b_2}$ and $\widehat{b_3}$ for the fixed and random effects are positive, negative and negative respectively. Hence, the emissions-income path is an inverted N-shaped pattern possibly yielding two turning points[11]. First, the per capita emissions decrease, and then increase once the first thresholds per capita GDP is reached, and then finally begin decreasing again beyond the second turning point. In the case where the emissions income path is an inverted N, if the range per capita GDP lies on the right half of the graph, it can be said that an EKC exits. However, unlike the quadratic model, none of the estimators are statistically significant at standard levels and therefore the result is a strong enough to conclude that the emissions path is an inverted N-shaped relationship in relation to the per capita GDP. Therefore, the relationship between the per capita GDP and per capita GHG emissions are better explained with the quadratic specification than the cubic specification.

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[10] If $b_2^2-3b_1b_3>0$, then the cubic function has a local maximum and a local minimum.

[11] The two turning points of the cubic representation are: $Y_t^* = \frac{-b_2 \pm \sqrt{{b_2}^2 - 3b_3b_1}}{3b_3}$

4: TIME-SERIES ANALYSIS OF VARIOUS AIRBORNE POLLUTANTS

Because the Canadian provincial and territorial level emissions data are only available for the total GHG emissions, in this section, I conduct a time-series analysis using the annual Canadian level data of the following six airborne pollutants: GHG, CO_2, NO_X, SO_X, CO and TPM. These pollutants have been commonly examined by numerous EKC literatures because they are all considered to have important adverse health consequences.

4.1 Data Sources and Description

The World Bank's World Development Indicator (WDI) database reports the data on the Canadian annual per capita carbon dioxide (CO_2) emissions[12] from the year 1961 to 2006 measured in metric tonnes per capita. The source of annual total Canadian GHG emissions data is the same as in the section 3. The database contains the years from 1990 to 2008. The Canadian annual total emissions data on the four other pollutants[13] (NO_X, SO_X, TPM, and CO) are obtained from the Environment Canada's Pollution Data Library[14] of the National Pollutant Release Inventory (NPRI). The most recent data set

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[12] Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. Source: Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States. (World Development Indicator (WDI) database)

[13] In addition to the four pollutants (NO_X, SO_X, CO, and TPM) that are examined in the section 4, the NPRI's database reports emissions data on four more pollutants such as PM10, PM25, VOC, and NH3. For this analysis, these pollutants are not included because the leading EKC literatures reviewed in the section 2 commonly examined NO_X, SO_X, CO, and TPM only.

[14] National Air Pollutant Emission Trends in MS Excel Format, Criteria Air Contaminants (1985-2007) , http://www.ec.gc.ca/inrp-npri/default.asp?lang=en&n=0EC58C98 (last accessed Sept. 27, 2010)

released by NPRI has the record of emissions from the year 1985 to 2007. The descriptive statistics of these pollutant variables are presented in Table 4-1.

In addition to these emissions data, the annual total GDP data is from CANSIM Table 380-0002[15] and the annual population data is from CANSIM 051-0001.

The CO_2 emissions data are available for the longest period of 46 years whereas the GHG data is only available for 19 years and the NO_X, SO_X, TPM, and CO data are available for 23 years. As relatively recent years of data are available for the GHG, NO_X, SO_X, TPM, and CO emissions, only a short-run emissions-GDP relationship can be attained for these pollutants.

4.1.1 Historical Trend of Per-capita Emissions

The annual Canadian per-capita carbon dioxide (CO_2) emissions data are plotted in Figure 4-1. Over the 46 years, the per-capita CO_2 emissions have increased by a factor of 1.56. The trend shows that the emissions increase up to early 80's at an average rate of annual 3% increase and it reverses to decrease in emissions to late 80's. According to the Carbon Dioxide Information Analysis Center[16], the continuing growth until 1980 was caused by continuing expansion of natural gas consumption and an upturn in coal consumption. The three main contributors of Canadian CO2 emissions are transportation sector (30.1%), power generation (20.4%), and industrial sector (19.7%) in year 2008[17]

The annual per capita GHG emissions data from the year 1990 to 2008 are plotted in Figure 4-2. It shows that during the recent 19 years, per capita GHG emissions have been steady at levels of 21 to 23 tonnes per person. A report, A Climate Change Plan for

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[15] Sources: Statistics Canada, CANSIM Table 3800002, Gross domestic product (GDP), expenditure-based, quarterly (2002 Constant Prices), (1961-2010)

[16] Carbon Dioxide Information Analysis Center (www.cdiac.ornl.gov)

[17] A Summary of Trends: 1990-2008, http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=0590640B-1(last *accessed Sept. 27, 2010)*

the Purposes of the Kyoto Protocol Implementation Act (2010)[18], by Environment states that Canada is among the highest in terms of per capita emissions and Canada faces challenges when it comes to making progress on reducing greenhouse gas emissions. Under the terms of the Kyoto Protocol, Canada's target is an average of 6% below 1990 levels over the 2008-2012 period.

Figure 4-3 shows Canadian per-capita emissions of NO_X, SO_X, CO, and TPM. The main source of nitrogen oxides (NO_X) emissions is the combustion of fuels in motor vehicles, residential and commercial furnaces, industrial and electrical-utility boilers and engines, and other equipment. Environment Canada[19] reports that in year 2000 that Canada's largest contributor of NO_X emissions was the transportation sector, which accounted for approximately 60% of emissions. Since 1985, the total emissions had been fairly constant at 2.5 million tonnes until 2000. In 2000, the Canada-US Air Quality Agreement[20] was made and since then Canada has been committed to reduce its annual NO_X emissions by approximately 39% by 2010 from 1990 level. Despite the effort of the agreement, the data in 2008 showed merely an 8 % decrease in the total emissions since1990. However, a larger reduction of 15% was achieved when the emissions were measured in per capita terms due to higher increase in population during the same period.

Sulphur dioxide (SO_X) is generally known as a by-product of industrial processes and burning of fossil fuels. Ore smelting, coal-fired power generators and natural gas processing are the main contributors. During 1985 to 2007, the per capita SO_X emissions have decreased by almost 60% from 0.144 tonnes per person to 0.058 thousand tonnes per person and the total emissions have reduced by 47% from 3.74 million tonnes to 1.97 million tonnes. The reduction may have been achieved through the following environmental programs. According to the Canadian Council of Ministers of the

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[18] A Climate Change Plan for the Purposes of the Kyoto Protocol Implementation Act. http://www.climatechange.gc.ca/Content/4/0/4/4044AEA7-3ED0-4897-A73E-D11C62D954FD/KPIA_2010.pdf. (last accessed Sept. 25, 2010)

[19] Acid Rain, Environment Canada. http://www.ec.gc.ca/air/default.asp?lang=En&n=7E5E9F00 (last accessed Sept. 25, 2010)

[20] Canada-U.S. Air Quality Agreement, Environment Canada, http://www.ec.gc.ca/air/default.asp?lang=En&n=FA26FE79-1(last accessed Sept. 25, 2010)

Environment[21], the Eastern Canada Acid Rain program was initiated in 1985 in order to cap SO_2 emissions in the seven provinces from Manitoba eastward at 2.3 million tonnes by 1994, a 40% reduction from 1980 levels. By 1994, all the seven provinces had achieved or exceeded their targets. In 1998, the provinces, territories and the federal government signed the Canada-Wide Acid Rain Strategy for Post-2000, committing them to further actions to deal with acid rain.

Carbon Monoxide (CO) and Total Particular Matter (TPM) also have some significant impact on human health. The CO can affect healthy individuals, impairing exercise capacity, visual perception, manual dexterity, learning functions, and ability to perform complex tasks. The TPM is linked to aggravated cardiac and respiratory diseases such as asthma, bronchitis and emphysema and to various forms of heart disease. The CO emissions seem to be generally decreeing, and no significant trend seems to be observed for the TPM emissions.

4.1.2 Graphical Representation of Emissions and GDP

Figures 4-4 to 4-9 present curves that describe the shape of the relationship between the per capita emissions and the per capita GDP for each type of pollutants, CO_2, GHG, NO_X, SO_X,, CO, and TPM. The per-capita emissions are plotted against the per capita GDP. The quadratic fit and cubic fit of each plot are provided as well and they are almost identical in all the cases.

