



Growth and the Environment in Canada: An Empirical Analysis

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by

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Abstract

Standard reduced form models are estimated for Canada to examine the relationships between real per capita GDP and four measures of environmental degradation. Of the four chosen measures of environmental degradation, only concentrations of carbon monoxide appear to decline in the long run with increases in real per capita income. The data used in the reduced form models are also tested for the presence of unit roots and for the existence of cointegration between each of the measures of environmental degradation and per capita income. Unit root tests indicate nonstationarity in logs of the measures of environmental degradation and per capita income. The Engle-Granger test and the maximum eigenvalue test suggest that per capita income and the measures of environmental degradation are not cointegrated, or that a long-term relationship between the variables does not exist. Causality tests also indicate a bi-directional causality, rather a uni-directional causality, from income to the environment. The results suggest that Canada does not have the luxury of being able to grow out of its environmental problems. The implication is that to prevent further environmental degradation, Canada requires concerted policies and incentives to reduce pollution intensity per unit of output across sectors, to shift from more to less pollution-producing-outputs and to lower the environmental damage associated with aggregate consumption.

JEL classification: Q2, C2

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1. Introduction

A fundamental question of economic development is to what extent increases in economic activity affect the natural environment. A common approach to testing the growth-environment relationship is to regress a measure of environmental degradation against a measure of economic activity. Such reduced form models are not structural in the sense that they do not explain the growth-environment relationship, but do have the advantage that they can capture both direct and indirect aggregate effects of the interrelationships.

Reduced form models of growth and environment have been estimated for a large number of measures of environmental degradation in both panel and cross-country studies for a variety of different countries. Some of the studies, often with panel data for a group of countries, provide some evidence to support a so-called environmental Kuznets curve (EKC) where environmental degradation initially increases with the level of per capita income, reaches a turning point, and then declines with further increases in per capita income. The empirical evidence for an EKC is not, however, unequivocal as an estimated inverted U curve often does not exist for a number of important measures of environmental degradation, particularly water quality, and for many consumption-based measures of environmental degradation (Rothman 1998). The potential problems with estimating reduced form models of income-environment relationships are detailed by Stern, Common, and Barbier (1996). Reviews of the EKC literature and the EKC hypothesis are provided by Stern (1998), de Bruyn and Heintz (2000), Ekins (2000), Rothman and de Bruyn (1998) and Arrow *et al.* (1995), among others. Useful summaries

of EKC results are provided by de Bruyn and Heintz (table 46.1, 2000), Ekins (table 7.A1, 2000), de Bruyn (table 5.1, 2000) and Stern (Table 1, p. 188, 1998).

Despite the mixed evidence for the existence of EKCs, reduced form studies have received a great deal of attention, especially the interpretation that, past a certain level of income, further economic growth will improve the quality of the environment. Explanations for such a result include, one, the income elasticity for environmental quality exceeds unity so that as people become richer they demand (and are able to afford) reduced environmental degradation, two, rising incomes are correlated with a greater awareness of and ability to measure and resolve environmental problems, three, higher incomes are associated with technological progress that reduces pollution intensity and, four, rising incomes are associated with structural changes that shift an economy to less pollution intensive outputs. In its extreme form, declining environmental degradation with rising per capita income has been interpreted to mean that economic growth can resolve problems of the environment (Beckerman 1992). However, even if the estimated EKC results are correct, the fact that many of the reported turning points are at a level greater than the current income of most countries then increasing per capita income implies *declining* environmental quality for poor and middle-income countries for the foreseeable future (Ekins, 2000). Further, even if an EKC exists for wealthier countries it may arise from the “export” of pollution-intensive industries and thus may represent the ability of rich countries to separate themselves from their own consumption by engendering environmental degradation in poor countries (Rothman 1998).

The possible existence of an EKC for some measures of environmental degradation in a panel of countries begs the question, what is the nature of the growth-environment relationships for Canada? In particular, will increasing per capita income improve measures of environmental

quality? A few studies have reviewed the state of the environment in Canada, and include the OECD (1995), Hayward and Jones (1998) and Statistics Canada (2000). In a key paper, Day and Grafton (2001) estimate reduced form models for ten measures of environmental degradation for Canada. Five of their ten measures of environmental degradation (concentrations of carbon monoxide, nitrogen dioxide, ground-level ozone, dioxin in herring gull eggs and dissolved oxygen in the Saskatchewan river¹) follow an inverted N pattern, which implies long-term declines in environmental degradation are associated with increases in per capita income. In their study, however, they do not test whether the variables are non-stationary, which may result in spurious regression results, or test whether per capita GDP and their measures of environmental degradation are cointegrated, which implies a long-term and stable relationship between the variables.

