Economic Growth and Environmental Degradation in Canada

Kathleen Day and R. Quentin Grafton

The stationary state of capital and wealth... would be, on the whole, a very considerable improvement on our present condition.
John Stuart Mill (1994)

INTRODUCTION

In the past generation Canada's population has increased by a third while its economy, as measured by its Gross Domestic Product (GDP),[1] has doubled. This growth has imposed stresses on our environment in terms of habitat loss, degradation and depletion of natural resources, and increased emissions of some important pollutants. In addition, Canada now faces serious consequences of global environmental challenges.[2] Despite these negative impacts, improvements have been made in terms of energy conservation, the water quality of the Great Lakes region and some aspects of air quality in urban areas.[3]

The key question for the next 25 years is what will be the effect of growth, and in particular economic growth, on Canada's environment? At one extreme are those who suggest that Canada has already reached its carrying capacity and that without a radical change in our consumption, production processes and waste disposal we will face major environmental losses. In this view, increases in GDP that arise from converting energy and natural resources into capital and consumption goods reduce environmental quality. In the most pessimistic outlook, deterioration of the environment, and its ability to provide inputs and assimilate wastes, will eventually lead to reductions in GDP. Before this point arises, however, broad-based measures of welfare will already be in decline.[4]

In a contrary view, called "weak sustainability," natural capital and human-made capital are substitutes in the production of environmental quality such that economic growth may be accompanied by reductions in environmental degradation.[5] In the most optimistic scenario, known as the Porter hypothesis, measures to reduce the environmental impacts of consumption and production stimulate total factor productivity, producing benefits for economic growth and the environment simultaneously (Porter and van der Linde 1995). If reducing environmental impacts imposes an opportunity cost on the economy, growth in GDP may still be compatible with an improvement in environmental quality, provided that increases in total factor productivity more than offset the economic costs of abating or mitigating environmental impacts.

By examining the environmental trends over the past few decades, and the relationship between environmental indicators and economic growth, we can better judge what the future may hold. Using environmental indicators, this paper provides an empirical analysis of economic growth and the environment from a Canadian perspective. The following section of the paper reviews the broad relationships between the environment and human activity. The third section focuses on the literature on economic growth and the environment. The fourth section reviews environmental trends in Canada and analyses their relationship to economic growth. The fifth section discusses the results and their insights. The final section provides conclusions about the study and its implications for the future.

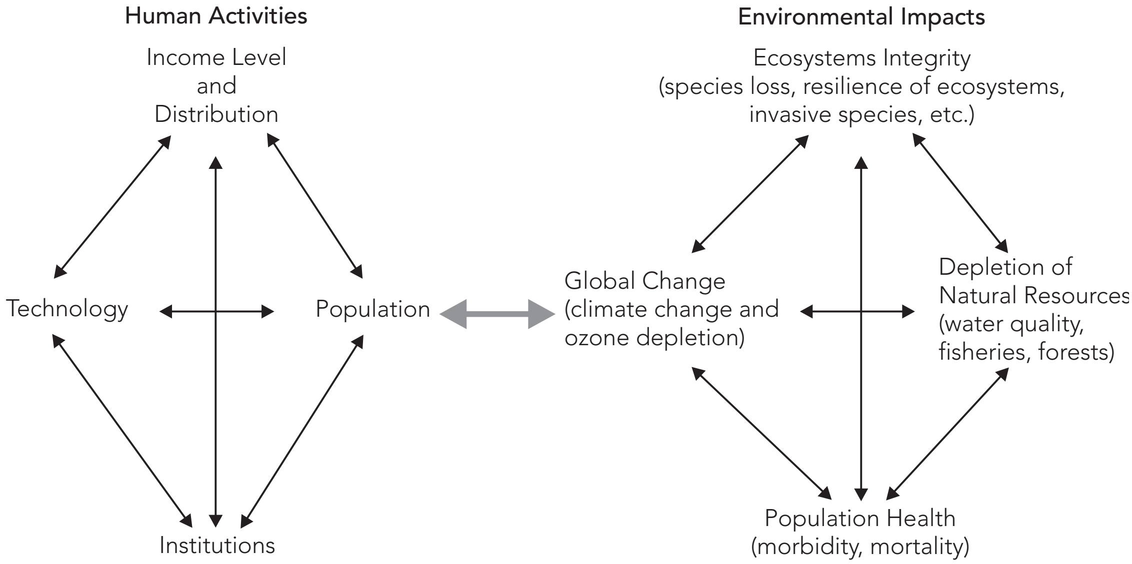
HUMAN ACTIVITIES AND ENVIRONMENTAL IMPACTS

The environment is a collective term for the ecosystems that we use and benefit from on a local, national and global scale. It includes non-renewable resources, such as minerals and energy deposits, that decline with extraction; renewable resources, such as fisheries, forests, soil and water, that can be degraded with use; and ecosystems that are affected by species loss, habitat destruction, the spread of invasive species, climate change and many other factors.

Human activities affect each component of the environment, but in different ways that change over time. For example, in 1900 Canada was highly dependent on coal as an input into production processes. As the economy developed, many industries switched to other energy sources, such as oil and natural gas, and coal's relative importance has declined. This fuel switching has substantially reduced the accumulation of particulate matter in the air, especially in urban centres, that would have occurred in the absence of substitution to cleaner-burning energy sources. By contrast, the widespread and increasing use of automobiles in major urban centres has led to very large increases in various other types of pollutants, such as carbon dioxide.

The main drivers of human activities are the size of the population, the level of income or output in the economy and its distribution, the institutions that determine the interactions and decisions of individuals and communities, and the state of technology. Combined, these factors determine environmental impacts due to human activities. These environmental effects can be observed in terms of population health, depletion of natural resources, ecosystem integrity and global change and are illustrated in Figure 1. The diagram shows the links between human activities and environmental impacts and indicates that these effects are unlikely to be uniform across the different components of the environment. For example, in recent years the area of land in provincial and national parks has increased significantly, but, contemporaneous with these changes, emissions of greenhouse gases have risen steeply.