Out of all the six pollutants, only GHG emissions seem to follow an inverted U curve with a turning point occurring at about $37,000. The CO_2 emissions curve appears to be better described by the cubic fit than the quadratic fit. This cubic fit describes an N shaped curve. The emissions seems to increase up until the per capita GDP reaches about $25,000 then decrease until the per capita GDP reaches about $35000 and finally increase again after this level of per capita GDP. Each of NO_X, SO_X, and CO emissions figures is a monotonically decreasing curve. This downward sloping pattern may represent the third stage of the EKC, which is the last segment of a full EKC. The TPM emissions exhibit a

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[21] Canadian Council of Ministers of the Environment (CCME). The Canada-Wide Acid Rain Strategy for Post-2000. http://www.ccme.ca/assets/pdf/acid_rain_e.pdf (last accessed Sept. 26, 2010)

U shape curve with the minimum level of per capita emissions occurring at about $35000. The per capita CO_2 and TPM emissions are on the increasing trend with per capita GDP. Before going through thorough empirical analyses and basing on these figures, an inverted-U relationship EKC appears to exist for only per capita GHG emissions.

4.2 Econometric Methods

As in the section 3, the goal is to empirically estimate the relationship between the per capita emissions and the per capita GDP and to test for the existence of an EKC for each pollutant. The quadratic and the cubic specifications of the time series models are as follows:

$$C_t = b_0 + b_1 y_t + b_2 {y_t}^2 + e_t \qquad \text{(Equation 3)}$$

$$C_t = b_0 + b_1 y_t + b_2 {y_t}^2 + b_3 {y_t}^3 + e_t \qquad \text{(Equation 4)}$$

,where C_t represents per capita emissions in year t, y_t represents per capita GDP in year t, and e_t is an error term. The b_i's are the parameters to be estimated. A particular pollutant can be said to exhibit an inverted U or an EKC if $\widehat{b_1} > 0$ and $\widehat{b_2} < 0$ for the quadratic model and if $\widehat{b_1} > 0$, $\widehat{b_2} < 0$ and $\widehat{b_3} = 0$ for the cubic model. There is a special case of the cubic model that exhibits an EKC, where $\widehat{b_3} < 0$, so that the emissions curve is an inverted N shape. If the per capita GDP data lies on the second half of the inverted N curve, the first half of the curve can be ignored and the second half is identical to the inverted U shape.

In time series data, the successive values in the error term are often correlated with one another causing a problem of serial correlation. In the presence of such a correlation, the OLS standard errors may be invalid. So the Durbin-Watson test is performed to detect for AR(1) serial correlation. After applying the test, if the AR(1) serial correlation is found to be present, the equations are re-estimated with the OLS

Newey-West method with a lag of one year to obtain Newey-West standard errors that are heteroskedasticity-and-autocorrelation consistent. Wooldridge (2003) states that the Newey-West procedure has become more popular in recent years because it is intended to provide standard errors that are robust to fairly arbitrary forms of serial correlation and heteroskedasticity. Moreover, the adjusted standard errors are expected to be higher than the usual OLS standard errors when there is serial correlation.

4.3 Estimation Results

The model equations (3) and (4) are estimated with the time-series data on the per capita emissions of CO_2, GHG, NO_X, SO_X, TPM, and CO. The regression results are presented in Table 4-2 to 4-5.

4.3.1 CO_2 Emissions

The regression results of per capita CO_2 emissions are presented in Table 4-2. For both quadratic and cubic specifications, the OLS estimators are all significant at 10% level. However, the Durbin-Watson test on the OLS regression rejects the null hypothesis of no auto-correlation in the error terms at 5% significance level for both quadratic and cubic cases. Thus, these OLS estimates are discarded and the regressions are re-estimated with the OLS regression with Newey-West HAC standard errors option with a lag of one. Both the quadratic and cubic estimators are significant at 1% level. The signs of the quadratic estimators correspond to the signs of an EKC and the turning point level of per capita GDP occurs at $32,051. The cubic estimators describe an N-shape curve that has two turning points of $27,428 and $33,057 and the income levels beyond the second turning point, the emissions are expected to increase. The two specifications give different forecasts about the future trend of the CO_2 emissions. The quadratic specification expects the emissions to decrease as per capita GDP increases while the cubic specification states the opposite. Hence, a future follow up study with more years of data are needed to determine the course of emissions.

The above results contradict the two Canadian EKC studies for CO_2 emissions by Lantz and Feng (2006) and He and Richard (2009) where the authors found no evidence of an EKC. In addition to my study, all the three Canadian studies used the emissions data from the early 1960's or 1970's. However, a direct comparison of the results is not possible due to the differences in the methodologies employed in testing the EKC hypothesis. These opposite results may suggest that a careful attention has to be paid to model specification and to methodology before drawing a conclusion about Canadian per capita CO_2 emissions.

4.3.2 GHG Emissions

Table 4-3 shows the regression results of per capita GHG emissions. The Durbin-Watson test on OLS regressions confirms that there is no auto-correlation in the error terms and as a result, there is no need to correct the OLS standard errors. The coefficient estimators for the quadratic model are significant at 1% level in contrast to cubic models. The positive b_1 and negative b_2 estimators describe an inverted U shape and the turning point is estimated at $36,225. A caveat on the data limitation is worth mentioning here. Since the data only covers a19 year period from 1990 to 2008, the result obtained here only explains a short term relationship and hence it should not be interpreted as Canada having this EKC relationship throughout the economic development in Canada.

4.3.3 NO_X, SO_X, CO, and TPM Emissions

Tables 4-4 to 4-6 present the regression results of the per capita emissions of NO_X, SO_X, CO, and TPM. The Durbin-Watson test on all of these four OLS regressions reveals that for the NO_X and SO_X emissions, the test rejects the null hypothesis of no auto-correlation in the error terms indicating that there exists first-order autocorrelation in the OLS residuals. Therefore, OLS Newey-West method is used to obtain standard errors that are corrected for autocorrelation.

Table 4-3 shows that the coefficient estimators for both quadratic and cubic specification of the NO_X emissions are not significant at standard levels. Therefore, these regression analyses do not support the existence of an EKC for NO_X. Table 4-5 provides the regression results of the SO_X emissions. The coefficient estimators of the quadratic models are more significant than the cubic model and they describe a U shape curve with a turning point level per capita GDP of $38,366. The cubic model is only significant at 15% significance level. Their estimators describe a monotonically decreasing[22] cubic function with no turning points. The OLS regression results of per capita CO and TPM emissions are presented in Table 4-6. These OLS estimations do not suffer from AR(1). Their quadratic estimators are significant at 10% and 5%, respectively although their cubic estimators are not significant. The coefficient estimates on quadratic CO emissions reveal an inverted U curve and a negative estimated turning point. Therefore, it can be inferred that the per capita CO emissions have never been increasing with respect to per capita GDP. The quadratic per capita TPM emissions curve is a U-shaped one, which has a minimum turning point at $31,858.

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[22] The turning points are not available because the shape described by the coefficient estimators is a cubic function that keeps decreasing without critical points. ($b_2^2 - 3b_1b_3 \leq 0$, the cubic is strictly monotonic)

5: CONCLUSIONS

This paper uses the most comprehensive data sets available on Canadian airborne pollution and provides an empirical framework for understanding Canada specific EKC's for five major airborne pollutants: GHG, CO_2, NO_X, SO_X, CO and TPM. Table 5-1 summarizes the results of this study.

For per capita GHG emissions, the empirical analysis of both provincial and territorial panel data and time series data find an EKC relationship however, the turning point for these two different data is different. It is estimated to be \$48,673 in the panel data and \$36,225 in the times series data.

Next for per capita CO_2 emissions, in addition to this study, two other studies, Lantz and Feng (2006) and He and Richard (2009) examined the relationship between Canadian per capita CO_2 emissions and per capita GDP. A direct comparison of these two existing studies and this one is not possible due to the differences in the methodologies employed in testing the EKC hypothesis. Both studies found no evidence of an EKC in the case of CO_2 emissions. On the other hand, this study finds that the per capita CO_2 emissions curve can be either an inverted U that has a turning point at \$32,052 or an N shape one that has two turning points at \$24,657 and at \$32,973. Both quadratic and cubic specifications give highly significant estimators. At income levels beyond \$33,000, the inverted U shape indicates that the emissions are expected to decrease with increase in per capita GDP and the N shape indicates exactly the opposite. Thus, the emissions data for the future years are needed in order to determine which one of the two shapes describe CO_2 emissions and per capita GDP relationship appropriately.
The NO_X regression results are not sufficient to support an EKC relationship. The SO_X regression results reveal that the emission-income relationship of SO_X emissions can be either a quadratic that is a U shape or a cubic that is monotonically decreasing. The

quadratic estimation gives a turning point at $38,366 and the cubic estimation gives monotonically decreasing curve without any turning point.

Next, the regression results of CO emissions show that an EKC exists but the estimated turning point is a negative value. This implies that the increasing segment of its EKC can be ignored. Hence, per capita CO emissions have been negatively related with per capita emissions. Then, per capita TPM emissions results show a U shape curve that meaning the emissions are positively related to per capita GDP at above $31,858.