To help determine whether a reduced form model of the growth-environment relationship for Canada is appropriate, we re-estimate four of the regressions used by Day and Grafton (2001) and test for the existence of unit roots and cointegrating relationships in the data. If unit roots exist then the reduced form regressions will be spurious unless the measures of environmental degradation and income series are cointegrated. Causality tests are also undertaken to assess whether there exists a uni- or a bi-directional relationship between per capita income and the four measures of environmental degradation. The purpose of the study is to assess the nature of the long-term relationship between per capita income and Canadian measures of environmental degradation and to determine whether increases in per capita income are associated with reductions in environmental degradation in Canada.

2. Reduced Form Models of the Growth-Environment Relationship

Following Day and Grafton (2001), we examine the relationship of four indicators of environmental degradation in Canada to income per capita, as measured by real gross domestic product (GDP) per capita. The four environmental indicators---emissions of carbon dioxide (CO₂) and concentrations of carbon monoxide (CO), sulphur dioxide (SO₂) and total suspended particulate matter (TSP)²---were chosen because they are available on a national basis and for the longest time period. Moreover, the measures are standard indicators of air quality in urban areas and are widely used measures of environmental degradation.³ For all four measures, an increase in the indicator implies an increase in environmental degradation.

We begin by estimating a standard reduced form model of the relationship between environmental degradation and per capita income, and then evaluate the model using various econometric tests. Estimation of a standard reduced form model with a per capita income term in levels and squared and cubed with a time trend does not necessarily imply that alternative specifications are inappropriate. For example, regressors that have also appeared in reduced form models estimated with panel data include trade intensity (Grossman and Krueger 1995), energy prices (de Bruyn, van den Bergh and Opschoor 1998), economic structure (Suri and Chapman 1998), spatial intensity of economic activity (Kaufmann *et al.* 1998) and income inequality (Torras and Boyce 1998). Some of these additional variables, however, vary very little over time and thus are unsuitable regressors in a reduced form model that uses time-series data for only one country. Estimates from a standard reduced form model also have the advantage that they can be directly compared to many of the models in the EKC literature. In addition, including other explanatory variables would not change whether or not a measure of environmental degradation or per capita income are nonstationary, whether or not there exists a cointegrating relationship

between the variables, or if there exists bi-directional causality rather than uni-directional causality between environmental degradation and per capita income.

The reduced form model estimated using Canadian data is given by equation (1):

$$LED_{it} = \alpha_1 + \alpha_2 LY_{it} + \alpha_3 LY_{it}^2 + \alpha_4 LY_{it}^3 + \alpha_5 t + \varepsilon_{it}, \quad (1)$$

where LED is the natural logarithm of the measure of environmental degradation and LY is the natural logarithm of real GDP per capita.⁴ Ordinary Least Squares (OLS) estimates of the coefficients of equation (1) are presented in table 1, together with a number of diagnostic statistics. The sample sizes range from 38 observations for carbon dioxide emissions to 24 for concentrations of CO, SO₂ and TSP. Despite the fact that all the equations were estimated using time series data, the reported Durbin-Watson statistics imply that the null hypothesis of no serial correlation can be rejected at the 5% level of significance only for CO₂ and TSP. Similarly, the results of the Breusch-Pagan-Godfrey test for heteroskedasticity indicate that at the 5% level of significance, the null hypothesis of a constant variance cannot be rejected for any of the measures of environmental degradation. Re-estimation of the CO₂ and TSP equations with a correction for first-order autocorrelation led to few major changes in the results, as indicated in the table. In neither case did the signs of the coefficient estimates change.

For all four measures of environmental degradation, the adjusted R² exceeds 0.9, implying that the reduced form model explains much of the variation in the measure of environmental degradation. F-tests of the overall significance of the regression led to the rejection (at the 5% level of significance) of the null hypothesis that $\alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$ for all equations. Thus the models, as a whole, appear to have explanatory power.

An inverted U-shaped curve exists if $\alpha_2 > 0$, $\alpha_3 < 0$, and $\alpha_4 = 0$. However, a desirable long-term relationship between income and environmental degradation also occurs if $\alpha_2 < 0$, α_3

= 0, and $\alpha_4 = 0$ (environmental degradation is monotonically decreasing in per capita income) or $\alpha_2 < 0$, $\alpha_3 > 0$, and $\alpha_4 < 0$ (environmental degradation follows an inverted N shape where the environmental indicator is measured on the ordinate and per capita income is measured on the abscissa).⁵ For the CO and SO₂ models, all the coefficients including that of the cubed term, are significantly different from zero at the 5% level of significance, implying that the appropriate functional form is cubic, not quadratic. The corrected estimates for CO₂ suggest a similar conclusion---although we cannot reject the null hypothesis that the coefficient of the cubed term is zero at the 5% level of significance, the p-value of the coefficient is 0.051, a value very close to 5%. Finally, where TSP is the regressand, only the coefficient of the time trend is significantly different from zero in the corrected equation, implying that a reduced form model is inappropriate for TSP.⁶

Of the four models, only in the case of CO does the pattern of signs of the coefficients of the powers of *LY* suggest a desirable long-run outcome for society as income per capita rises. In this equation, $\alpha_2 < 0$, $\alpha_3 > 0$ and $\alpha_4 < 0$, which implies that environmental degradation will first decrease as income per capita rises, then increase, and finally decrease with income per capita again after the second turning point has been surpassed. For the other three measures of environmental degradation, the pattern of signs of the coefficients implies that over some range of per capita income environmental degradation will decline as income rises, but eventually another turning point will be reached and, thereafter, environmental degradation will increase as per capita income rises.