FIGURE 1
Human Activities and Environmental Impacts



Several authors have examined human activity-environmental impact from an aggregate or macro perspective. To help present the drivers of the system, an identity given by equation (1) is useful:[6]

$$ED = P \bullet Y \bullet I \quad (1)$$

where ED is gross or aggregate environmental degradation, P is total population, Y is real output or income per capita and I is an aggregate environmental impact coefficient per unit of aggregate economic activity. Overall environmental impact can be affected by changes in population, per capita income and the environmental impact coefficient.

Given current projections for the Canadian population[7] and an average growth rate in real GDP of 2 percent/year, the identity in equation (1) implies that the environmental impact coefficient will need to decline by some 22 percent if the current impact of human activities on the environment in Canada is not to increase in the next 25 years.[8] In other words, if the annual aggregate human impact on Canada's natural capital is not to worsen in the next generation, the environmental impact per dollar of economic activity must decline at a rate of a little less than 1 percent/year for the next 25 years. If the current impact on our environment is not sustainable, then even larger declines in the aggregate environmental impact coefficient will be required.

Reductions in the overall environmental impact coefficient will occur only if changes occur in individual sectors of the economy. These changes can be summarized by changes in inputs (such as switching fuel from coal to natural gas), composition of outputs (such as switching from producing chemicals to producing software) and the production process (such as developing less-polluting technologies).[9] All three types of changes will be required if projected economic growth is not to impose further burdens on the Canadian environment.

ECONOMIC GROWTH AND THE ENVIRONMENT

Ideally, a model that relates economic growth to the environment will account for the feedbacks inherent in such a system. For example, production that leads to greenhouse gas emissions may, with lags, affect output if greenhouse gas emissions contribute to climate change. Similarly, pollution produced today can have both immediate and lagged effects in terms of population health. These linkages can be fully examined only within a general equilibrium model that explicitly measures environmental quality and accounts for environmental policy.

Unfortunately, the data required to build a structural model of the economy and environment that is capable of providing a range of environmental indicators do not exist. Consequently, researchers have resorted to estimating reduced form models that relate indicators of environmental quality to economic performance, measured in terms of per capita income. In this approach, an environmental quality indicator (such as sulphur dioxide emissions) is treated as a dependent variable and regressed on a range of variables, particularly per capita income. Most of these reduced form studies have been undertaken using cross-sectional data from several countries for a range of pollutants, and often for multiple time periods. These regressions do not purport to explain the economic growth-environmental quality relationship but, instead, measure the nature of the relationship. For example, if environmental degradation decreases while per capita income rises in a reduced form model, this result provides no guidance as to why this relationship occurs.

The reduced form models that measure the economy-environment relationship have sometimes generated Environmental Kuznets Curves (EKCs), so called because the estimated relationships can resemble the inverted U, made famous by Kuznets, that suggests that inequality rises with increasing income and then eventually declines.[10] Similarly, some reduced form models suggest that environmental degradation initially increases with rises in per capita income but reaches a turning point and then declines, as illustrated in Figure 2. Various explanations have been offered as to why this relationship might exist: the income elasticity of demand for environmental quality may exceed one, so that as incomes rise, citizens support initiatives to reduce environmental degradation; rising incomes may be associated with shifts in the economy from resource-intensive to research-intensive outputs; and rising income, coupled with improvements in human capital and technology, may help "decouple" economic growth and pollution.

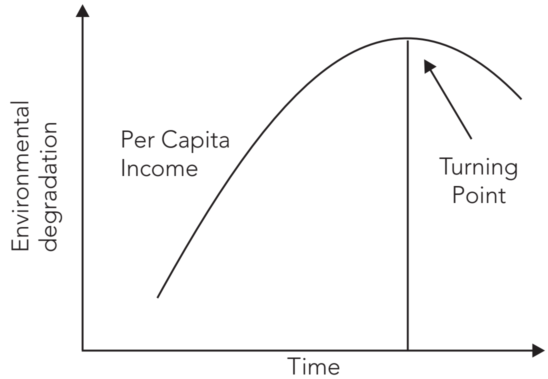
To obtain an EKC from a reduced form model, a quadratic term in per capita income must also appear in the model. Many authors have also included a cubic term in per capita income, a variable to account for the existence of a deterministic trend, exogenous variables and intercepts to account for individual country or regional fixed effects. A typical reduced form model is given by equation (2):

$$ED_{it} = \alpha_1 + \alpha^2 Y_{it} + \alpha^3 Y_{2it} + \alpha_4 Y_{3it} + \alpha_5 t + \alpha_6 X_{it} + e_{it} \quad (2)$$

where ED_{it} is a measure of environmental degradation in country i at time t, Y_{it} is per capita income of country i at time t, t is a linear time trend, X_{it} represents exogenous variables that may affect environmental quality in country i at time t, and e_{it} is an error term assumed to be independently and normally distributed. The EKC, or inverted U relationship, arises if $\alpha_2 > 0$, $\alpha_3 < 0$, and $\alpha_4 = 0$, but several other potential relationships may exist.[11] For example, environmental degradation may be monotonically increasing ($\alpha_2 > 0$, $\alpha_3 = \alpha_4 = 0$) or decreasing ($\alpha_2 < 0$, $\alpha_3 = \alpha_4 = 0$) with per capita income, or it may be a U shape ($\alpha_2 < 0$, $\alpha_3 > 0$ and $\alpha_4 = 0$). More complicated yet, two turning points may exist such that environmental degradation at first rises (falls) with income and then falls (rises) and then rises (falls) again such that $\alpha_2 > 0$, $\alpha_3 < 0$ and $\alpha_4 > 0$ ($\alpha_2 < 0$, $\alpha_3 > 0$ and $\alpha_4 < 0$).[12]

