Revisiting the Environmental Kuznets Curve Model: Greenhouse Gas Emissions within Canada

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Abstract The change in human behavior from living on the land to living off the land's resources through industrialization, increasing living standards, and rising incomes have been marked by rapidly increasing emissions of greenhouse gasses (GHGs) into the earth's atmosphere. The Environmental Kuznets curve (EKC) hypothesis posits that as income grows, environmental degradation increases until an economy reaches a tipping point, beyond which environmental degradation will decline as income increases (Stern, 2004). This study empirically examines the validity of the EKC hypothesis as applied to Canada's provinces and territories from 1990-2020, using data on GHG emissions and GDP per capita as environmental degradation and income indicators. Overall, the results of this study support the EKC hypothesis at the Canadian level and confirm the results found by previous studies. Confirmation of the EKC indicates that increasing economic growth in Canada's provinces and territories is unlikely to lead to higher greenhouse gas emissions and instead is likely to result in decreasing GHG emissions.

INTRODUCTION

Climate change is one of the largest global challenges faced by society today (Mikhaylov et al., 2020). Canada's rapid economic development has been marked by a rapid transition from living on the land to utilizing the land's resources through industrialization, thereby increasing incomes, living standards, and rapidly increasing emissions of greenhouse gasses (GHGs) into the earth's atmosphere. The Environmental Kuznets curve (EKC) describes the trade-off between economic growth and environmental degradation (Stern, 2004). The EKC hypothesis posits that in the early stages of economic development, environmental degradation will increase as income rises until it reaches a turning point. At this point, environmental degradation will begin to decrease as income continues to rise, resulting in an inverted U-shaped curve. Therefore, if appropriate policies are taken, economic growth can eventually lead to environmental improvement (Dinda, 2004; Karsch, 2019).

This study builds upon work conducted by Olale et al. (2018), who examined the EKC hypothesis for Canada from 1990 to 2014, using data from 1990 to 2020 for all of Canada's provinces and territories. Through this research project, we will answer the following key question: is the relationship between GDP per capita and GHG emissions per capita within Canada's provinces and territories consistent with the EKC hypothesis? In addition, by comparing our results with those of Olale et al. (2018), we can examine whether recent developments have changed the relationship between economic development and environmental degradation in the Canadian provinces and territories.

METHODS

The Environmental Kuznets Curve hypothesis

The EKC hypothesis originates from the Kuznets curve, which was developed by the Russian economist Simon Kuznets (Stern, 2004). Kuznets hypothesized that economic inequality rises and falls as economic development increases (Kuznets, 1955). The concept of the EKC first emerged with a paper by Grossman and Kreuger (1991), which was subsequently popularized by the 1992 World Bank Development Report (Stern, 2004; World Bank, 1992). As shown in Figure 1, the EKC hypothesis posits that an inverted U-shaped curve represents the relationship between different pollutants and income per capita. Therefore, measures of environmental degradation (such as GHG emissions) increase with economic growth, reach a peak, and decrease as economic development advances.

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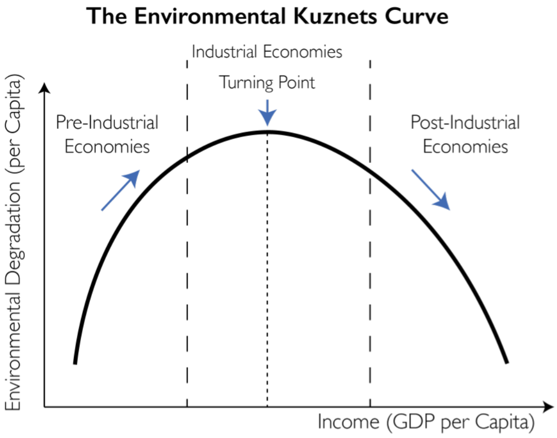

Figure 1 The EKC Hypothesis: The figure depicts the EKC Hypothesis, where environmental degradation initially increases as income rises, reaching a turning point after which environmental degradation then decreases as income continues to grow.