The reduced form results suggest that a comprehensive long-term beneficial relationship between per capita income and measures of environmental degradation does not appear to exist for Canada. However, given that the results are obtained from time-series data, the possibility

exists that the results may be spurious if the variables are nonstationary. Thus further empirical investigation is required to understand the Canadian growth-environment relationship.

3. Stationarity and Cointegration

An important criticism that has been leveled against reduced form models is that the results may be invalid due to the presence of unit roots in the underlying variables. If unit roots exist in the data, then estimates of reduced form models will be spurious unless the explanatory variables in the model are cointegrated. Unfortunately, the short length of the time series data available on environmental degradation in Canada makes it difficult to test for the presence of unit roots or cointegration. It is well known that unit root and cointegration tests are less reliable in small samples, and asymptotic critical values are often inaccurate unless the sample contains more than 100 observations (Maddala and Kim 1998, 219). To counter this problem, we carry out several different tests for unit roots and cointegration, looking for consistency in the results. As all the tests are sensitive to the choice of lag lengths in the test equations, we also use several different criteria to choose lag lengths and, when these criteria yield conflicting results, carry out the tests for different lag lengths.

Table 2 presents the results of two popular unit root tests, the Augmented Dickey-Fuller test and the Phillips-Perron test, carried out for various lag lengths. In all cases, the test equation includes both a constant and a linear deterministic trend, as visual inspection of graphs of the series indicated that they all displayed an upward trend. The results imply that in all cases, we *fail* to reject the null hypothesis of nonstationarity at either the 5% or 10% levels of significance.⁷ The log of per capita GDP was also found to be nonstationary. Re-application of the tests to the first differences of each series indicated that the first differences of all four

measures of environmental degradation and real GDP per capita were stationary, i.e., that all the series were integrated of order 1.

The implication of the unit root tests is that the reduced form results may be spurious and least squares regression may be inappropriate. To determine whether or not this is the case, we carried out a number of tests for cointegration of the logs of real GDP per capita and the four measures of environmental degradation. First, following de Bryun (2000), we applied the augmented Engle-Granger test to several alternative specifications of the reduced form model.⁸ The results of these tests can be found in table 3. In total, three different model specifications were tested: the cubic equation, a quadratic equation, and a simple linear model, all with a linear deterministic trend included. In all cases the test was carried out with neither a constant nor a trend in the test equation, because both are already included in the cointegrating equation (the reduced form model). For each specification, the table presents the value of the statistic obtained for various lag lengths, along with the 5% and 10% critical values for a cointegrating equation including both constant and trend from MacKinnon (1991).

The results in table 3 indicate that only in one case---that of SO₂ in the cubic model---can we reject the null hypothesis of no cointegration at even the 10% level of significance, regardless of the choice of lag length. These results suggest that estimates of the reduced form models may indeed be spurious.⁹ But the Engle-Granger test is only one of many possible tests for cointegration. Two widely used alternatives to the Engle-Granger test are the trace and maximum eigenvalue tests described in Johansen (1995).

Johansen's tests differ from the Engle-Granger test in that they are carried out in the context of a vector autoregression (VAR) model. Although the VAR framework is very different from static reduced form models like equation (1), it offers an alternative means of exploring the

relationship between measures of environmental degradation and per capita GDP. Even if a reduced form relationship exists between the variables, it is likely to be a dynamic rather than a static relationship. In the short run, it is quite likely that there would be lags in the adjustment of measures of environmental degradation to changes in per capita GDP. Moreover, the VAR framework offers the possibility of testing for causality between measures of environmental degradation and GDP, to see if the relationship between them appears to be unidirectional, as reduced form models assume, or bi-directional.

Whether or not the variables included in a VAR model are cointegrated has implications for the form of that model and for the type of causality test that is appropriate. If the Johansen tests support the conclusion that most of the measures of environmental degradation are not cointegrated, then causality tests must be based on a VAR model in first differences. If, however, the variables are cointegrated, then causality tests should be based on an error correction model. Thus testing for cointegration is also a first step towards causality testing.

Tables 4 and 5 contain the results for Johansen's trace test and Johansen's maximum eigenvalue test respectively, with 5% and 10% critical values from Osterwald-Lenum (1992). For each measure of environmental degradation, the lag length or order of the VAR model was determined by applying several alternative criteria to the following unrestricted VAR model in two variables:

$$LED_t = a_1 + \sum_{i=1}^k b_{1i} LED_{t-i} + \sum_{i=1}^k c_{1i} LY_{t-i} + \varepsilon_{1i} \quad (2)$$

$$LY_t = a_2 + \sum_{i=1}^k b_{2i} LED_{t-i} + \sum_{i=1}^k c_{2i} LY_{t-i} + \varepsilon_{2i} \quad (3)$$

where k is the order of the VAR model. In cases where the criteria led to different choices of k , the tests were carried out for each lag length selected by at least one criterion.