Several reviews of reduced form models of the environment and income have been carried out. Stern, Common and Barbier (1996) compare five different studies and discuss the weaknesses of the reduced form approach, including its inability to lead to informed policy, while Day and Grafton (2001) provide econometric critiques of the reduced form approach. Ekins (1997) finds scant evidence for an EKC or inverted U relationship, and de Bruyn (2000),[13] in a review of 23 reduced form regressions, finds that only 12 of the studies estimated an inverted U-shaped curve. Overall, the strongest support for an EKC curve is that for some air pollutants such as sulphur dioxide, nitrogen oxide, nitrogen dioxide and carbon monoxide, but there is little evidence for an EKC for common measures of water pollution or land-use changes. One possible explanation for this result is that air emissions may be better regulated and controlled than other forms of environmental degradation, such as land-use changes, or that some pollutants (such as sulphur dioxide) are more amenable to technical control (through the use of scrubbers) than other emissions, such as carbon dioxide, where input substitution or mitigation is much more expensive.[14]

FIGURE 2
Environmental Kuznets Curve



A broad-based EKC also contradicts other evidence based on several measures of environmental quality. For instance, MacGillivray (1993) used an index of 11 environmental indicators for 21 countries and found little evidence of a relationship between income and an index of environmental degradation.[15] Moreover, there is considerable evidence of increased environmental degradation in a number of critical areas, such as species and habitat loss and depletion of natural resources, even in the wealthiest of countries such as Canada (Devlin and Grafton 1999). Indeed, for a broad-based set of EKCs to exist there must be a tendency to reduce energy use, material use and waste, or all three components, as throughputs in an economy. Finally, even if an EKC exists for an individual country, it does not imply that such a relationship exists universally, because reductions in environmental degradation in rich countries may arise from the migration of "dirty" or heavily polluting industries to poorer countries with less strict regulations.

THE CANADIAN EXPERIENCE

Canada's environmental record has been the subject of several reviews. A 1995 report by the Organization for Economic Co-operation and Development provides a snapshot of Canadian environmental performance in terms of ecosystems, water, waste, air and public policy (OECD 1995). Using data from Environment Canada, Hayward and Jones (1998) and Devlin and Grafton (1999) provide overviews or syntheses of environmental trends over the past two decades. Hayward and Jones used 20 separate measures of environmental degradation in the categories of air quality, water quality, natural resources and solid waste and conclude that overall environmental quality improved between 1980 and 1995. Devlin and Grafton conclude that in a number of significant areas, particularly air quality, Canada has improved its environmental quality but important challenges remain. Devlin and Grafton observe that the successes that have been attained are due to effective policies at both the federal and provincial level. For instance, the 1988 Canadian Environmental Protection Act (revised in 1999 and proclaimed in 2000) has played an important role in improving waste disposal, and the 1998 Environmental Harmonization Accord set national standards for important air and water pollutants.

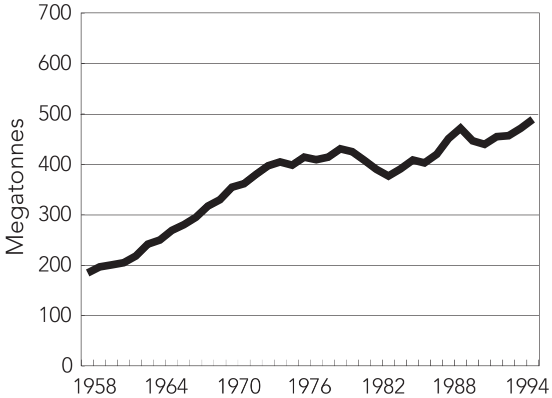
The latest review of Canada's environment is provided by Statistics Canada and includes discussions and data on the driving forces of environmental impact, the state of natural resources, measures of ecosystem health and policies (Statistics Canada 2000). The data from Statistics Canada, supplemented with data from Environment Canada's National Environmental Indicator Series, provide the most comprehensive set of measures of environmental degradation in Canada. Despite this wealth of data, most of the series on environmental indicators are available only for relatively short periods of time and thus are of limited value in terms of time-series analysis or for evaluating environmental progress in the medium to long run. Further, almost all the variables available over longer periods relate to emissions or concentrations of air pollutants and thus provide only a partial perspective on the environmental impacts of economic growth.

Reduced Form Models

In the Canadian case, the relationship of 10 measures of environmental degradation to income per capita, as measured by real GDP per capita, can be explored. The approach consists of estimating reduced form models of the relationship between environmental degradation and per capita income, and then evaluating the models using various econometric tests. The measures of environmental degradation examined in the analysis include carbon dioxide emissions (CO_2); concentrations of carbon monoxide (CO), nitrogen dioxide (NO_2), ground-level ozone (O_3), sulphur dioxide (SO_2) and total suspended particulate matter (TSP);[16] concentrations of dioxin (2,3,7,8) in herring gull eggs in the St. Lawrence River; concentrations of fecal coliform in the Saskatchewan River; and concentrations of dissolved oxygen in the Saskatchewan and Saint John Rivers.

The data on carbon dioxide are presented in Chart 1. All other air pollutants, given as averages for Canada as a whole, are graphed in Chart 2. Concentrations of dis-

CHART 1
Carbon Dioxide Emissions, 1958-1995



Source: Environment Canada.

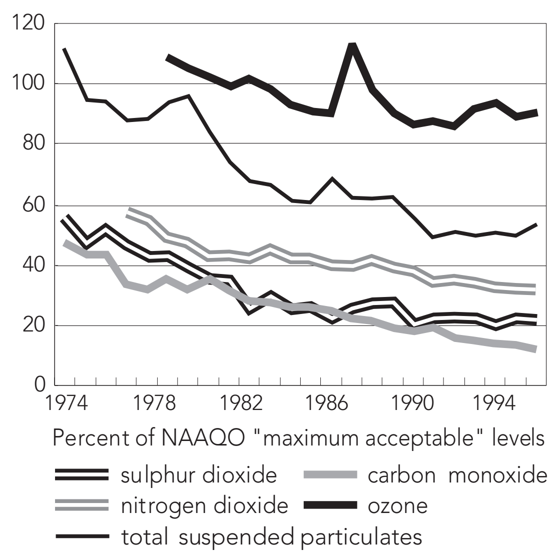
solved oxygen, fecal coliform and concentrations of dioxin, given in Charts 3, 4 and 5, apply to more restricted geographical areas. Data on real GDP per capita for Canada as a whole were obtained from CANSIM and are graphed in Chart 6.[17] The data used in the analysis, with the exception of concentrations of CO, NO_2, O_3, SO_2 and TSP, are presented in Table A1.[18]

These measures of environmental degradation represent only a very limited set of possible environmental indicators.[19] The chosen measures of air pollution are standard indicators of air quality in urban areas and are widely used measures of environmental degradation. Fecal coliform and dissolved oxygen levels are commonly used indicators of water quality and, especially, organic water pollution. Dioxins can persist for a long time in the environment and are formed in the production of organochlorine compounds and in the manufacture of chlorine-bleached wood pulp. Measures of dioxins in eggs provide an indicator of the level of bioaccumulation of persistent organic pollutants in the environment.