The current annual Canadian per capita GDP is $38,752 as of year 2010 and this can be used to determine which stage each pollutant currently positions on its own EKC. First, for per capita GHG emissions, two interpretations are possible. The panel data analysis implies that the emissions have not reached the turning point yet and are currently at an increasing stage of the EKC. Alternatively, the time-series analysis suggests that they just have passed the turning point and are at the stage three or at the downward slopping segment of the EKC. Next, for CO emissions, the estimated turning point is negative meaning that the emissions have been decreasing ever since and currently are in the third stage. Lastly, the quadratic CO_2 emissions suggest that the emissions have passed the turning point level of per capita GDP in year 1997 when the per capita GDP was $33,073 and therefore concluding that its emissions lie also in the third stage.

Finally, the results of this study can give policy implications. A special attention needs to be paid to per capita CO_2, SO_X, and TPM emissions because the empirical evidence found in this study supports that they are positively related with the growth of per capita GDP. This emission-income pattern is the opposite of what is known to be an EKC relationship and hence, it signals the need for environmental regulations and enforcement to control for growing emissions of these pollutants.

APPENDIX

Figure 1-1 Three Stages of an EKC

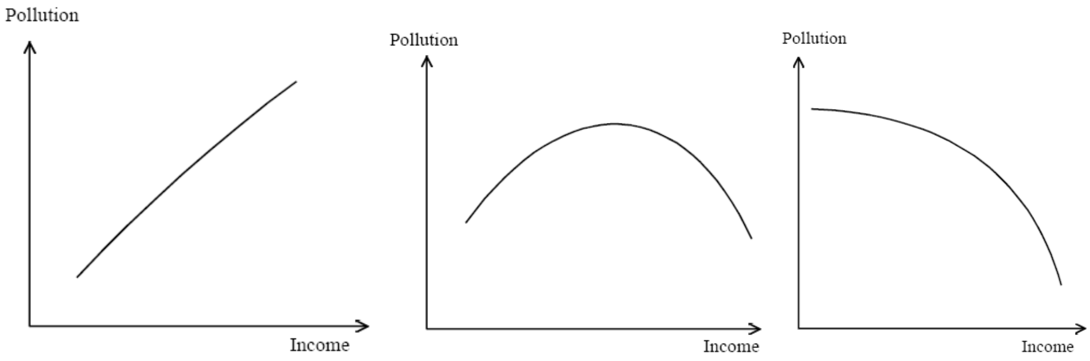

Figure 1-a **Figure 1-b** **Figure 1-c**

Table 2-1 Summary of Single Country EKC Studies

Authors	Data	Methodology	Results
Lantz and Feng (2006)	Canada (five regions), 1970-2000, CO_2, GDP, population, technological change	Panel data analysis, pooled and fixed effects, quadratic specification with and without technology	EKC for CO_2 is not confirmed
He and Richards (2009)	Canada, CO_2, 1948-2004	Parametric Cubic Model	No Evidence of an EKC
de Bruyn et al. (1998)	Netherlands, UK, USA, Western Germany, 1961-1993, CO2, NOx, SO_2, GDP, energy price index	Estimation of a dynamic OLS model	Economic growth and levels of emissions has a positive relationship

Roca et al. (2001)	Spain, 1972-1996 for CO_2 and 1980-1996 for SO_2, CH_4, N_2O, NO_x, NMVOC[23]	Time series model, cubic specification	EKC is found to exist only for SO_2
Cialani (2007)	Italy, 1861-2002, annual frequency, CO2, GDP	Time series model, OLS estimation and index decomposition analysis, linear, quadratic and cubic specifications in logs	No EKC is found. Emissions increase as income increase. Development path has not yet reached the turning point.
Halicoglu (2008)	Turkey, 1960-2005, annual frequency, CO2, GDP, trade openness, energy consumption	Time series model, ARDL[24] co-integration approach, stability tests, Granger causality, quadratic specification	No EKC is found. Emissions elasticity with respect to income is greater than one.

Table 3-1 Descriptive Statistics of GHG Panel Data

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
GHG	228	26.01	19.01	10.46	74.97

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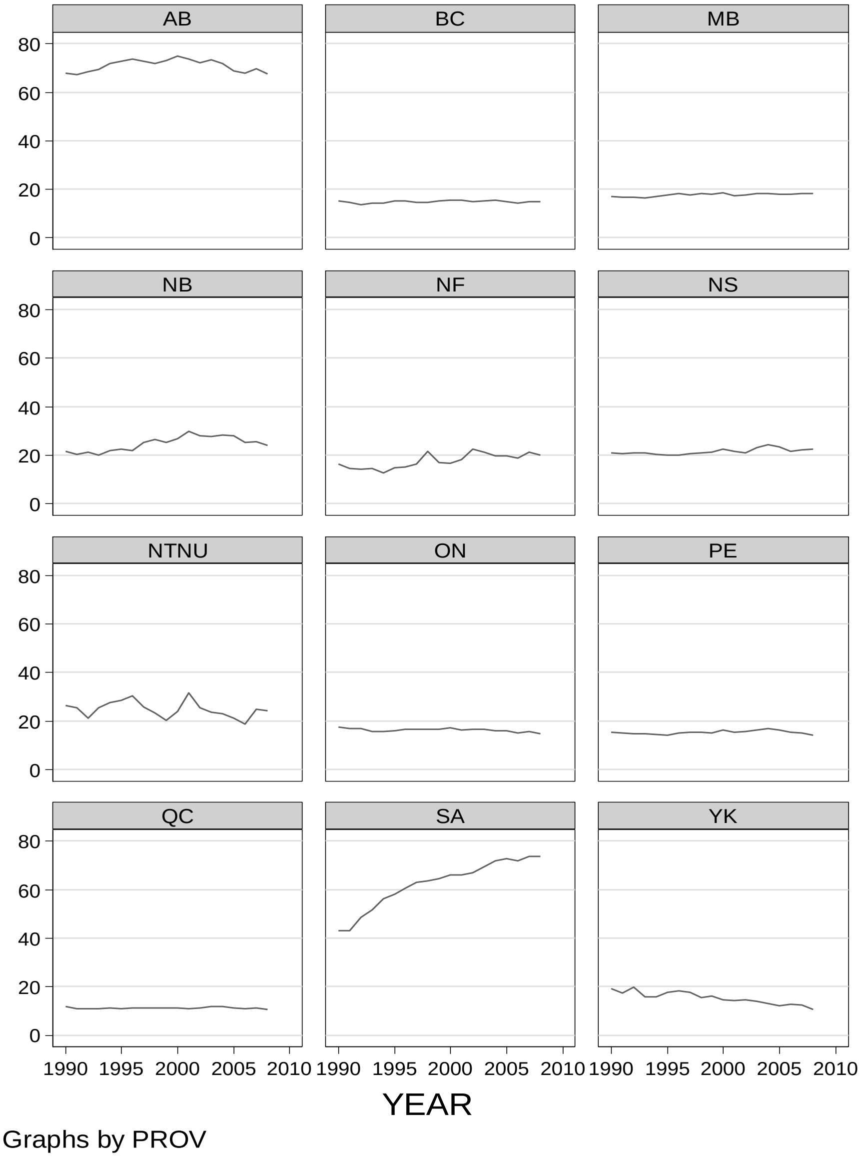
[23] NMVOC: non-methanic volatile organic compounds