Validity of the EKC at a Global, National, and Regional Scale

Contradictory conclusions have been made about the applicability of the EKC on a global scale (Kaya Kanlı & Küçükefe, 2022; Narayan & Narayan, 2010). Some studies use a time series approach to evaluate the EKC within individual countries. In contrast, other studies use a panel data approach where several countries are grouped to test if the EKC holds (Narayan & Narayan, 2010; Uchiyama, 2016). Empirical studies show that the EKC hypothesis does not hold for every single economy or group of economies in the world (Kaya Kanlı & Küçükefe, 2022). This is because the EKC assumes consistent economic development across all countries included in the panel, and panel data analysis imposes strong assumptions on the groups' economic 1growth, which might not represent all countries in the panel (Churchill et al., 2018; Dinda, 2004). analysis of a single country captures country-specific characteristics, such as a country's growth, technological advancements, and policies that affect the relationship between GHG emissions and economic development (Kaya Kanlı & Küçükefe, 2022).

Theoretically, because Canada is in a later stage of economic development, environmental quality should improve as income increases (Dinda, 2004). Several studies find evidence of the EKC in Canada (Ajmi et al., 2015; Hamit-Haggar, 2012; Olale et al., 2018); in contrast, others find that the Canadian relationship between GHG emissions and GDP per capita invalidates the EKC hypothesis (Baek 2015; Day & Grafton 2003; He & Richard, 2010; Kaya Kanlı & Küçükefe, 2022). The Canadian economy varies significantly across the country, and differences in provincial and territorial industrial activities have large implications for GHG emissions (Olale et al., 2018). It follows that the EKC hypothesis in Canada may be better evaluated at the provincial and territorial levels as opposed to the national level.

Given the lack of consensus on studies done at the national level for the EKC hypothesis in Canada, research has been conducted to attempt to identify the cause of these disagreements. Heterogeneity makes the EKC results sensitive to the sample which may result in the differences between the EKC empirical results in cross-country analysis and country-level analysis (Leal & Marques, 2022). Internationally, various methods have been used to examine the EKC with a regional focus, but only two **studies,** Lantz and Feng (2006) and Olale et al. (2018), have studied the EKC at the national and provincial levels in Canada. Therefore, our study contributes to the literature by using more recent data, and by including variables that better capture economic development in the Northwest Territories (NWT) and the Yukon (YK).

Data & Methodology

This study uses panel data on Canadian provinces and territories from 1990 to 2020. The data[1] consists of 13 panels that include 10 provinces and 3 territories over 30 years, resulting in a total of 385 observations. Data on annual GHG emissions (measured as tonnes of CO2 equivalent) was obtained from Environment and Climate Change Canada, while data on population and GDP was acquired from Statistics Canada (Environment and Climate Change Canada, 2022; Statistics Canada, 2022). Figure 2 displays GDP per capita and GHG per capita from 1990-2020 in all of Canada's provinces and the YK and from 1999-2020 in the NWT and Nunavut (NU). The graphs show the relationship between GHG per capita and GDP per capita in Canada's provinces and territories, which provides some visual evidence consistent with the EKC hypothesis.

[1]Two data sets were used: data set A was used to create Model 1 and Model 3 which excludes data on GHG emissions and GDP from the Northwest Territories (NWT) and Nunavut (NU); data set B was used to create Model 2 and Model 4, which is identical to data set 1 but with the addition of data on the NWT and NU from 1999-2020. This was done because data on NWT and NU from 1990-1998 is unavailable resulting in an unbalanced panel, as well as the mean GDP per capita in NWT not being representative of Canada, possibly influencing results, both were included for transparency.

GDP per Capita and GHG per Capita in Canada's Provinces and Territories (1990-2020)