Two versions of the basic reduced form model given by equation (2) were estimated, but neither included any exogenous variables (X_{it}) other than income. The first version estimated the relationship with all variables in levels and the second version estimated the model with the income measures and the measure of environmental degradation in natural logarithms.[20]

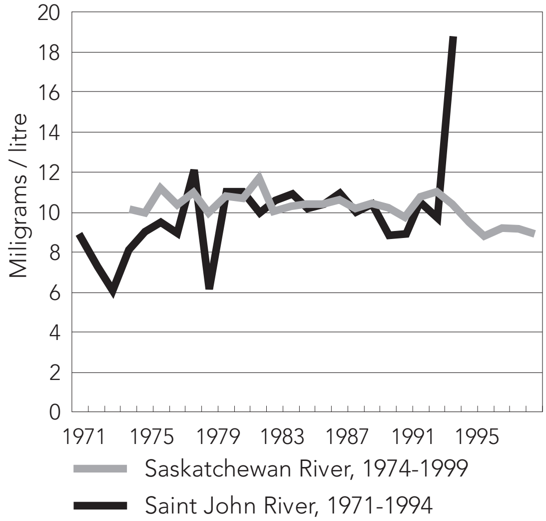
The sample sizes range from a high of 38 observations for carbon dioxide emissions to a low of 19 for concentrations of ground-level ozone. For six of the 10 pollutants — CO, CO_2, NO_2, SO_2, TSP and dioxin in herring gull eggs — the adjusted R^2 exceeds 0.9 for the equations in both levels and logs, 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 a rejection of the null hypothesis that the model had no explana-

CHART 2
Annual Average Concentrations of Air Pollutants, 1974-1997



Source: Statistics Canada (2000), Table 6.2.1.

CHART 3
Concentration of Disolved Oxygen



Source: Environment Canada.

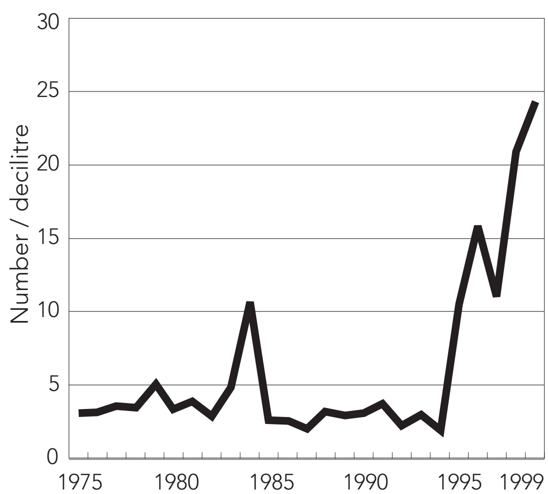
tory power for all specifications of the model except for dissolved oxygen in the Saint John River. Despite the fact that the reduced form model appears to have some explanatory power for nine of the 10 measures of environmental degradation, for most of the coefficients statistical tests do not allow us to reject the hypothesis that the coefficient is zero.

Evidence for an Environmental Kuznets Curve

As noted in the third section of the paper, an EKC exists if $\alpha_2 > 0$, $\alpha_3 < 0$ and $\alpha_4 = 0$. If we restrict our attention to those equations where the estimates of at least one of the coefficients α_2 and α_3 are statistically significant — the equations in levels for CO_2, NO_2, dioxin and fecal coliform and the equations in logs for CO, NO_2, SO_2, dioxin and fecal coliform — the evidence in favour of an EKC is not strong.[21] Only the equations for CO_2 and fecal coliform in levels and SO_2 and fecal coliform in logs display the correct pattern of signs for α_2 and α_3, and in all of those equations the estimate of α_4 is also positive and significantly different from zero at the 5-percent level of significance. These results imply that for CO_2 in levels, SO_2 in logs, and fecal coliform in levels and logs 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.

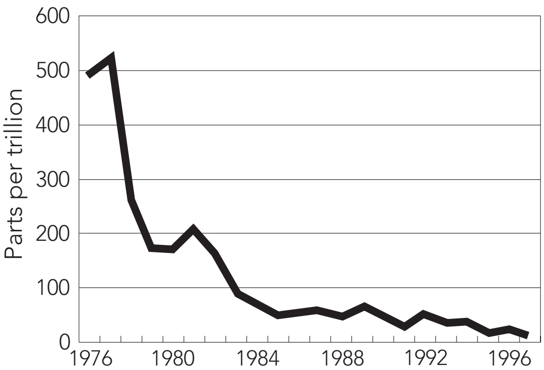
If all equations, for all measures of environmental degradation, are considered, only two different patterns of signs for the coefficients α_2, α_3 and α_4 emerge. Either $\alpha_2 > 0$, $\alpha_3 < 0$ and $\alpha_4 > 0$, which implies that environmental degradation will increase with income after the second turning point of the cubic function in income per capita has been surpassed, or $\alpha_2 < 0$, $\alpha_3 > 0$ and $\alpha_4 < 0$, which implies that environmental degrada-

CHART 4
Fecal Coliform in Saskatchewan River, 1975-1999



Source: Environment Canada.