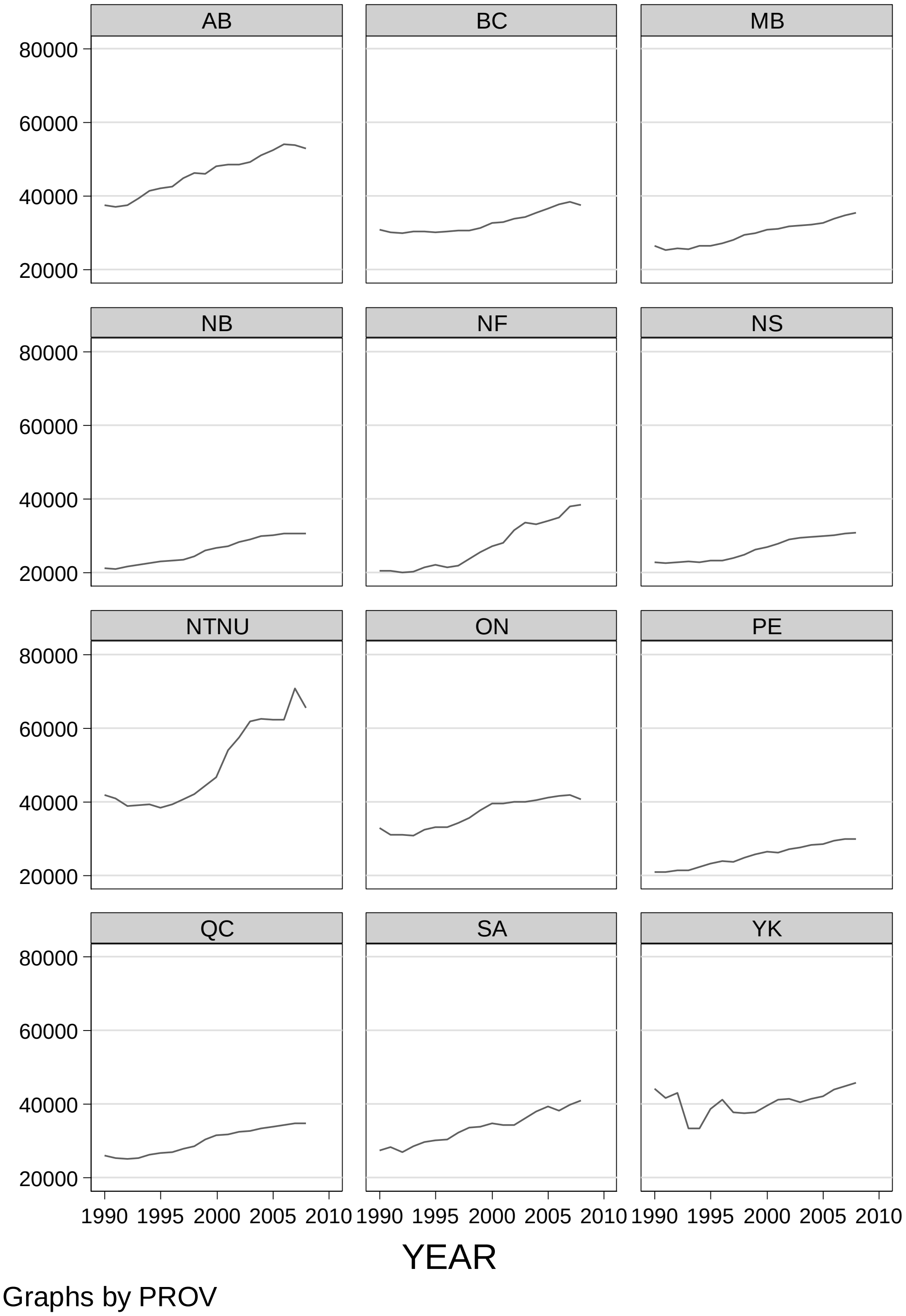
[24] ARDL: Autoregressive Distributed Lag model

Figure 3-1 Annual Provincial/Territorial Per-Capita GHG Emissions Trend



SOURCE: *Environment Canada, Greenhouse Gas Inventory; Statistics Canada, CANSIM Table 051-0001*

Figure 3-2 Annual Provincial/Territorial Per-Capita GDP Trend



***SOURCE**: Statistics Canada, CANSIM 384-0002, CANSIM Table 051-0001*
(Dollar amounts are in 2002 constant prices)

Figure 3-3 Annual GHG emissions/capita and GDP/capita – Newfoundland, Prince Edward Island, Nova Scotia

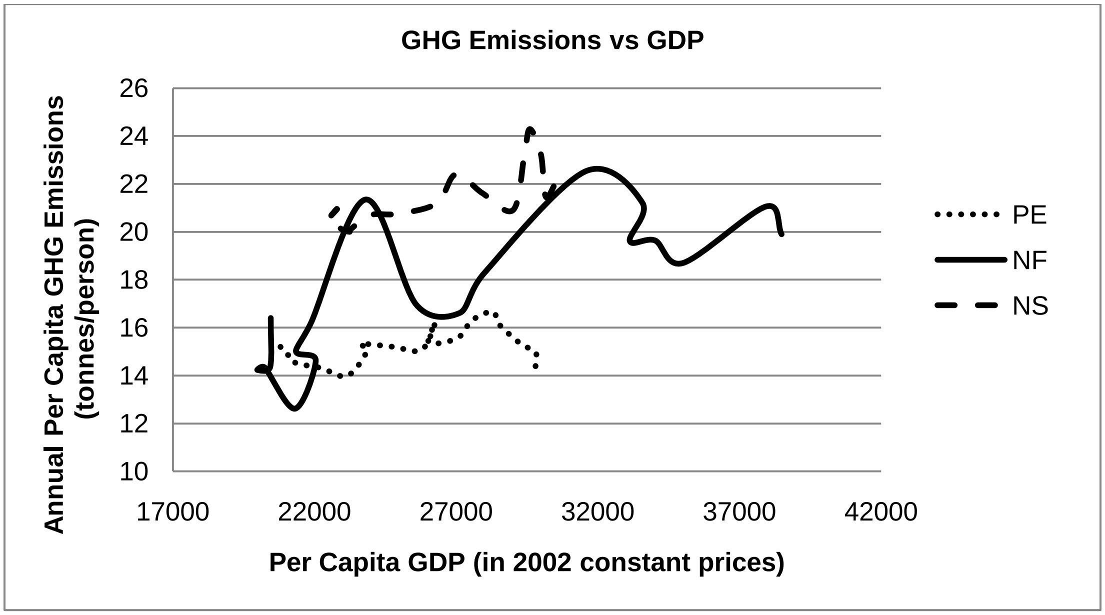


Figure 3-4 Annual GHG emissions/capita and GDP/capita – New Brunswick, Quebec, Ontario

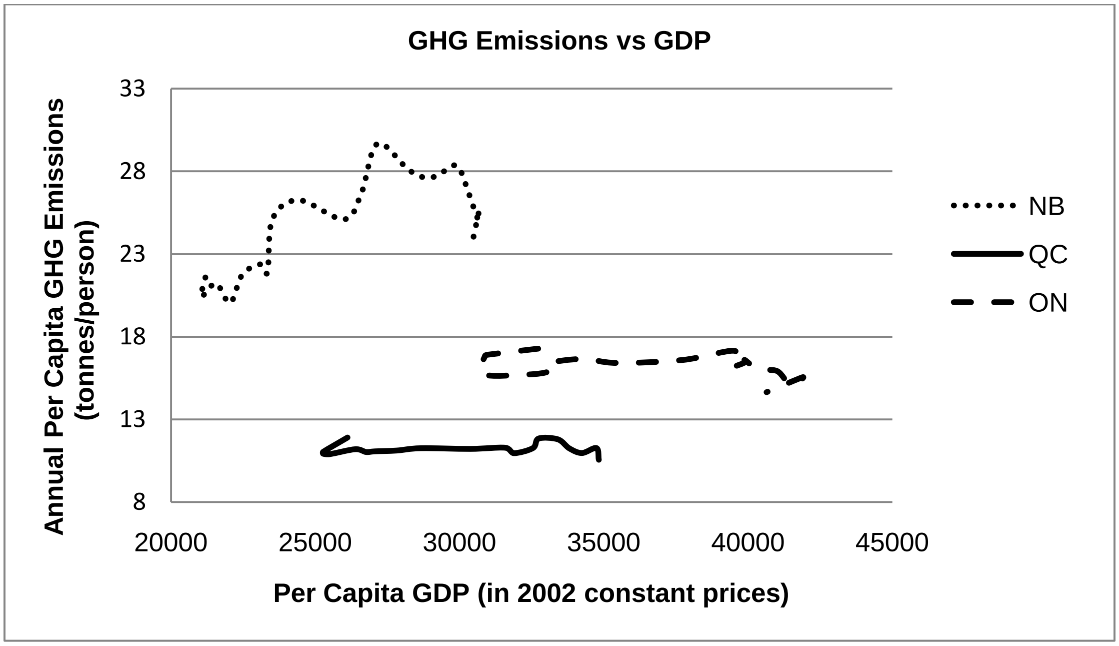


Figure 3-5 Annual GHG emissions/capita and GDP/capita - Manitoba, Saskatchewan, Alberta

