# Regional and sectoral level convergence of greenhouse gas emissions in Canada

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## 1 Introduction

There is a broader consensus in Canada and elsewhere that action is required to address mounting challenges of climate change. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), global anthropogenic greenhouse gas (GHG) emissions grew on average by 0.4 gigatonne carbon dioxide equivalent (GtCO2 eq) per year from 1970 to 2000, whereas during the period of 2000 to 2010, emissions have risen by 1.0 GtCO2 eq on annual basis[1]. The report also states that the unprecedented increase in GHG emissions observed over the last few decades is unequivocally responsible for the discernible adverse impact on the climate and are very likely to have contributed to the increase of global warming. A wide range of recent scientific assessments also highlighted that most of the global warming has been caused by human activities, mainly human-induced GHG emissions. GHG emissions are known to have severe adverse effects on global average temperature, average sea level, more extreme heat waves, floods and droughts as well as environmental refugees, among others (Lashof and Ahuja, 1990; Manne et al, 1995; Dasgupta et al, 2007; Cayan et al, 2008).

As awareness of the stakes involved has increased, so has the will to combat, limit or prevent GHG emissions reinforced. Admittedly, governments around the globe have made significant efforts to effectively mitigate emissions and to address other climate change issues. International climate negotiations among parties, such as the United Nations Framework Convention on Climate Change (UNFCCC) was one of the most tangible proof of efforts towards this direction.

[1] GHG emissions are considered as the main cause of global warming and climate change.

As a signatory to the UNFCCC, Canada has committed to reduce its GHG emissions to 17% below the 2005 level by the year 2020. Although, Canada emissions represent only 1.6% of the global GHG emissions in 2012, it is one of the highest per capita emitters. Canada's emissions gradually increased since 1990.[2] In 2014, Canada's total GHG emissions were estimated to be 732 of megatonnes of carbon dioxide equivalent (Mt CO2 eq), about 20% higher of what it was in 1990[3]. As a result, in May 2015, the Canadian government has reiterated its intent to take ambitious action to reduce GHG emissions by 30% below 2005 levels by 2030. However, to attain this objective, the Canadian government understands that the need for all provinces and territories in Canada to play their part in stabilizing atmospheric greenhouse gases is crucial in fulfilling its international emissions-reductions commitments. As such, a comprehensive plan to curb emissions across all sectors of Canada's economy was launched in 2016 (*The Pan-Canadian Framework on Clean Growth and Climate Change)*. The goal of the Pan-Canadian Framework is to build in a collaborative approach between provincial, territorial, and federal governments in order to reduce GHG emissions while enabling sustainable economic growth.

Mitigating GHG emissions in Canada requires a good understanding of the status of per capita GHG emissions of each province as well as the behaviour, evolution and relative lags between sectors and across provinces. To our knowledge, no previous empirical study has examined the distribution of GHG emissions among Canadian provinces still less at disaggregated level. We argue that a good understanding of the Canadian carbon footprint is important in helping implement effective environmental policies. As it has been claimed by

[2] 1990 is the base year required by the UNFCCC Reporting Guidelines.
[3] Emissions exclude Land Use, Land Use Change and Forestry estimates.

Apergis et al (2017), any environmental policy design should consider regional differences in order to deliver a mitigation policy that does not adversely affect the underlying economic structure of each region.

Thus, the aim of this paper is to investigate the convergence of per capita GHG emissions across Canadian provinces for the period from 1990 to 2014. We use aggregate and sectoral (residential and transportation) level data and apply the log (*t)* convergence test and clustering algorithm developed by the Phillips and Sul (2007, 2009). Specifically, we would like to test whether there is convergence, or if not, is there convergence clubs among Canadian provinces? Basically, our question is: are Canadian provinces per capita GHG emissions converging to a unique steady state or are they clustering around different steady states? The application of the convergence test indicates that per capita GHG emissions do not converge to a single steady state at aggregate and at sectoral levels. The lack of overall convergence forces us to investigate for the possibility of convergence clubs. By controlling for the structural characteristics of provinces, we observe that Canadian provinces' per capita GHG emissions form distinct groups that converge to different steady states. Moreover, the study reveals that, club members are not necessarily geographically neighboring. Therefore, we do believe that the analysis presented in this paper provide clearer pictures of the emissions patterns either at aggregated or sectoral levels. These findings might serve as a base for environmental policies debate and could certainly provide valuable insights for policy makers to implement efficient local environmental policies that help achieve national emission reduction targets.

The remainder of the paper is organised as follows; the next section provides a brief survey of the literature. Section 3 presents the methodology proposed by Phillips and Sul (2007,

2009) to test for convergence and convergence clubs. Section 4 describes the data. Section 5 presents and discusses the results. The last section concludes.

## 2 Literature review

The widening gap in per capita GHG emissions among countries has attracted a lot of attention from both policy makers and academics in the field of environmental economics. As argued by Timilsina (2016), the huge differences in per capita CO2 emissions between countries was one of the contentious issues of the ongoing climate negotiations.