CHART 5
Average Concentration of Dioxin (2, 5, 7, 8) in Herring Gull Eggs along the St. Lawrence River, 1976-1997

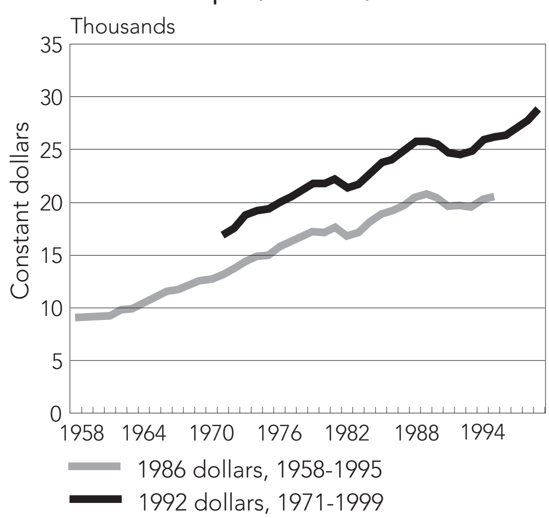


Source: Constructed by authors using data from Environment Canada.

tion 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. This latter pattern of signs, although not consistent with the EKC hypothesis, does imply a more desirable long-run relationship between environmental degradation and economic growth. This more desirable pattern of signs is evident in the reduced form estimates in both levels and logs for CO, NO_2, O_3, dissolved oxygen in the Saskatchewan River and dioxin in herring gull eggs in the St. Lawrence River, and in only the level version of the model for dissolved oxygen in the Saint John River.[22]

In order to see how close, or how far, Canada currently is from the turning points implied by the reduced form estimates, the implied level of real GDP per capita at each turning point was computed for each set of estimates.[23] The results of this calculation are presented in Table 1. It is interesting to note that in most cases (the exception being dissolved oxygen in the Saskatchewan River) the predicted turning points are similar for the level and log versions of the model. In four cases — CO_2 in levels, and TSP, dioxin and dissolved oxygen in the Saint John River — the turning points proved to be undefined. In those cases where the turning points were defined, the first turning point has long since been passed in Canada. The second turning point has also been passed in all cases except that of dissolved oxygen in the Saskatchewan River. The pattern of signs in this case implies that Canada is currently in a region where the level of dissolved oxygen is decreasing as per capita income increases, but in the future Canada should expect a reversal of this trend. The parameter estimates also imply that Canada has already reached the level of per capita income where environmental degradation will increase with income per capita in the cases of CO_2, SO_2, TSP and fecal coliform in the Saskatchewan River.

CHART 6
Real GDP Per Capita, Canada, 1958-1999



Source: Constructed by authors using data from Environment Canada.

TABLE 1
Estimated Levels of Real GDP Per Capita at Turning Points of Reduced Form Models (1992 dollars)

Equations in Levels[1] Measure of Environmental Quality	First	Year Surpassed	Second	Year Surpassed[2]	Does environmental degradation eventually decrease with income?
CO	23,552	1985	25,166	1988,1994	yes
CO_2	N/A	N/A	N/A	N/A	no
NO_2	22,463	1984	26,606	1997	yes
O_3	22,662	1984	28,308	1999	yes
SO_2	13,266	prior to 1971	23,711	1986	no
TSP	18,636	1974	22,443	1984	no
Dioxin in herring gull eggs	23,510	1985	26,296	1996	yes
Fecal coliform, Saskatchewan River	19,974	1976	24,936	1988, 1994	no
Dissolved oxygen,					
Saskatchewan River[3]	22,216	1984	34,920		yes
Saint John River[3]	18,604	1973	24,716	1987, 1993	yes
Equations in Logs[4]					
CO	20,239	1977	24,321	1987	yes
CO_2	19,133	1975	20,761	1978	no
NO_2	22,355	1984	26,251	1996	yes
O_3	22,472	1984	30,905		yes
SO_2	19,784	1976	23,157	1985	no
TSP	N/A	N/A	N/A	N/A	no
Dioxin in herring gull eggs	N/A	N/A	N/A	N/A	yes
Fecal coliform, Saskatchewan River	20,172	1977	25,176	1988, 1994	no
Dissolved oxygen,					
Saskatchewan River[3]	22,425	1984	186,354		yes
Saint John River[3]	N/A	N/A	N/A	N/A	no

[1] Based on parameter estimates in Tables 4.1 and 4.2 of Day and Grafton (2001).
[2] Empty cells in the table indicate that the level of real per capita income has not yet been achieved.
[3] An increase in dissolved oxygen is associated with an improvement in environmental quality or a reduction in environmental degradation.
[4] Based on parameter estimates in Tables 4.3 and 4.4 of Day and Grafton (2001).

If the reduced form estimates are to be taken at face value, they provide little support for the existence of EKCs in Canada, at least for the 10 measures of environmental degradation used in this study. Strong correlations, however, between the income terms make it difficult to conclusively distinguish between a quadratic and a cubic relationship in many cases. It would appear that the reduced form models might represent 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 10 measures of environmental degradation used in the study, there is little evidence to suggest there has been a decoupling of growth and environmental degradation.

EXPLAINING THE ECONOMIC GROWTH-ENVIRONMENT RELATIONSHIP

The results suggest that the interrelationships between economic growth and the environment cannot, in general, be determined by reduced form models.[24] Unfortunately, data limitations often prevent the building of detailed structural models of the environment and the economy.

As an alternative, a sectoral approach is proposed, which picks "key" environmental indicators and, where data are available, directly relates them to specific human activities. For example, in Canada sulphur dioxide emissions come from several key sources including power plants, smelting and vehicle emissions. To understand the relationship between sulphur dioxide emissions and economic activity, emissions from the major sources need to be tracked and the changes explained.[25] For example, sulphur dioxide emissions may decline due to fuel switching (from high- to low-sulphur coal), increased energy efficiency (less fuel used per unit of output produced) or the use of emissions-control devices. Changes in these factors, in turn, need to be explained by shifts in regulations or other factors. A sectoral analysis for a range of environmental indicators, such as carbon monoxide, total suspended particulate matter and dissolved oxygen, would provide a wealth of information about the underlying relationship between environmental degradation and human activity.