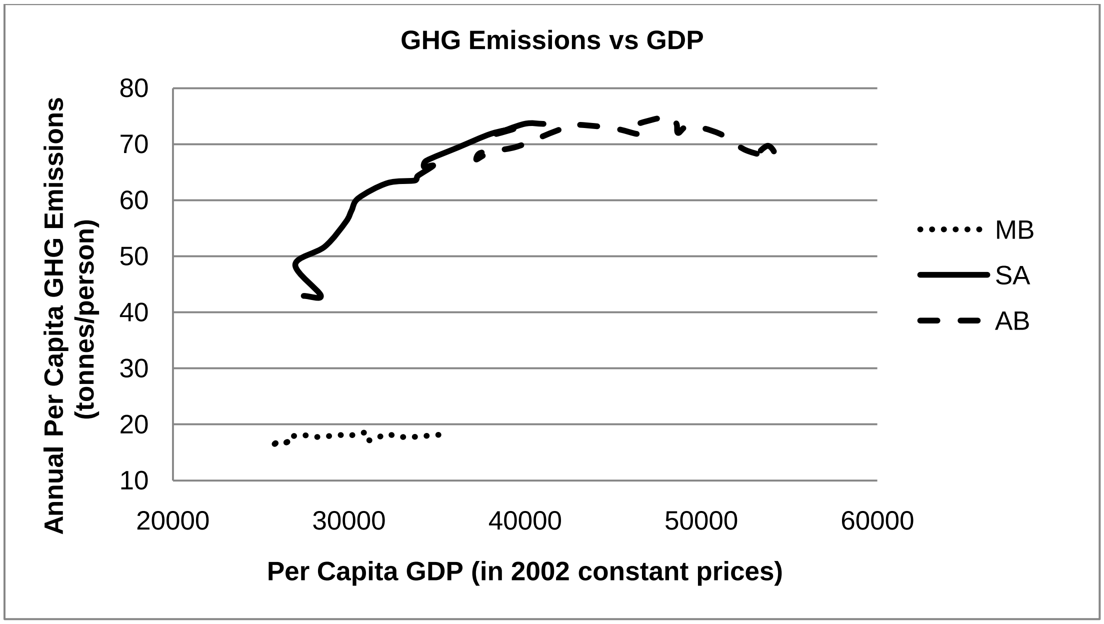


Figure 3-6 Annual GHG emissions/capita and GDP/capita – British Columbia, Yukon, Nunavut and Northwest Territories

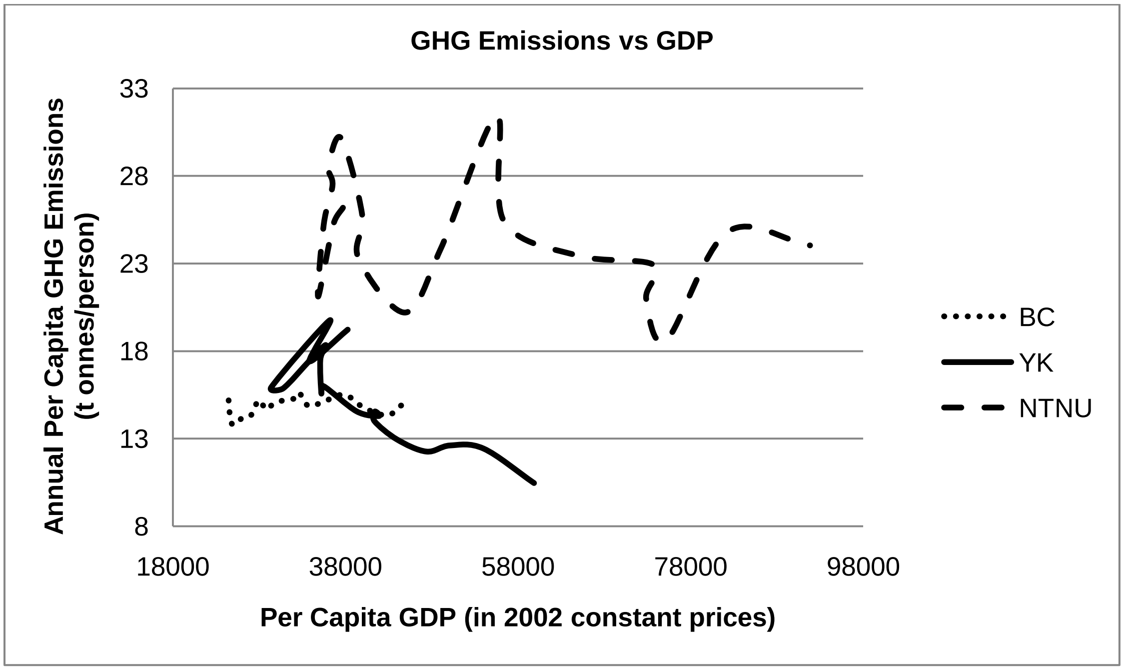


Table 3-2 Quadratic Model Estimation Results of GHG Emissions

Variable	Pooled Cross Sections	Fixed Effect	Random Effect
Constant	-26.12*** (12.99)	2.44 (10.28)	2.31 (7.37)
GDP per capita	0.002245*** (0 .0006903)	0.001114*** (0.0004521)	0.001120*** (0.000453)
$(\text{GDP per capita})^2$	-1.92E-08*** (8.71E-09)	-1.14E-08*** (4.06E-09)	-1.15E-08*** (4.08E-09)
R^2	0.14	0.20	0.21
F-test	-	28.38	-
Breusch and Pagan LM-Test	-	-	57.86
Hausman Test	-	-	0.20
Turning point($)	$58,460	$48,877	$48,673
Sample Size	228	228	228

Note:
- Standard errors in parentheses. Significance levels: *10 percent; ** 5 percent; *** 1 percent
- Dollar amounts in 2002 constant prices

Table 3-3 Cubic Model Estimation Results of GHG Emissions

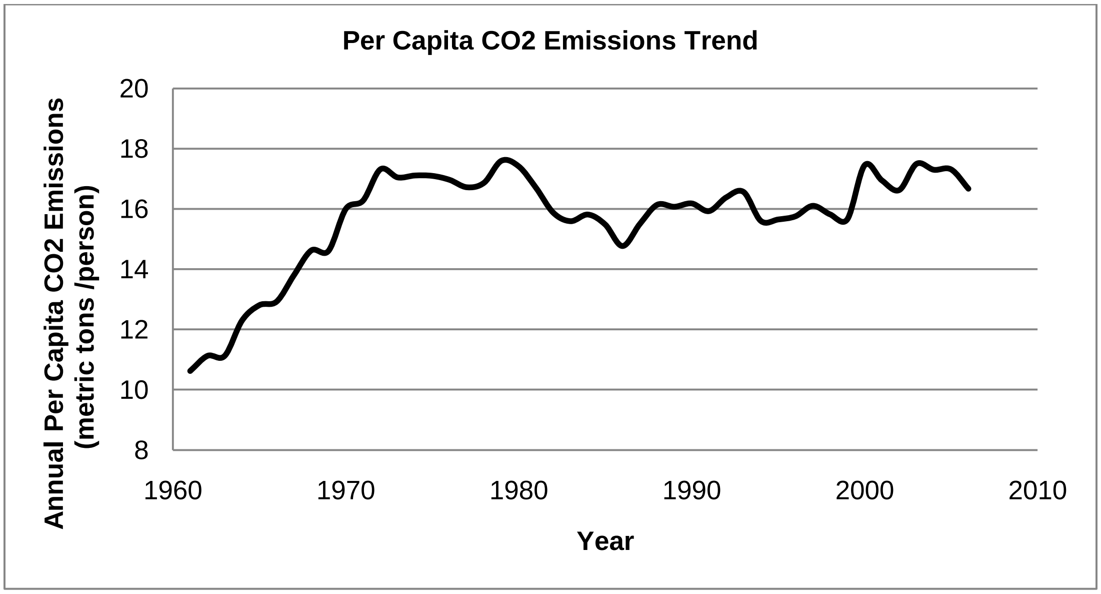
Variable	Pooled Cross Sections	Fixed Effect	Random Effect
constant	109.48*** (41.21)	3.69 (13.31)	3.97 (15.92)
GDP per capita	-0.008916*** (0.003297)	0.001007 (0.001351)	0.0009774 (0.001351)
(GDP per capita)^2	2.68E-07*** (8.34E-08)	-8.63E-09 (4.06E-08)	-7.75E-09 (4.06E-08)
(GDP per capita)^3	-2.29E-12*** (6.63E-13)	-2.25E-14 (3.48E-13)	-2.98E-14 (3.48E-13)
R^2	0.18	0.20	0.21
F-test	-	18.84	-
Breusch and Pagan LM-Test	-	-	57.59
Hausman Test	-	-	0.50
Turning Point(s)	$24,044 $53,976	-304678 $48,974	Negative $49,133
Sample Size	228	228	228

Note:
- Standard errors in parentheses. Significance levels: *10 percent; ** 5 percent; *** 1 percent
- Dollar amounts in 2002 constant prices

Table 4-1 Descriptive Statistics of Time Series Data

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
GHG	19	22.40	0.78	20.98	23.53
CO_2	46	15.68	1.71	10.62	17.60
NO_X	23	0.0926	0.0092	0.0755	0.1118
SO_X	23	0.0930	0.0276	0.0581	0.1449
CO	23	0.5306	0.1449	0.3310	0.9112
TPM	23	0.5160	0.0269	0.467	0.5744