The null hypothesis for Johansen's trace test is that there are, at most, r cointegrating vectors, while the alternative is that there are more. The test is performed sequentially, beginning with the null hypothesis that there are at most zero cointegrating vectors, and if this null hypothesis is rejected, continuing with the null hypothesis that there is at most one cointegrating vector. In a VAR model of only two variables, there can be at most one cointegrating vector.

As is the case for unit root and Engle-Granger tests, the critical values for the test (and the estimation procedure in this case) depend on whether and how constants and trends are assumed to enter into the cointegrating equation. Note that in a linear dynamic model, the cointegrating equation will be identical to a linear reduced form model. Because we wish to examine the evidence in favour of the existence of a favourable long-term relationship between per capita income and environmental degradation, we consider only two possible specifications of the dynamic model, both of which assume that there is a trend in the cointegrating equation itself.¹⁰ If in a beneficial long-term relationship exists, we would expect the relationship between environmental degradation and real GDP per capita to be changing over time, with environmental degradation decreasing as GDP per capita rises. In other words, the gap between the two series is thus likely to be decreasing over time.

Cointegration tests for two types of models with a linear deterministic trend in the cointegrating equation are described in Johansen (1995, chapters 5 and 6). In the first case, the solution to the dynamic model allows for a quadratic trend in the data. In the second, restrictions imposed on the model result in a linear deterministic trend in the data as well as in the cointegrating equation. The results in table 4 indicate that only for SO₂ are the results consistent across the two specifications. For this measure of environmental degradation, the trace test implies that there is one cointegrating vector, i.e., that SO₂ and GDP per capita are indeed

cointegrated at the 5% level of significance. For the other three measures of environmental degradation, the trace test results differ with both the choice of lag length and the specification of the model, sometimes implying cointegration and sometimes not. In two cases, both involving CO₂ with 5 lags in the case of a linear deterministic trend and with 2 lags with a quadratic trend if the level of significance is raised to 10%---the test implies that there are two cointegrating vectors. Since there can be two cointegrating vectors only if the data are stationary, this result is not consistent with the earlier finding that all series are I(1). This inconsistent result can perhaps be attributed to the small sample size. In general, however, the trace test seems to provide more evidence in favour of cointegration than the Engle-Granger test for all variables.

One problem with the trace test is that the asymptotic critical values used for the test may not be applicable in our small samples. For Johansen's other test, the maximum eigenvalue test, Maddala and Kim (1998) recommend a correction factor first proposed by Reimers (1992): the value of the statistic λ_{\max} should be multiplied by the factor $(T-nk)/T$, where T is the number of observations, n is the number of variables in the VAR model, and k is the order of the VAR model. According to Reimers, this adjustment will improve the size properties of the test in finite samples. The values of λ_{\max} reported in table 5 have been adjusted using this formula. The tests are performed for the same two possible specifications of the dynamic model.

For the maximum eigenvalue test, the null hypothesis is that there are exactly r cointegrating vectors, while the alternative is that there are exactly $r+1$. Again, the test is carried out sequentially, beginning with the null hypothesis that there are no cointegrating vectors. As in table 4, the critical values in table 5 are from Osterwald-Lenum (1992), and the test is carried out for alternative lag lengths. In contrast to the results in table 4, using the corrected λ_{\max} we cannot

reject the null hypothesis of no cointegration for any of the measures of environmental degradation for any of the lag lengths considered.

Thus both the Engle-Granger test and the maximum eigenvalue test suggest that the variables are not cointegrated at the 5% level of significance (nor at the 10% level of significance for most measures as well). Given the small sample sizes we are working with, these tests are likely to be more reliable than the trace test since either the critical values, or the value of the trace test statistic itself, have been adjusted to reflect the sample size. We are not aware of adjustments that can be made to the trace test for small sample sizes.

Overall, the test results suggest that there is no long-run relationship between per capita GDP and the measures of environmental degradation examined, at least if a linear deterministic trend belongs in the relationship between them. Any causality between the measures of environmental degradation and per capita GDP, if it exists, must therefore be short run in nature.