A sectoral analysis would help explain the over 50-percent decline in sulphur dioxide emissions in Canada between 1970 and 1995, with concomitant reductions in sulphur dioxide concentrations. For instance, the 1985 Acid Control Program and the ensuing regulations led to a 40-percent reduction in sulphur dioxide emissions for all provinces except British Columbia, Alberta and Saskatchewan between 1980 and 1993 (OECD 1995). Recent regulations introduced under the 1999 Canadian Environmental Protection Act will, by 2005, result in a reduction of over 90 percent in the sulphur content of gasoline used in Canada (Statistics Canada 2000). Similarly, public concerns over dioxins resulted in much stricter emissions controls on pulp and paper mills beginning in the 1990s, and ultimately led to large investments in wastewater treatment facilities to reduce discharges. Similar sectoral analyses for other pollutants, and by economic activity, would enable policy-makers to ascertain the effects of regulations, technological progress and other factors on emissions. This approach would be extremely useful in understanding what factors cause changes in environmental degradation over time. Such analysis, and indeed any meaningful environmental study, requires reliable data collected on a regular and on-going basis for a variety of measures of environmental quality in the air, water and land.

A range of environmental indicators can also be developed to provide a sectoral analysis of environmental degradation and economic growth. A report by the OECD proposed a set of indicators for its member countries and criteria for evaluating indicators that include their policy relevance, analytical soundness and measurability (OECD 1999). The US National Research Council has proposed a different set of criteria and ecological indicators for use in the United States that measure land-use change (land-use cover by ecological status), the state of the ecological capital (total species diversity, native species diversity) and ecosystem functioning (net primary productivity, soil organic matter, stream oxygen, lake trophic status, land-use and nutrient-use efficiency) (National Research Council 2000). Both approaches try to link the proposed environmental indicators to direct human activity. For example, indicators of dissolved oxygen can be telemetered, continuously measured and directly related to upstream discharges. Such an approach, unlike a reduced form model, helps explain the underlying relationship between the economy and environmental degradation. Such analysis naturally feeds back into improved policies and actions to address environmental challenges.

CONCLUDING REMARKS

Canada faces a number of important challenges in terms of its environment. These include climate and atmospheric change, species loss, degradation of ecosystems and depletion of renewable natural resources. To a great extent, these challenges are driven by human activity in terms of consumption patterns, production processes and waste disposal.

A common method for analysing 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. Some of the researchers who have used this approach have found evidence for a so-called EKC where environmental degradation supposedly increases with per capita income, reaches a turning point and then declines. Some authors have used such results to suggest that economic growth is a sine qua non to reduce environmental degradation and that increasing incomes provide the stimulus for improvements in environmental quality.

The results in this paper, derived from Canadian data on 10 measures of environmental degradation, indicate that reduced form models do not provide an adequate representation of the growth-environment relationship. Moreover, there is little evidence to suggest that increases in real per capita income will themselves reduce environmental degradation.

To adequately assess the environment-economic growth relationship, a sectoral analysis is recommended. This approach requires the collection of various measures of environmental indicators and, for each measure, an analysis of the factors affecting the major sources that help determine the level of the indicator. Although this approach has its own limitations due to the long-range transportation of pollution and transboundary pollutants, it will help to explain the effects of economic and social progress on the environment. Further research, including the development of sectoral studies and the enlargement of Canada's environmental data base and indicators, is required if Canada is to understand the environment-growth relationship and to address its ongoing environmental challenges.

NOTES

The authors are grateful for the research assistance of Markes Cormier and the valuable comments of Andrew Sharpe and Robert Smith on an earlier draft. We acknowledge the assistance of Environment Canada in supplying some of the data used in the study.

1 GDP is a frequently used measure of economic activity and represents the total income (wages, profits and rents) produced in a country in a 12-month period. It also is equal to total consumption, investment and government expenditures less the value of imports plus the value of exports. Thus GDP is not a true measure of economic growth because it does not account for declines in natural capital and the environment or measure non-monetary production in an economy.

2 A description of the environmental challenges of the 20th century is provided by McNeill (2000). A review of the causes and effects of anthropogenic environmental degradation, from the earliest times, is given by Ponting (1991).

3 An excellent summary of the state of Canada's environment is given in Statistics Canada (2000).

4 Various measures of economic welfare have been developed. A very useful summary of these indexes, and how they are applied in the Canadian context, is provided by Sharpe (2000).

5 For further details on the nature of strong and weak sustainability, consult Neumayer (1999).

6 The identity appears in this form in Holdren and Ehrlich (1974), 288. The first reference to such an identity is in Ehrlich and Holdren (1971). Such an identity is also described in Daly (1973).

7 Population projections are derived from Table 4.1.16 in Statistics Canada (2000).

8 The projection for Canada is calculated by using the population projection discussed in supra note 7 and assuming a 2-percent increase/year in GDP for the 25 years. The calculated decline in I is the amount by which I must fall to ensure that gross environmental degradation remains unchanged over the next 25 years.

9 For further details see Lecomber (1975).

10 Such nomenclature is unfortunate as both the theoretical and empirical observation of an inverted U, in terms of income inequality and income, is in dispute: Anand and Kanbur (1993). For further details see Kuznets (1955).

11 It also requires that $\alpha 3 < \alpha 2$.

12 Such a relationship also requires that $\alpha 4 < \alpha 3 < \alpha 2$.

13 Table 5.1 in de Bruyn (2000). The table includes regressions from seven different studies that examine four different measures of air pollution/quality (sulphur dioxide, particulate matter, nitrogen oxide, carbon dioxide), two measures of water quality (fecal coliform, dissolved oxygen) and one measure of land-use change (deforestation).

14 We are grateful to Robert Smith for suggesting possible reasons for differences in EKC relationships for different pollutants.

15 The indicators include carbon dioxide emissions per capita, oxides of nitrogen per capita, oxides of sulphur per capita, water abstractions per capita, wastewater treatment as percentage of population served, major protected areas as percentage of land area, threatened mammal and bird species as percentage of total number of mammals and birds, municipal solid waste per capita, energy supply per unit of GDP, passenger kilometres in private road vehicles per capita, and nitrate fertilizers per square kilometre of arable and permanent cropland. In this study, Canada was the worst performer, except for the United States, out of 21 countries.