Figure 4-1 Annual Per Capita CO_2 Emissions Trend



Source: World Development Indicators, The World Bank

Figure 4-2 Annual Per Capita GHG Emissions Trend

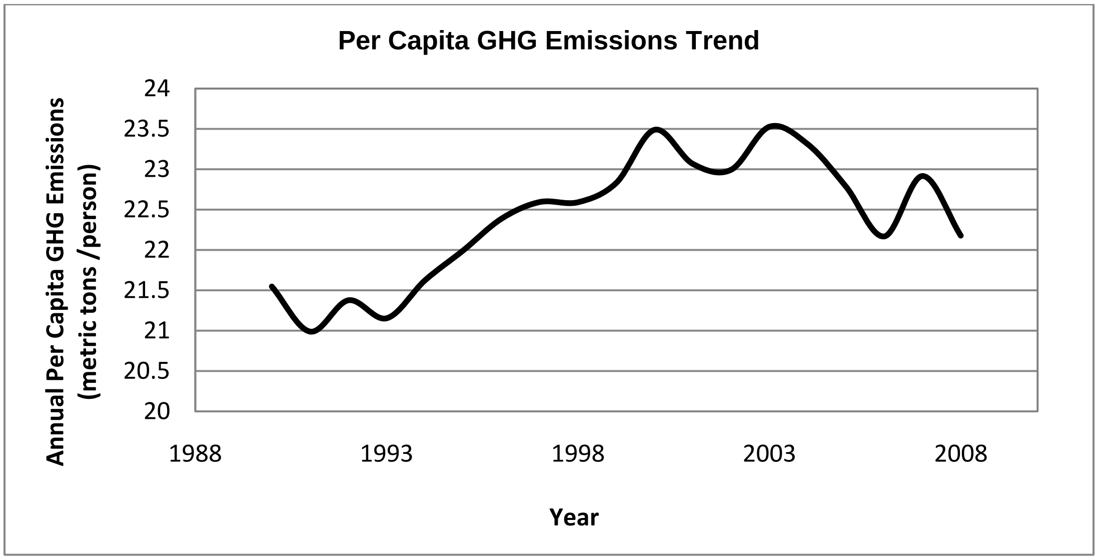


Figure 4-3 Annual NO$_X$, SO$_X$, CO and TPM Per capita Emissions Trend

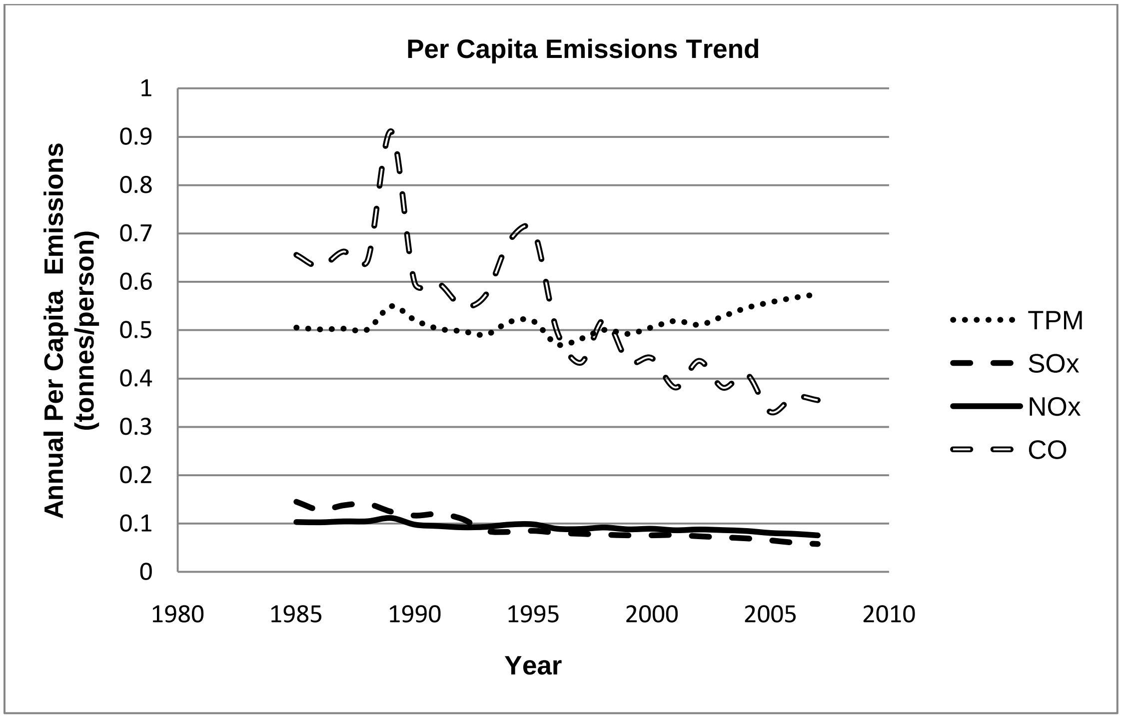


Figure 4-4 Annual Per Capita CO_2 Emissions vs. Per Capita GDP

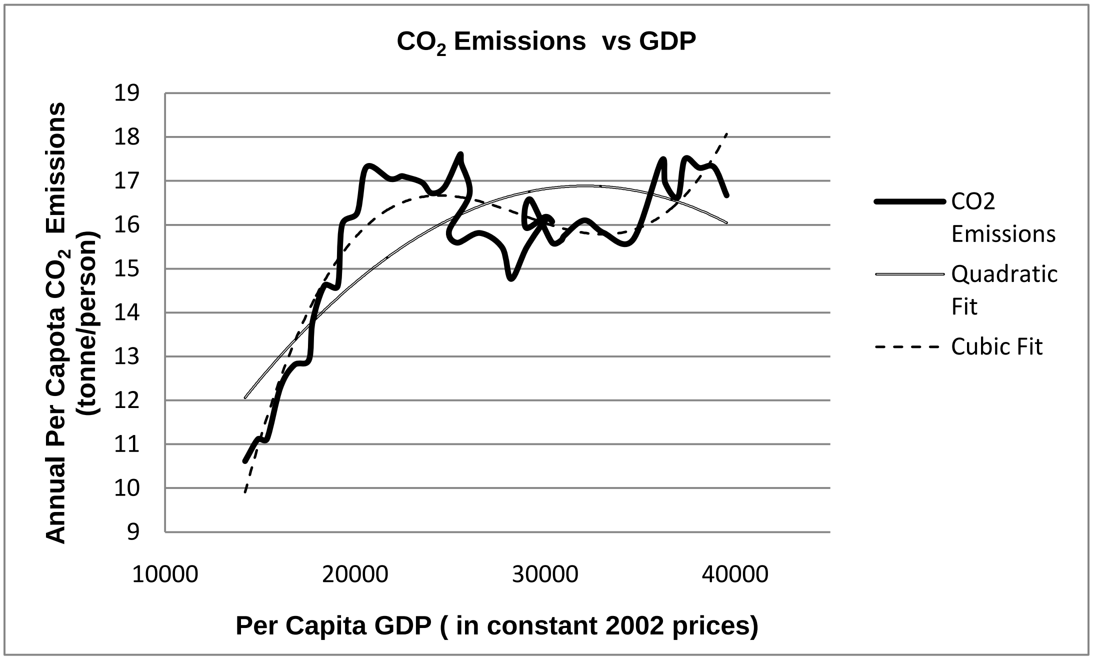


Figure 4-5 Annual Per Capita GHG Emissions vs. Per Capita GDP

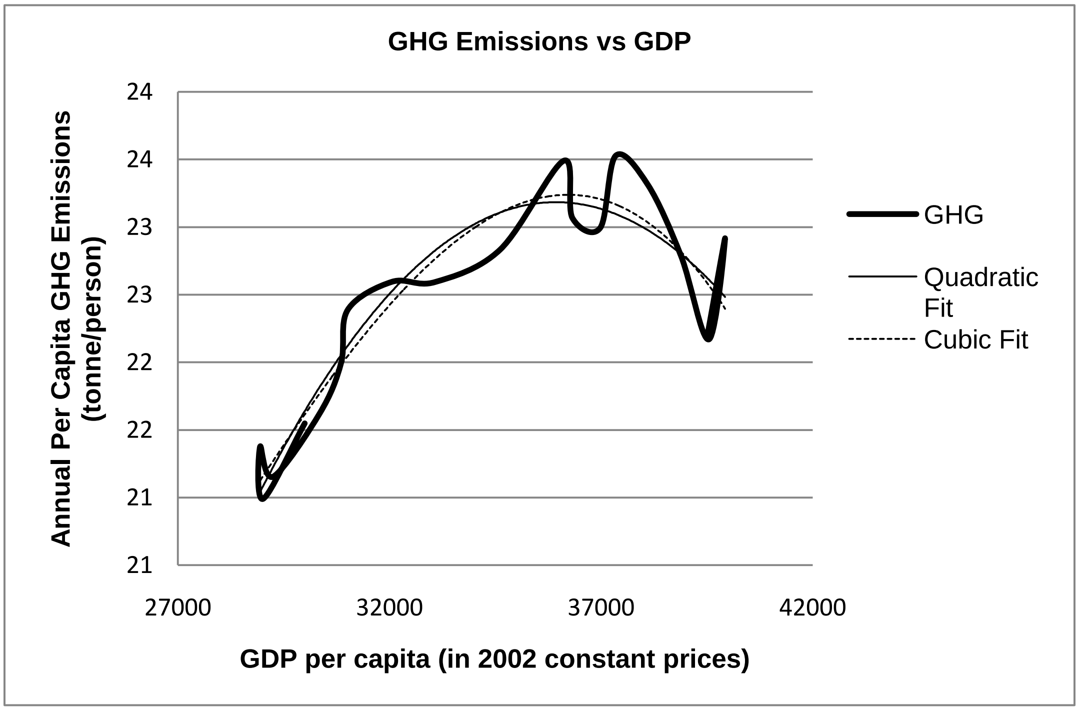


Figure 4-6 Annual Per Capita NO_X Emissions vs. Per Capita GDP

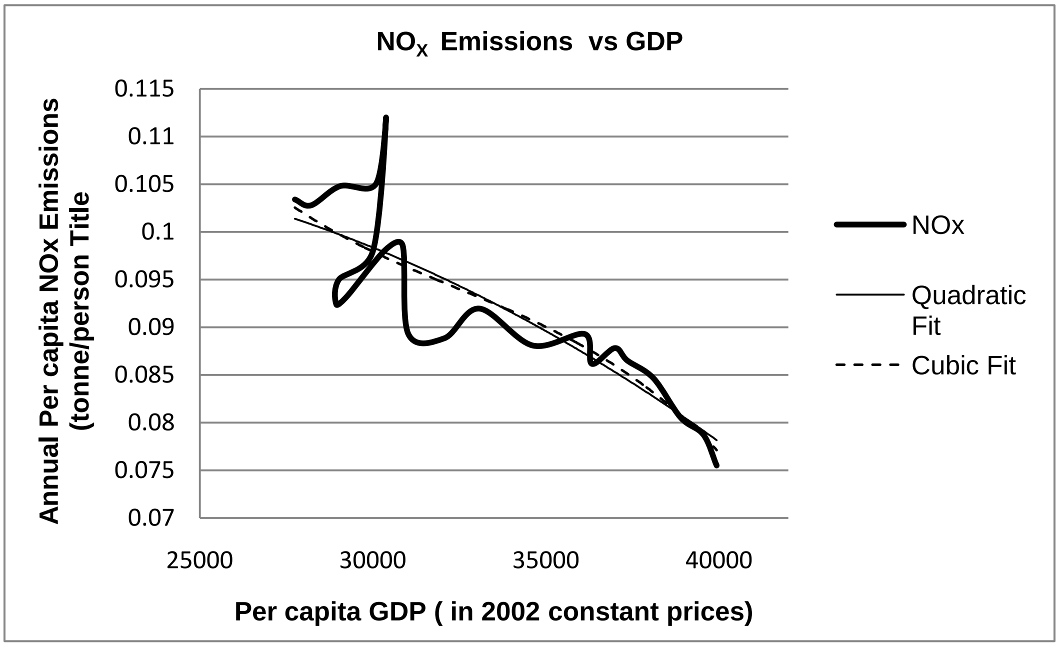


Figure 4-7 Annual Per Capita SO_X Emissions vs. Per Capita GDP

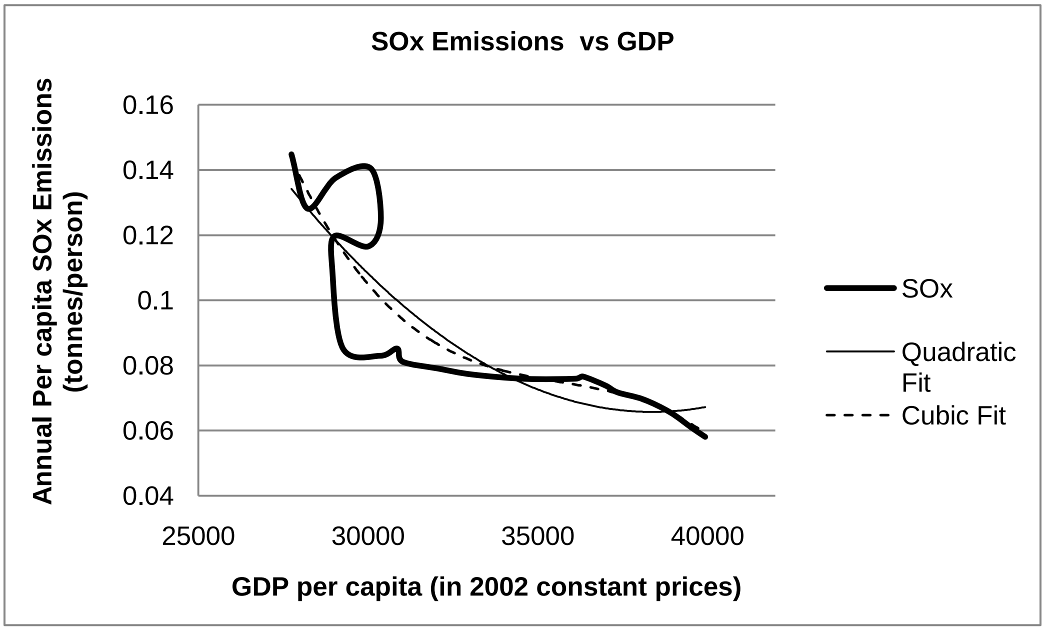


Figure 4-8 Annual Per Capita CO Emissions vs. Per Capita GDP

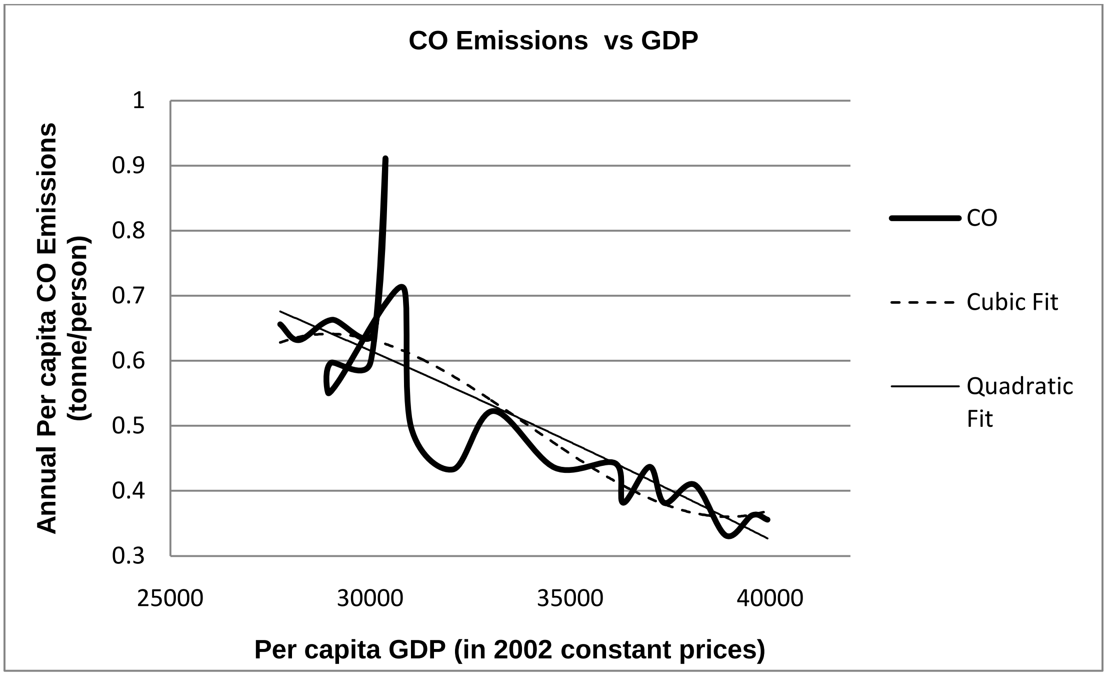


Figure 4-9 Annual Per Capita TPM Emissions vs. Per Capita GDP

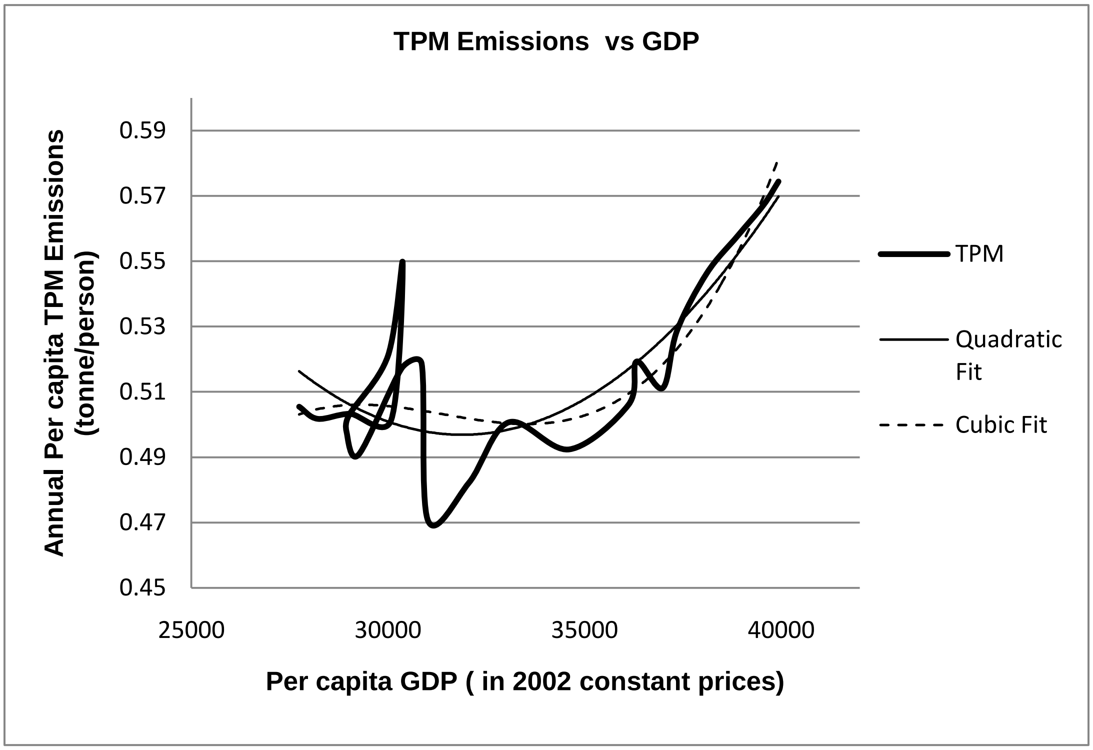


Table 4-2 Estimation Results of CO_2 Emissions

Variable	**Quadratic Model**		**Cubic Model**	
	OLS	Newey-West Lag(1)	OLS	Newey-West Lag(1)
constant	1.352** (2.273)	1.352** (3.057)	-44.80*** (5.865)	-44.80*** (6.682)
GDP per capita	0.000968*** (0.000176)	0.000968*** (0.000233)	0.00665*** (0.0007099)	0.0066589*** (0.0008271)
(GDP per capita)^2	-1.51E-08*** (3.27e-09)	-1.51E-08*** (4.23E-09)	-2.36E-07*** (2.73E-08)	-2.36E-07*** (3.23E-08)
(GDP per capita)^3	-	-	2.73E-12*** (3.37E-13)	2.73E-12*** (4.05E-13)
Durbin-Watson	0.28		0.82	
R^2	0.61		0.83	
Turning Point(s)	$32,052	$32,052	$24,657 $32,973	$24,657 $32,973
Sample Size	46	46	46	46

Note: standard errors in parentheses.