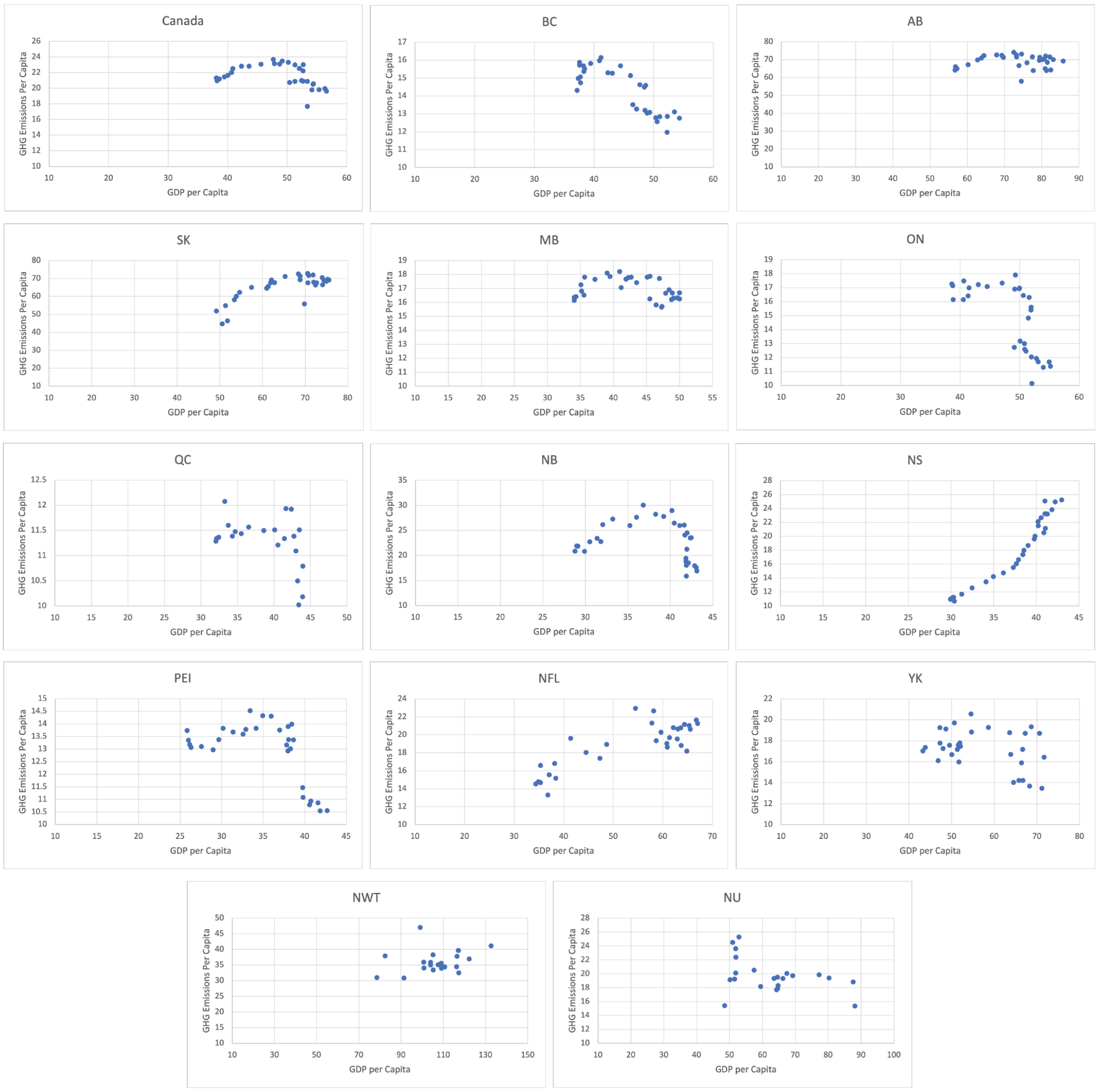

Figure 2 GDP per Capita and GHG per Capita in Canada's Provinces and Territories (1990-2020): GDP measured in constant 2012 dollars ($000), and GHG emissions are measured in tonnes; both GDP and GHG axes start at 10 units to show better the dispersion of data. Data displayed for NWT and NU is for 1999-2020.

The four models used in this study are adapted from Olale et al.'s (2018) Model 1 specification. The environmental degradation indicator is the dependent variable of GHG emissions per capita. The explanatory variables are GDP per capita (measured in thousands of 2012 dollars) and GDP per capita squared. Each province/territory is represented with a dummy variable in the panel data, and an interactive dummy variable is included that is calculated by multiplying each province/territory dummy by the GDP. This model includes GDP per capita squared to capture the inverted-U shape for the EKC hypothesis. Specifically, we estimate the following model:

$$\frac{GHG\ Emissions_{it}}{Population_{it}} = a_i + \beta_1\left(\frac{GDP_{it}}{Population_{it}}\right) + \beta_2\left(\frac{GDP_{it}}{Population_{it}}\right)^2 + +\delta_i IT_i + \varepsilon_{it} \qquad (1)$$

where i indexes the province/territory, t denotes the year, IT_i is an interaction term for GDP and provincial/territorial dummies (interactive dummy variables), a_i is the province/territory intercept, β_1 and β_2 are the coefficients to be estimated for our key dependent variables, δ_i is the coefficient for the interactive dummy variable, and ε_{it} is the random error term. In accordance with Olale et al. (2018), the EKC hypothesis is supported at the Canadian level if β_1 is positive, β_2 is negative, $|\beta_1| > |\beta_2|$, and both coefficients are statistically significant. The EKC hypothesis also holds at the provincial/territorial level if the interactive dummy variable δ_i for a given province/territory is statistically significant.