4. Causality Tests

Given that the cointegration tests suggest that there is no cointegration between per capita GDP and measures of environmental degradation, tests of Granger causality should be carried out using a VAR in first-differences. Thus for the purposes of causality testing, the following two-equation vector autoregression model was estimated:

$$\Delta LED_t = \alpha_1 + \sum_{i=1}^p \beta_{1i} \Delta LED_{t-i} + \sum_{i=1}^p \gamma_{1i} \Delta LY_{t-i} + \varepsilon_{3i} \quad (4)$$

$$\Delta LY_t = \alpha_2 + \sum_{i=1}^p \beta_{2i} \Delta LED_{t-i} + \sum_{i=1}^p \gamma_{2i} \Delta LED_{t-i} + \varepsilon_{4i} \quad (5)$$

where ΔX_t is the first difference of the variable X_t and p is the order of the VAR in first differences. In this model, changes in the measure of environmental degradation are assumed to

be a function of past changes in both environmental degradation and real income per capita. Similarly, changes in real income per capita are assumed to be a function of past changes in environmental degradation and real income per capita. Within the context of this model, *LED* can be said to “cause” *LY* in the sense of Granger if one can reject the null hypothesis that the β_{2i} , $i = 1, \dots, p$ are jointly zero. Similarly, we can say that *LY* causes *LED* if the γ_{1i} , $i = 1, \dots, p$, are jointly zero.

As the top panel of table 6 indicates, the results of the causality tests are often sensitive to the order of the VAR model in first differences.¹¹ The longer is the lag length of the VAR, the greater is the likelihood that some short-run causality will be observed. Indeed, if we examine the longest lag length chosen for each measure of environmental degradation, the null hypothesis that *LED* does not cause *LY* is always rejected at the 5% level of significance. However, the null hypothesis that *LY* does not cause *LED* is rejected at the 5% level of significance only in the case of SO₂. It is rejected at the less stringent 10% level, however, in the cases of CO₂ and TSP.

Although there is reasonable evidence that the measures of environmental degradation are not cointegrated with real GDP per capita, in view of the small sample size, we also carried out an alternative causality test proposed by Toda and Yamamoto (1995). The advantages of their MWALD test are that it does not rely on the results of cointegration tests, and that, as illustrated by Rambaldi and Doran (1996), it is easy to implement. The test involves estimating an unrestricted VAR model, with the number of lags equal to $k + d$, where k is the previously selected order of the VAR model and d is the order of integration of the variables of the model. Afterwards a standard Wald test is applied to the augmented VAR model, ignoring the additional lagged terms. For example, *LED* is said to “cause” *LY* in the sense of Granger if one can reject the null hypothesis that the b_{2i} , $i = 1, \dots, k$, where k is the lag length chosen for the unrestricted

VAR in levels, are jointly zero, even though the model actually estimated for the purposes of the test consists of equations (2) and (3) augmented by the addition of $d = 1$ lagged values of each variable.

The drawback of this test is that, as demonstrated by Zapata and Rambaldi (1997), it is subject to a loss of power in small samples of the size available to us. However, it is still interesting to compare the results of this test to those based on the VAR in first differences. The second panel of table 6 indicates that, once again, the probability of rejecting the null hypothesis of no causality increases with the lag length of the underlying VAR model. Like the test based on the VAR in first differences, the MWALD test implies that we can reject the null hypothesis that *LED* does not cause *LY* at the 5% level of significance, except in the case of CO₂. Using the longest lag lengths for each variable, the MWALD test implies that one can reject the null hypothesis that *LY* does not cause *LED* at the 5% level of significance for all measures of environmental degradation except TSP.

Thus while the causality tests provide evidence that changes in real GDP per capita cause changes in the level of environmental degradation, they also provide evidence of causality in the reverse direction. These causality results do *not* imply that measures of environmental degradation determine Canadians' income, but do suggest that a bi-directional relationship may exist between real per capita GDP and some aggregate measures of environmental degradation. More importantly, the causality results contradict the reduced form model's implicit assumption that the direction of causality is one way, from income per capita to environmental degradation. In fact, in some cases such as CO₂, the direction of causality appears to be the reverse. Thus the reduced form models might be capturing the nature of the process through which environmental

degradation occurs rather than, say, an increase in the demand for increased environmental quality as income per capita rises.

Overall, the results indicate that for the chosen measures of environmental degradation used in the study there is little evidence to suggest of a decoupling of growth and environmental degradation. The findings also indicate that increases in per capita income will not, by themselves, lead to improvements in Canada's state of the environment.

5. Concluding Remarks

A common approach to analyzing the environment-economic growth relationship is to estimate a reduced form model that regresses a measure of environmental degradation against per capita income over time, and across countries. In some of these studies, evidence has been found for a beneficial relationship between per capita income and some measures of environmental degradation. We examine such a relationship using Canadian data and four measures of environmental degradation.

Using a standard reduced form model of the growth-environmental relationship, only one of the four chosen measures of environmental degradation, carbon monoxide, is shown to eventually decline with real per capita income. Time-series analysis of the relationships, however, suggest that the estimates from a standard reduced form model with a linear time trend may be spurious for such measures as carbon monoxide, carbon dioxide, and total suspended particulate matter. Furthermore, causality tests indicate that the hypothesis that environmental degradation does *not* influence per capita income is rejected. In other words, the evidence indicates a bi-directional causality, rather a unidirectional causality from income to the environment.