Over the past few decades, numerous studies have borrowed heavily from the income growth literature to explore the convergence of emissions across countries/regions[4]. Common methodological approaches, such as beta, sigma, stochastic and club convergence have been applied in the environmental economics literature to investigate convergence of per capita emissions[5].

In one of the earliest investigations in the field, List (1999) applied *beta*-convergence to take a closer look at convergence of dioxide and nitrogen oxides across states in the U.S. for the period between 1929 to 1994. The finding showed that per capita emissions are converging among U.S states. In the same vein, Romero-Ávila (2008) examined the convergence of CO2

[4] Convergence entails that per capita emissions across countries become more equal or to some extent start narrowing over time.

[5] Sigma-convergence is measured as standard deviation of the natural logarithm of per capita emissions. If this measure declines over time, then per capita emissions are converging in a sigma-sense (Barro and Sala-i-Martin, 1992). On the other hand, the stochastic-convergence tests whether time series of relative emissions per capita were characterized by a unit root. If per capita emissions are converging in a stochastic sense, then shocks to emissions are temporary and the data are stationary over time.

emissions in 23 countries of the Organisation for Economic Co-operation and Development (OECD) over the period 1960–2002. His results supported the convergence of $CO_2$ emissions after applying both stochastic and deterministic convergence tests. Drawing from the economic growth literature on *sigma*-convergence, Aldy (2006) investigated whether per capita $CO_2$ emissions have been converging among 23 OECD countries over 1960–2000 period. The result showed that per capita emissions are converging in a sigma sense. By considering annual data for over more than a century, spanning from 1870–2004, Barassi et al (2011) studied the convergence of $CO_2$ emissions within the OECD using a stochastic convergence testing approach; they discovered that 13 out of 18 OECD countries are indeed converging. Although most research results have provided support of convergence in per capita emissions among industrialized countries, there is still ongoing debate when it comes to global convergence in per capita emissions. For instance, Van (2005) applied a nonparametric distribution approach to investigate the convergence in per capita emissions among 100 countries during 1966–1996. The results offered strong evidence of convergence among industrial countries, but no evidence of convergence was found for the entire sample. Similarly, Criado and Grether (2011) employed a nonparametric stochastic approach to investigate the convergence of per capita emissions among 166 countries for the period 1960–2002. They found no evidence for convergence. On the other hand, Panopoulou and Pantelidis (2009) used a sample of 128 countries for the period the 1960–2003 to explore convergence of per capita emissions. They employed the convergence club test to look for evidence of convergence. Their results showed that countries tend to converge in the early years of the sample, but two convergence clubs were formed in the later years. Many studies thereafter have followed in the footsteps of Panopoulou and Pantelidis (2009) by applying the Phillips and Sul (2007, 2009) methodology to detect for existence of convergence clubs among countries and regions. For instance, Camarero et al. (2013) applied the Phillips and Sul (2007, 2009) methodology to investigate convergence in CO2 emission intensity (emission over gross domestic product) among OECD countries over the period 1960-2008. They identified distinctive groups of countries that converge to different equilibria in the emission intensity for the majority of OECD countries. Herrerias (2013) also used the convergence clubs technique to assess environmental convergence hypothesis in carbon dioxide emissions for a large group of developed and developing countries from 1980 to 2009. Although some countries displayed divergence, he found convergence clubs for a large group of countries.

More recently, Apergis and Payne (2017) applied the convergence clubs approach to per capita carbon dioxide emissions at the aggregate and sectoral level. They found evidence for presence of multiple equilibria with respect to per capita carbon dioxide emissions at aggregate and sectoral level. Compared with traditional convergence methodologies, the Phillips and Sul (2007, 2009) procedure is viewed as a conditional sigma convergence that controls for the common factors. Furthermore, the method accommodates for convergence clusters without exogenously assuming any convergence pattern in advance; previous applied methods can only examine the panel convergence behaviour. As such, we do believe that the Phillips and Sul (2007, 2009) convergence test is the most appropriate approach to apply for identitification of convergence clusters with respect to per capita carbon dioxide emissions in Canada.

## 3 Methodology

### 3.1 The log (*t*) test

To identify convergence patterns of per capita greenhouse gas emissions across Canadian provinces and territories at the aggregate and sectoral levels, we run the regression based technique introduced by Phillips and Sul (2007, 2009). The novel aspect of this methodology is that, it is a nonlinear model with a growth component and a time varying factor that allows for transitional dynamics and capture heterogeneity across individuals and over time. Furthermore, it permits to classify convergence clusters endogenously. Phillips and Sul's methodology is robust to the stationarity properties of the series. That is, it does not suffer from the small sample properties of traditional unit root and cointegration tests. Their methodology assumes the time-varying common-factor representation for the observable series $X_{it}$, of province $i$ at time $t$ as follows:

$$X_{it} = \varphi_i \mu_t + \epsilon_{it} \qquad (1)$$

here $X_{it}$ is the log value of per capita greenhouse gas emissions; $\varphi_i$ represents the unit characteristic component; $\mu_t$ is a common component which may follow either a non-stationary stochastic trend with drift or a trend-stationary process and $\epsilon_{it}$ the error term. In the specification above, the per capita greenhouse gas emissions can be further decomposed into a common trend component $\mu_t$ and an individual element $\delta_{it}$ such as:

$$X_{it} = \left(\varphi_i + \frac{\epsilon_{it}}{\mu_t}\right)\mu_t = \delta_{it}\mu_t \qquad (2)$$