Olale et al. (2018) group YK, NWT, and NU into a "Territories" variable. Models 1 and 3 use data from 1990-2020 for all Canadian provinces, including YK, but excluding NWT and NU. Models 2 and 4 use data from all provinces and YK from 1990-2020, including NWT and NU from 1999-2020. Models 1 and 2 are estimated using a pooled regression that constrains the estimated intercept term to be identical across provinces and territories (i.e., $a_i = a$). Models 3 and 4 are estimated using a fixed-effects regression, which permits the estimated intercept term to be unique for each province/territory. This allows exogenous and time-invariant factors unique to each province or territory that may affect GHG in the province/territory to be captured in the intercept. Results in previous studies generally indicate that the fixed-effects specification is the preferred approach (Lantz & Feng, 2006).

RESULTS

Table 1 summarizes the results of the pooled and the fixed-effects regressions. Our preferred model is Model 3 because Model 1 does not control for fixed effects, and Models 2 and 4 include NWT and NU, which are not representative of the greater Canadian economic and historical context, creating an unbalanced panel that could hurt model fit. Models 1, 2, and 3 all provide support for the EKC hypothesis at the Canadian level, which is indicated by the positive β_1 estimate, β_2 negative estimate, $|\beta_1| > |\beta_2|$, and both coefficients being statistically significant. Model 4's β_2 is statistically insignificant and positive, therefore not supporting the EKC hypothesis at the Canadian level..

Table 1 Summary of the Regression Results: Values in parentheses represent standard errors; ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The intercept for the fixed-effects regression includes the province effects.

Variable	Pooled Regression		Fixed-Effects Regression	
	Model 1	Model 2	Model 3	Model 4
GDP per capita		0.390***	0.364***	0.100***
	-0.11	-0.069	-0.055	-0.029
GDP per capita^2	-0.010***	-0.004***	-0.024***	0.001
	-0.001	-0.001	-0.003	-0.001
BC	-0.098***	-0.0128***	1.391***	-0.438***
	-0.017	-0.019	-0.263	-0.128
AB	0.773***	0.674***	3.055***	-0.225*
	-0.015	-0.014	-0.387	-0.134
SK	0.765***	-0.695***	2.737***	-0.153
	-0.013	-0.014	-0.322	-0.123
MB	-0.038**	-0.069***	1.394***	-0.408***
	-0.017	-0.019	-0.243	-0.122
ON	-0.085***	-0.114***	1.824***	0.151
	-0.016	-0.017	-0.291	-0.149
QC	-0.185***	-0.218***	2.507***	0.829***
	-0.018	-0.021	-0.233	-0.128
NB	0.132***	0.091***	1.004***	0.107
	-0.02	-0.022	-0.217	-0.092
NS	0.009	-0.035	1.125***	0.107
	-0.021	-0.023	-0.222	-0.098
PEI	-0.126***	-0.178***	1.144***	0.017
	-0.022	-0.025	-0.204	-0.113
NFL	0.036**	-0.013	2.583***	-0.031
	-0.014	-0.015	-0.278	-0.112
YK	-4.850*	-0.051***	2.314***	-0.052
	-2.769	-0.015	-0.322	-0.122
NWT	-	0.243***	-	-0.054
	-	-0.021	-	-0.129
NU	-	9.799***	-	-0.079
	-	-2.042	-	-0.131
Adjusted R^2	0.977	0.972	0.623	0.278
F test: Overall Significance	1221.164***	941.020***	44.916***	11.645***

At the provincial and territorial levels, evidence for the EKC hypothesis differs depending on the estimation method used. Models 1 and 2 use a pooled regression method, and Model 1's interactive dummies are statistically significant at 10% or better in all provinces and territories except for NS. In Model 2, the interactive dummies are statistically significant in all provinces and territories except for NS and NFL. Therefore, these results support the EKC hypothesis in all provinces and territories except for NS in Model 1, and all provinces and territories except for NS and NFL in Model 2. With the fixed effect estimates of Models 3 and 4, the interactive dummies are statistically significant in all provinces and territories in Model 3. However, in Model 4, the only interactive dummies that are statistically significant are BC, AB, MB, and QC, validating the EKC hypothesis only in these provinces.