Significance levels: *10 percent; ** 5 percent; *** 1 percent

Table 4-3 Estimation Results of GHG Emissions

	GHG	
	Quadratic	Cubic
constant	-29.89*** (7.48)	32.46 (46.94)
GDP per capita	0.00293*** (0.000442)	-0.00261 (0.00414)
GDP per capita)^2	-4.05E-08*** (6.46E-09)	1.22E-07 (1.21E-07)
(GDP per capita)^3	-	-1.59E-12 (1.18E-12)
Durbin-Watson	2.21	2.19
R^2	0.90	0.91
Turning Point(s)	$36,225	$15,209 $35,943
Sample Size	19	19

Note: standard errors in parentheses.
Significance levels: *10 percent; ** 5 percent; *** 1 percent

Table 4-4 Estimation Results of NO_X Emissions

	Quadratic		Cubic	
	OLS	Newey-West Lag(1)	OLS	Newey-West Lag(1)
constant	0.0913 (0.110)	0.0913 (0.0908)	0.615 (1.032)	0.615 (0.961)
GDP per capita	1.93E-06 (6.60E-06)	1.93E-06 (5.45E-06)	-0.0000452 (0.0000926)	-0.0000452 (0.00008523)
(GDP per capita)^2	-5.67E-11 (9.75E-11)	-5.67E-11 (8.04E-11)	1.35E-09 (2.75E-09)	1.35E-09 (2.49E-09)
(GDP per capita)^3	-	-	-1.38E-14 (2.71E-14)	-1.38E-14 (2.40E-14)
Durbin-Watson	0.95	-	0.98	-
R^2	0.71	-	0.72	-
Turning Point(s)	$17,109	$17,109	N/A	N/A
Sample Size	23	23	23	23

Note: standard errors in parentheses.
Significance levels: *10 percent; ** 5 percent; *** 1 percent

Table 4-5 Estimation Results of SO_X Emissions

	Quadratic		Cubic	
	OLS	Newey-West Lag(1)	OLS	Newey-West Lag(1)
constant	0.957*** (0.325)	0.957*** (0.248)	5.066** (2.924	5.066** (2.715
GDP per capita	-0.0000465*** (0.0000195)	-0.0000465*** (0.000015)	-0.000416* (0.000262)	-0.000416* (0.000243)
(GDP per capita)^2	6.06E-10*** (2.88E-10)	6.06E-10*** (2.23E-10)	1.16E-08 (7.79E-09)	1.16E-08* (7.15E-09)