The results provide little evidence for a long-term relationship between per capita income and the chosen measures of environmental degradation, or that higher levels of real per capita income improve environmental quality in Canada. It would appear, therefore, that Canada does not have the luxury of being able to grow out of its environmental problems. Thus, if Canadians wish to prevent further environmental degradation it would seem that concerted policies and incentives are required to reduce pollution intensity per unit of output across sectors, to shift from more to less pollution-producing-outputs and to lower the environmental damage associated with aggregate consumption.

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Table 1. Estimates of Reduced Form Model in Logs (OLS unless otherwise indicated)

Variable	CO	CO ₂	CO ₂ with correction for AR(1) errors	SO ₂	TSP	TSP with correction for AR(1) errors
LY	-9551.2 (-2.474)	352.83 (2.009)	545.31 (2.083)	12945 (2.107)	8022.7 (1.868)	5949.2 (1.195)
(LY) ²	954.51 (2.479)	-35.64 (-1.930)	-56.43 (-2.054)	-1298.3 (-2.120)	-803.9 (-1.877)	-597.18 (-1.203)
(LY) ³	-31.794 (-2.484)	1.200 (1.854)	1.948 (2.029)	43.401 (2.132)	26.852 (1.886)	19.982 (1.212)
t	-0.5606 (-8.858)	0.004279 (0.938)	0.002444 (0.470)	-0.04465 (-4.434)	-0.04687 (-6.659)	-0.04767 (-5.576)
Constant	31859 (2.469)	-1159.1 (-2.083)	-1752.7 (-2.108)	-43016 (-2.095)	-26683 (-1.859)	-19752 (-1.187)
Adjusted R ²	0.9771	0.9711	0.9898	0.9158	0.9312	0.9408
F statistic	246.81	312.24	39.99	63.53	78.87	40.79
DW statistic ^b	1.746 (0.059)	0.452 (0.000)	-0.009 ^c	1.9784 (0.166)	1.230 (0.002)	0.956 ^c
B-P-G statistic ^c	9.113 (0.058)	4.816 (0.307) ^d		2.343 (0.673)	5.745 (0.219)	
No. of obs.	24	38	38	24	24	24
Sample period	1974-1997	1958-1995	1958-1995	1974-1997	1974-1997	1974-1997
Data type	Concentration as percent of NAAQO “maximum acceptable” level	Emissions	Emissions	Concentration as percent of NAAQO “maximum acceptable” level	Concentration as percent of NAAQO “maximum acceptable” level	Concentration as percent of NAAQO “maximum acceptable” level

^a Values in parentheses under coefficient estimates are t-statistics.

^b Durbin-Watson test statistic for autocorrelation, with p-value in parentheses.

^c Breusch-Pagan-Godfrey test statistic for heteroskedasticity, with p-value in parentheses.

^d The residuals failed at least one test for normality at the 5% level of significance, so the Koenker (1981) variant of the B-P-G test is used.

^e Durbin’s h-statistic, modified for AR(1) errors.

Table 2. Results of unit root tests

Variable	No. of lags	No. of obs.	τ	10% critical value	5% critical value
<i>ADF tests</i> ^a					
CO	0	23	-2.847	-3.2474	-3.6211
	4	19	-0.6635	-3.6733	-3.2762
	5	18	-0.4234	-3.2856	-3.6906
CO ₂	0	37	-1.759	-3.1988	-3.5345
	1	36	-1.747	-3.2009	-3.5382
SO ₂	0	23	-2.659	-3.2474	-3.6211
	3	20	-0.5311	-3.2678	-3.6580
TSP	0	23	-2.245	-3.2474	-3.6211
	5	18	-1.123	-3.2856	-3.6906
<i>Phillips-Perron tests</i> ^b					
CO	1	23	-2.858	-3.2474	-3.6219
	2	23	-2.850	-3.2474	-3.6219
CO ₂	1	37	-1.746	-3.1988	-3.5348
	3	37	-1.747	-3.1988	-3.5348
SO ₂	1	23	-2.559	-3.2474	-3.6219
	2	23	-2.606	-3.2474	-3.6219
TSP	1	23	-2.452	-3.2474	-3.6219
	2	23	-2.482	-3.2474	-3.6219

^a Three alternative methods were used to choose lag lengths: t-tests on the coefficient of the highest lag, the Akaike Information Criterion (AIC), and the Schwartz Criterion (SC). In the first case, the lag length was chosen such that the coefficient of the highest-order lag was significant at the 10% level, beginning with the highest plausible lag and testing down. In the other two cases, the lag length was chosen so as to minimize the criterion, where

$$AIC = \ln \tilde{\sigma}^2 + 2 \frac{n}{T} \text{ and } SC = \ln \tilde{\sigma}^2 + \frac{n \ln T}{T}.$$

^b Two alternative methods were used to choose lag lengths: the highest significant lag order from either the autocorrelation function or the partial autocorrelation function of the first-differenced series, as chosen by SHAZAM 8.0; and the Newey-West automatic truncation lag, as chosen by Eviews 3.1.