DISCUSSION

The results from Model 3 in this study confirm and reflect the results of Model 1 by Olale et al. (2018). Under the pooled regression by Olale et al. (2018), the interactive dummies are statistically significant at 10% or better in all provinces and territories except NB; additionally, the fixed-effects regression done by Olale et al. (2018) finds that all interaction variables are statistically significant. We find that including NWT and NU in the fixed-effects regression model (Model 4) significantly affects the results, with the EKC hypothesis not supported for all of Canada, and the only statistically significant interactive variables being BC, AB, MB, and QC.

The turning point of the EKC is the level of income in which environmental degradation reaches a peak and begins to decline. The turning point is calculated as:

$$\frac{GHG\ Emissions_i}{Population_i} = -\frac{\beta_1 + \delta_i}{2\beta_2} \quad (2)$$

Table 2 summarizes the turning point results for this study. The turning points for Model 3 consider all provinces except for QC to be past their turning point. This result differs from Olale et al. (2018) where SK was the only province to have not reached its turning point within the same model parameters. Our contrasting result with SK is likely due to a large increase in GDP per capita in SK in recent years, as there is only a slight change in turning point from the Olale et al. (2018) study. However, our result showing QC not having reached its turning point is the result of the turning point calculation for QC doubling in this study compared to Olale et al. (2018). Models 2 and 4 estimate a relationship that is not the U-shape hypothesized by the EKC, but due to the limitations in the models, will not be focused on in this analysis. Model 1 has turning point estimates that are much lower than those found in Olale et al. (2018). These lower estimates do not reflect the observed behavior of the relationship between GDP and GHG in the provinces and territories of Canada and are symptomatic, which is one of the reasons that fixed effects estimates of Model 3 are preferred for this study.

Table 2 Turning Point of Annual GDP per Capita ($000)

Geography	Pooled Regression		Fixed-Effects Regression	
	Model 1	Model 2	Model 3	Model 4
BC	10.01	-4.15	37.04	286.04
AB	8.58	-5.14	72.15	105.64
SK	9.95	-3.87	65.45	44.21
MB	10.7	-3.81	37.1	259.99
ON	9.94	-3.86	46.18	-213.01
QC	10.05	-3.88	60.58	-786.73
NB	9.69	-4.18	28.87	-175.87
NS	10.18	-3.83	31.43	-175.79
PEI	9.81	-4.06	31.83	-99.4
NFL	10	-3.8	62.2	-59.03
YK	10.15	-3.9	56.53	-40.78
NWT	-	-4.45	-	-39.2
NU	-	-4.08	-	-17.82

CONCLUSIONS

Overall, the results of our study support the EKC hypothesis at the Canadian level and confirm the results found by Olale et al. (2018). As we expected, Model 3 best supports these conclusions, indicative that the inclusion of data from the NWT and the YK within Models 2 and 4 changes the relationship between our relationships of interest. Additionally, the NWT has a significantly higher GDP relative to population density than other provinces, which likely plays a role in our findings.

Under the preferred model, Model 3, all provinces/territories except for QC were found to have a GDP per capita that surpassed the turning point. This suggests that all of Canada's provinces and territories (excluding QC) are past the turning point of the EKC and should have to decrease GHG emissions per capita as GDP per capita increases. The implication of most of Canada's provinces and territories surpassing the turning points is that continued economic growth may be compatible with reducing GHG emissions. Canada's current stage of economic development is advanced and is, therefore, conducive to growth without negatively affecting the environment.

A weakness of this study is that the statistical significance of the provincial interaction variables is taken as the sole confirmation of the EKC in those provinces, and further analysis or interpretation of the magnitude of the regression coefficients, other than the turning point calculations, is not provided. Analysis of this issue is beyond the scope of this study, and further work determining more robust conditions to assess the validity of the EKC at a provincial and territorial level is recommended as a future research avenue.

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CONFLICT OF INTERESTS

The authors declare no conflicts of interest.

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