16 The concentrations of these five 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

17 See Table A1 for detailed information regarding data sources. Because the data on dioxin concentrations, dissolved oxygen and fecal coliform are for specific geographical areas, it might have been better to use provincial GDP per capita for the relevant provinces in our analysis, rather than national GDP per capita. However, Statistics Canada does not produce consistent time series on real provincial GDP that go back beyond 1981.

18 The remaining data are provided in Table 6.2.1 in Statistics Canada (2000), 126.

19 A good discussion of how to use and apply the environmental performance indicators employed is provided by Segnestam (1999).

20 Ordinary Least Squares (OLS) estimates of the coefficients of equation (2), in levels and logs, are provided in Day and Grafton (2001), together with a number of diagnostic statistics.

21 "Statistically significant" means that a statistical test led to the rejection of the null hypothesis that the true value of the coefficient is zero. See Day and Grafton (2001) for a thorough discussion of the statistical tests undertaken.

22 By contrast to the other environmental measures, increases in dissolved oxygen are associated with decreases in environmental degradation.

23 The turning points are the levels of real per capita GDP such that the first derivative with respect to Y or log of Y is zero. Because equation (2) is a cubic polynomial, its first derivative is a quadratic equation.

24 Day and Grafton (2001) use time series models to assess the growth-environment relationship.

25 Ekins (2000) provides one of the very few sectoral analyses of the environment-economy relationship. Using this approach, he explains changes in sulphur dioxide emissions in the United Kingdom from 1970 onwards.

REFERENCES

Anand, S., and S.M.R. Kanbur. 1993. "Inequality and Development: A Critique." *Journal of Development Economics* 41:19-433.

Bishop, C.A., D.V. Weseloh, N.M. Burgess, J. Struger, R.J. Norstrom, R. Turle and K.A. Logan. 1992. *An Atlas of Contaminants in the Eggs of Fish-Eating Colonial Birds of the Great Lakes (1970-1988). Vol. 2: Accounts by Chemical*. Technical Report Series #153, Environment Canada, Canadian Wildlife Service, Ontario Region.

Daly, H.E. 1973. "The Steady-State Economy: Toward a Political Economy of Biophysical Equilibrium and Moral Growth," in *Toward a Steady-State Economy,* ed. H.E. Daly. San Francisco: W.H. Freeman, 149-174.

Day, K., and R.Q. Grafton. 2001. "Economic Growth and the Environment: A Canadian Perspective." Working Paper 0101E. Ottawa: University of Ottawa, Department of Economics.

De Bruyn, S.M. 2000. *Economic Growth and the Environment: An Empirical Analysis.* Dordrecht: Kluwer Academic, 82-83.

Devlin, R.A., and R.Q. Grafton. 1998. *Trends in Canada's Natural Capital.* Paper prepared for the conference on the State of Living Standards and the Quality of Life in Canada, Ottawa, October 30-31, 1998.

Ehrlich, P.R., and J.P. Holdren. 1971. "Impact of Population Growth," *Science* (26 March):1212-1217.

Ekins, P. 1997. "The Kuznets Curve for the Environment and Economic Growth: Examining the Evidence," *Environment and Planning A* 29:805-830.

——— 2000. *Economic Growth and Environmental Sustainability: The Prospects for Growth*. London: Routledge.

Hayward, S., and L. Jones. 1998. *Environmental Indicators for Canada and the United States*. Critical Issues Bulletin. Vancouver: Fraser Institute.

Holdren, J.P., and P.R. Ehrlich. 1974. "Human Population and the Global Environment." *American Scientist* 62 (May/June):282-292.

Kuznets, S. 1955. "Economic Growth and Income Inequality." *American Economic Review* 45:1-28.

Lecomber, R. 1975. *Economic Growth Versus the Environment*. London: Macmillan.

MacGillivray, A. 1993. *A Green League of Nations: Relative Environmental Performance in OECD Countries*. London: New Economics Foundation.

McNeill, J.R. 2000. *Something New Under the Sun: An Environmental History of the Twentieth-Century World*. New York: W.W. Norton.

Mill, J.S. 1994. *Principles of Political Economy and Chapters on Socialism,* ed. Jonathan Riley. Oxford: Oxford University Press, 126.

National Research Council. 2000. *Ecological Indicators for the Nation*. Washington: National Academy Press.

Neumayer, E. 1999. *Weak Versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms*. Cheltenham: Edward Elgar.

OECD. 1995. *Environmental Performance Reviews: Canada*. Paris.

——— 1999. *Towards More Sustainable Household Consumption Patterns Indicators to Measure Progress*. Paris.

Pekarik, C.D., V. Weseloh, G.C. Barrett, M. Simon, C.A. Bishop and K.E. Petit. 1998. *An Atlas of Contaminants in the Eggs of Fish-Eating Colonial Birds of the Great Lakes (1993-1997). Vol. 2: Accounts by Chemical*. Technical Report Series #153. Environment Canada, Canadian Wildlife Service, Ontario Region.

Petit, K.E., C.A. Bishop, D.V. Weseloh and R.J. Norstrom. 1994. *An Atlas of Contaminants in the Eggs of Fish-Eating Colonial Birds of the Great Lakes (1989-1992). Vol. 2: Accounts by Chemical*. Technical Report Series #153. Environment Canada, Canadian Wildlife Service, Ontario Region.

Ponting, C. 1991. *A Green History of the World: The Environment and the Collapse of Great Civilizations*. New York: Penguin.

Porter, M.E., and C. van der Linde. 1995. "Toward a New Conception of the Environment-Competitiveness Relationship." *Journal of Economic Perspectives* 9(4):97-118.

Segnestam, L. 1999. *Environmental Performance Indicators: A Second Edition Note*. Washington: World Bank Environment Department.

Sharpe, A. 2000. *A Survey of Indicators of Economic and Social Well-Being*. Background paper prepared for Canadian Policy Research Networks, Ottawa.

Statistics Canada. 2000. *Human Activity and the Environment 2000*. Ottawa: Statistics Canada.

Stern, D.I., M.S. Common and E.B. Barbier. 1996. "Economic Growth and Environmental Degradation: The Environmental Kuznets Curve and Sustainable Development." *World Development* 24:1151-1160.