(GDP per capita)^3	-	-	-1.08E-13 (7.67E-14)	-1.08E-13* (6.95E-14)
Durbin-Watson	0.43	-	0.52	-
R^2	0.73	-	0.75	-
Turning Point(s)	$ 38,366	$ 38,366	N/A	N/A
Sample Size	23	23	23	23

Note: standard errors in parentheses.
Significance levels: *10 percent; ** 5 percent; *** 1 percent

Table 4-6 Estimation Results of CO and TPM Emissions

	CO		TPM	
	Quadratic	**Cubic**	**Quadratic**	**Cubic**
constant	1.253** (1.954)	-20.13 (17.78)	1.644*** (0.365)	-4.261 (3.166)
GDP per capita	-0.0000154** (0.000117)	0.001908 (0.001593)	-0.000072*** (0.0000219)	0.0004591* (0.000283)
(GDP per capita)^2	-1.95E-10** (1.73E-09)	-5.75E-08 (4.73E-08)	1.13E-09*** (3.23E-10)	-1.47E-08** (8.43E-09)
(GDP per capita)^3	-	5.64E-13 (4.66E-13)	-	1.56E-13** (8.30E-14)
Durbin-Watson	1.77	1.85	1.49	1.66
R^2	0.64	0.67	0.70	0.70
Turning Point(s)	Negative Value	$28,789 $39,177	$31,858	$29,309 $33,781
Sample Size	23	23	23	23

Note: standard errors in parentheses.
Significance levels: *10 percent; ** 5 percent; *** 1 percent

Table 5-1 Summary of Results

Indicator	**Data Type**	**Existence of an inverted U EKC**	**Quadratic or Cubic**	**Estimated Turning Point(s)**
GHG	Provincial/Territorial Panel 1990-2008	YES	Quadratic (inverted U)	$48,673
	Time-series 1990-2008	YES	Quadratic (inverted U)	$36,225
CO_2	Time-series 1961-2006	YES	Quadratic (inverted U)	$32,052
		NO	Cubic (N shape)	$27,428 $33,057
NO_X	Time-series 1985-2007	NO	Neither	-
SO_X	Time-series 1985-2007	NO	Quadratic (U shape)	$ 38,366
CO	Time-series 1985-2007	YES	Quadratic (inverted U)	Negative Value
TPM	Time-series 1985-2007	NO	Quadratic (U shape)	$31,858

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