Table 3. Results of augmented Engle-Granger cointegration tests

Variable	No. of lags ^a	No. of obs.	τ	10% critical value	5% critical value
<i>Cubic reduced form model with linear deterministic trend</i>					
CO	0	23	-4.133	-4.6515	-5.0968
	3	20	-4.068	-4.7304	-5.2033
CO ₂	0	37	-1.899	-4.4564	-4.8356
	1	36	-2.116	-4.4652	-4.8473
SO ₂	0	23	-4.682	-4.6515	-5.0968
TSP	0	23	-3.448	-4.6515	-5.0968
	3	20	-3.624	-4.7304	-5.2033
<i>Quadratic reduced form model with linear deterministic trend</i>					
CO	0	23	-3.444	-4.2430	-4.6669
CO ₂	1	36	-2.442	-4.0934	-4.4634
SO ₂	0	23	-3.924	-4.2430	-4.6669
TSP	0	23	-2.700	-4.2430	-4.6669
<i>Linear reduced form model with linear deterministic trend</i>					
CO	0	23	-3.060	-3.8167	-4.2190
CO ₂	0	37	-1.780	-3.6935	-4.0465
	3	34	-2.156	-3.7112	-4.0710
	4	33	-2.827	-3.7179	-4.0802
SO ₂	0	23	-3.038	-3.8167	-4.2190
TSP	0	23	-2.475	-3.8167	-4.2190

^a For a description of the criteria used to choose the lag length, see note *a* of table 1.

Table 4. Johansen's trace test for cointegration

Variable	Order of VAR ^a	λ_{trace}	10% critical value	5% critical value	Value of r under H_0
<i>Constant and deterministic trend in cointegrating equation, linear deterministic trend in data</i>					
CO	2	19.16832	22.76	25.32	0
		4.331753	10.49	12.25	1
	5	43.95329	22.76	25.32	0
		15.21628	10.49	12.25	1
CO ₂	1	17.99144	22.76	25.32	0
		5.819460	10.49	12.25	1
	7	27.64228	22.76	25.32	0
		8.642821	10.49	12.25	1
SO ₂	4	35.21472	22.76	25.32	0
		9.236114	10.49	12.25	1
TSP	2	20.52147	22.76	25.32	0
		3.455161	10.49	12.25	1
	4	20.18521	22.76	25.32	0
		4.804045	10.49	12.25	1
<i>Constant and deterministic trend in cointegrating equation, quadratic deterministic trend in data</i>					
CO	2	18.14936	16.06	18.17	0
		3.327131	2.57	3.74	1
	5	26.04205	16.06	18.17	0
		0.209288	2.57	3.74	1
CO ₂	1	9.743071	16.06	18.17	0
		2.068511	2.57	3.74	1
	7	16.60340	16.06	18.17	0
		1.742261	2.57	3.74	1
SO ₂	4	22.09676	16.06	18.17	0
		0.150798	2.57	3.74	1
TSP	2	18.29432	16.06	18.17	0
		1.562077	2.57	3.74	1
	4	14.73284	16.06	18.17	0
		0.102407	2.57	3.74	1

^a Three criteria were used to choose the order of the unrestricted VAR: likelihood ratio tests, the multivariate generalization of the AIC, and the multivariate generalization of the SC. In the first case, the order was chosen such that the null hypothesis that the coefficients of the highest-order lag were jointly zero could be rejected at the 10% level of significance, beginning with the highest plausible lag and testing down. In the other two cases, the lag length was chosen so as to minimize the criterion. The AIC and SC are defined as follows:

$AIC = T \log |\hat{\Sigma}| + 2N$ and $SC = T \log |\hat{\Sigma}| + N \log T$, where $\hat{\Sigma}$ is the maximum likelihood estimate of the system variance-covariance matrix, T is the number of observations, and N is the total number of parameters to be estimated in the VAR model.

Table 5. Johansen's maximum eigenvalue test for cointegration					
Variable	Order of VAR ^a	λ_{\max}	10% critical value	5% critical value	Value of r under H_0
<i>Constant and deterministic trend in cointegrating equation, linear deterministic trend in data</i>					
CO	2	12.13902	16.85	18.96	0
		3.544151	10.49	12.25	1
	5	13.61227	16.85	18.96	0
		7.207714	10.49	12.25	1
CO ₂	1	11.51403	16.85	18.96	0
		5.504914	10.49	12.25	1
	7	6.430901	16.85	18.96	0
		1.918957	10.49	12.25	1
SO ₂	4	15.58714	16.85	18.96	0
		5.541664	10.49	12.25	1
TSP	2	13.96336	16.85	18.96	0
		2.826949	10.49	12.25	1
	4	9.228707	16.85	18.96	0
		2.882424	10.49	12.25	1
<i>Constant and deterministic trend in cointegrating equation, quadratic deterministic trend in data</i>					
CO	2	12.1273	14.84	16.87	0
		2.722202	2.57	3.74	1
	5	12.23656	14.84	16.87	0
		0.099139	2.57	3.74	1
CO ₂	1	7.259711	14.84	16.87	0
		1.956711	2.57	3.74	1
	7	13.50647	14.84	16.87	0
		4.583821	2.57	3.74	1
SO ₂	4	13.16757	14.84	16.87	0
		0.090484	2.57	3.74	1
TSP	2	13.69003	14.84	16.87	0
		1.278056	2.57	3.74	1
	4	8.778266	14.84	16.87	0
		0.061441	2.57	3.74	1

^a For a description of the criteria used to choose the lag length, see note *a* of table 4.