TABLE A1
Data Used in Empirical Analysis

Year	CO_2 Emissions[1] (mega-tonnes)	Concentration of Dioxin (2,3,7,8) in Herring Gull Eggs, St. Lawrence River[2] (parts / trillion)	Concentration of Dissolved Oxygen, Saskatchewan River[3] (milligrams / litre)	Concentration of Fecal Coliform, Saskatchewan River (number / decilitre)	Concentration of Dissolved Oxygen, Saint John River[4] (milligrams / litre)	GDP Per Capita, Canada, 1986 Dollars[5] (D14606)	GDP, Canada, Millions of 1992 Dollars (D22467)	Population, Canada (C892268)	GDP Per Capita, Canada, 1992 Dollars (calculated by authors)
1958	185					8,984			
1959	197					9,122			
1960	200					9,184			
1961	205					9,281			
1962	219					9,754			
1963	242					10,072			
1964	250					10,543			
1965	269					11,037			
1966	280					11,567			
1967	295					11,694			
1968	317					12,128			
1969	330					12,595			
1970	355					12,742			
1971	362				8.88	13,030	370,859	21,962,082	16,886
1972	380				7.34	13,617	390,702	22,219,560	17,584
1973	397				6.07	14,488	418,797	22,493,842	18,618
1974	405		10.10		8.13	14,917	436,151	22,808,446	19,122
1975	399		9.86	3.17	9.00	15,085	445,813	23,142,275	19,264
1976	414	489.00	11.22	3.13	9.55	15,804	470,291	23,449,793	20,055
1977	409	518.00	10.43	3.60	8.96	16,184	486,562	23,726,345	20,507
1978	414	261.00	11.00	3.50	12.10	16,756	506,413	23,963,967	21,132
1979	431	169.00	9.93	5.00	6.20	17,231	527,703	24,202,205	21,804
1980	425	170.00	10.78	3.30	11.01	17,263	535,007	24,516,278	21,823
1981	408	207.00	10.72	3.82	10.98	17,676	551,305	24,820,382	22,212
1982	390	166.50	11.69	3.00	10.00	16,902	535,113	25,117,424	21,304
1983	377	90.00	10.00	4.89	10.53	17,263	549,843	25,366,965	21,676
1984	391	70.33	10.25	10.55	10.91	18,176	581,038	25,607,555	22,690
1985	409	53.00	10.41	2.62	10.20	18,867	612,416	25,842,590	23,698
1986	403	53.75	10.36	2.62	10.32	19,297	628,575	26,100,587	24,083
1987	420	58.00	10.61	2.00	10.87	19,839	654,360	26,449,888	24,740

TABLE A1 (Continued)

Year	CO_2 Emissions[1] (mega-tonnes)	Concentration of Dioxin (2,3,7,8) in Herring Gull Eggs, St. Lawrence River[2] (parts / trillion)	Concentration of Dissolved Oxygen, Saskatchewan River[3] (milligrams / litre)	Concentration of Fecal Coliform, Saskatchewan River (number / decilitre)	Concentration of Dissolved Oxygen, Saint John River[4] (milligrams / litre)	GDP Per Capita, Canada, 1986 Dollars[5] (D14606)	GDP, Canada, Millions of 1992 Dollars (D22467)	Population, Canada (C892268)	GDP Per Capita, Canada, 1992 Dollars (calculated by authors)
1988	451	45.67	10.23	3.14	10.01	20,560	686,176	26,798,303	25,605
1989	470	63.00	10.39	3.00	10.38	20,691	703,577	27,286,239	25,785
1990	447	52.00	10.21	3.08	8.90	20,351	705,464	27,700,856	25,467
1991	440	29.25	9.75	3.70	8.92	19,739	692,247	28,030,864	24,696
1992	455	49.30	10.70	2.23	10.50	19,596	698,544	28,376,550	24,617
1993	457	36.89	11.03	3.00	9.70	19,755	714,583	28,703,142	24,896
1994	471	34.94	10.40	1.94	18.80	20,341	748,350	29,035,981	25,773
1995	489	14.75	9.42	10.33		20,565	769,082	29,353,854	26,200
1996		20.39	8.84	15.83			780,916	29,671,892	26,318
1997		9.39	9.25	11.00			815,013	29,987,214	27,179
1998			9.17	20.91			842,002	30,247,949	27,837
1999			8.91	24.29			880,254	30,493,433	28,867

[1] Data on CO_2 emissions were obtained from http://www.ec.gc.ca/Ind/English/Climate/Bulletin/ccind1_e.cfm. The data were last updated in 1998. The original source is the Environmental Protection Service, Environment Canada, Ottawa, Ontario.

[2] Data on dioxin in herring gull eggs were obtained from Bishop *et al.* (1992) for the years 1974–88; from Petit *et al.* (1994) for the years 1989–92; and from Pekarik *et al.* (1998) for the years 1993–97. The value for each year is the mean over each site along the St. Lawrence River at which measurements were taken in that year.

[3] Data on water quality in the Saskatchewan River were supplied by Bing Chu in Regina, from Environment Canada's Envirodat data base, on 24 October 2000.

[4] Data on water quality in the Saint John River were supplied by David Lockerbie of Environment Canada in Moncton on 25 October 2000, with the following disclaimer: "The data are provided 'as-is' and although normal quality control/quality assurance techniques were used during the course of data collection, the Department makes no warranty, either expressed or implied, including but not limited to warranties of fitness for a particular purpose. In no event will the Department be liable for any indirect, consequential or similar damages resulting from the use of the data."

[5] Data on Canadian GDP were obtained from CANSIM. Series D14606 (matrix 6845), real per capita GDP at market prices in constant 1986 dollars, was used with the data on CO_2 emissions. The last update before the data were retrieved was 25 June 1996. For use with the remaining measures of environmental degradation, real GDP was computed using series D22467 (matrix 8602), GDP at 1992 prices, expenditure-based; and C892268 (matrix 6367), population of Canada as of 1 July. The last update prior to the retrieval of the data was 6 June 2000 for the GDP data and 24 October 2000 for the population data.