Table 6. Results of causality tests

Variable	Order of unaugmented VAR model ^a	Sample period	H ₀ : <i>LED</i> does not cause <i>LY</i> ^b	H ₀ : <i>LY</i> does not cause <i>LED</i> ^b
<i>Wald tests (VAR model in first differences)</i>				
CO	1 ^c	1976-1997	7.692 (0.006)	0.112 (0.973)
	5	1980-1997	23.462 (0.000)	5.534 (0.354)
CO ₂	1 ^c	1960-1995	0.730 (0.393)	2.094 (0.148)
	6	1965-1995	13.038 (0.042)	12.202 (0.058)
SO ₂	1 ^b	1976-1997	0.245 (0.621)	3.116 (0.078)
	5	1980-1997	13.546 (0.019)	21.820 (0.001)
TSP	1 ^c	1976-1997	0.006 (0.940)	2.167 (0.141)
	3 ^d	1978-1997	9.669 (0.022)	7.678 (0.0532)
<i>MWALD tests (augmented VAR model in levels with linear deterministic trend)</i>				
CO	2	1976-1977	6.058 (0.048)	1.098 (0.578)
	5	1979-1997	126.951 (0.000)	11.512 (0.042)
CO ₂	1	1959-1995	0.048 (0.827)	3.839 (0.050)
	7	1965-1995	11.127 (0.133)	15.290 (0.032)
SO ₂	4	1978-1997	12.981 (0.011)	39.720 (0.000)
TSP	2	1976-1997	7.811 (0.020)	1.665 (0.435)
	4	1978-1997	18.430 (0.001)	5.396 (0.249)

^a See note *a* of table 4 for a description of the criteria used to choose VAR order.

^b Values in parentheses are p-values.

^c This value was not actually selected by any of the criteria used; instead, 0 was chosen. The tests were carried out anyway for this case because 1 is the smallest possible order for a VAR model.

^d This value was selected not by one of the three criteria described in note *a* of table 4, but by a sequence of Wald tests, another possible method of choosing the VAR order.

End Notes

¹ Dissolved oxygen is associated with *reduced* environmental degradation so the curve for this relationship is an N shape.

² The concentrations of these three air pollutants are actually measured as percentages of the National Ambient Air Quality Objectives (NAAQO) “maximum acceptable” concentration. A table summarizing the NAAQO can be found at http://www.ec.gc.ca/Ind/English/Urb_Air/Tech_Sup/uasup5_e.cfm.

³ The data on CO, SO₂ and TSP were obtained from Table 6.2.1 in Statistics Canada (2000, p. 126). Data on CO₂ and GDP per capita are available in Table A1 of Day and Grafton (2001, pp. 308-309).

⁴ Although there is no theory to guide us as to whether the reduced form relationship is most likely to hold in terms of levels or logs of variables, in this paper we restrict our attention to logs because the times-series based tests we carry out later are conducted exclusively on the logs of the data series.

⁵ This also requires that $|a_4| < |a_3| < |a_2|$.

⁶ Interestingly, when a quadratic reduced form model is estimated for TSP it seems to perform better than the cubic equation. After a correction for autocorrelation, the coefficients of both LY and LY^2 are significantly different from zero at the 6% level (results are available from authors upon request). This discrepancy between the quadratic and cubic reduced form models is likely due to the high degree of multicollinearity between the explanatory variables as indicated by auxiliary R^2 values in excess of 0.9999 from regressions of each of the explanatory variables upon all of the others. However, it should be noted that even if the estimates of the quadratic reduced form for TSP are assumed to be reliable, they imply that increases in per capita income will increase TSP.

⁷ Critical values are from MacKinnon (1991).

⁸ Note that it is not entirely clear whether the test is appropriate for the quadratic and cubic specifications, as they really constitute nonlinear models of the relationship between two variables, rather than models involving three or four completely different variables. The theory of cointegration testing is not well developed for nonlinear relationships. See Granger and Teräsvirta (1993), chapter 5, for some discussion of this issue.

⁹ It is interesting to note that when the Engle-Granger test was applied to reduced form models that excluded the time trend, the results generally implied that the variables were cointegrated. Yet if the series do contain a deterministic trend and are stationary about that trend, there is once again a risk of spurious results if that trend is excluded from the equation.

¹⁰ The case of a trend in the cointegrating equation is referred to as stochastic, as opposed to deterministic, cointegration.

¹¹ For all four measures of environmental degradation, at least one of the three criteria used to determine lag length implied that the appropriate lag length was zero. A lag length of zero would imply no VAR model and hence no causality.