Since it quite impossible to estimate $\delta_{it}$ from equation (2) due to over parameterization, Phillips and Sul (2007, 2009) construct the convergence and long run equilibrium of the series based on a relative measure of the loading coefficient as:

$$h_{it} = \frac{X_{it}}{N^{-1}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{N^{-1}\sum_{i=1}^{N} \delta_{it}} \qquad (3)$$

note that the common component $\mu_t$ is removed[6]. Hence, $h_{it}$ measures the transition path of province $i$ to the panel average at time $t$. If the factor loadings $\delta_{it}$ converge to $\delta_i$, the relative transition paths governed by $h_{it}$ converges to 1 for all $i$ as $t \to \infty$. Therefore, the cross-sectional variance of $h_{it}$ given by $H_t = N^{-1} \sum_i^N (h_{it} - 1)^2$ converges to zero as $t \to \infty$. To test the null hypothesis of convergence, Phillips and Sul (2007, 2009) propose a semiparametric form for the loading coefficient $\delta_{it}$ as follows:

$$\delta_{it} = \delta_i + \sigma_i \xi_{it} L(t)^{-1} t^{-\alpha} \qquad (4)$$

where $\delta_i$ is fixed, $\sigma_i$ is an idiosyncratic scale parameter, $\xi_{it} \sim idd(0,1)$, $L(t)$ is a slow varying function of time and $\alpha$ is a decay rate. This representation ensures that $\delta_{it}$ converges to $\delta_i$ for all values of $\alpha \geq 0$. The null hypothesis of convergence can be written as:

$$H_0: \delta_i = \delta \text{ and } \alpha \geq 0 \text{ vs. } H_A: \delta_i \neq \delta \text{ for all } i \text{ or } \alpha < 0 \quad (5)$$

To test for relative convergence, Phillips and Sul (2007, 2009) suggest estimating the following regression by ordinary least squares.

$$\log\left(\frac{H_1}{H_t}\right) - 2\log L(t) = \hat{a} + \hat{b} \log t + \widehat{u_t} \qquad (6)$$

where $L(t) = \log(t+1)$ and $\hat{b} = 2\hat{\alpha}$ where $\hat{\alpha}$ is the ordinary least squares estimate of $\alpha$. The null hypothesis of convergence can be tested by applying a conventional one-sided $t$-test for the slope coefficient $\hat{b}$ constructed using heteroskedasticity and autocorrelation consistent standard

[6] Note that the common component $\mu_t$ is eliminated through rescaling by the panel average.

errors. At the 5 % significance level, the null hypothesis of convergence is rejected if $t_{\hat{b}} < -1.65$. Note that the regression starts at some point $t = [rT]$, where $[rT]$ is the integer part of $rT$. Phillips and Sul (2007, 2009) recommend $r = 1/3$ as a satisfactory choice in terms of both size and power. However, the rejection of full convergence does not imply the absence of convergence in subgroups of the panel. Phillips and Sul (2007, 2009) propose the following algorithm for detecting convergence clubs.

### 3.2 The clustering algorithm

Schnurbus et al. (2017) propose some minor adjustments to the original clustering algorithm of Phillips and Sul (2007, 2009). The Schnurbus et al. (2016) adjusted algorithm is briefly outlined below. Schnurbus et al. (2017) apply the following stepwise procedures to identify initial convergence clubs, to merge clubs and to establish final convergence clubs.

Step 1: Sorting

The first step consists of sorting the Hodrick and Prescott (1997)-smoothed per capita greenhouse gas emissions series according to the last observation.

Step 2: Core group formation

Step 2.1: Start with the highest per capita greenhouse gas emissions, find the first two consecutive provinces for which the log *(t)* regression test statistic $t_{\hat{b}} > -1.65$. If $t_{\hat{b}} < -1.65$ for all sequential pairs of provinces, exit the algorithm and conclude that there are no convergence subgroups in the panel[7].

[7] The term log *(t)* stands for a parameter, which is twice the speed of convergence of this club towards the average. The convergence test is distributed as a simple one-sided *t*-test with a critical value of −1.65.

Step 2.2: Start with the $k = 2$ provinces identified in Step 2.1, increase $k$ proceeding with the subsequent province and perform the log *(t)* regression test. Stop increasing $k$ if the convergence hypothesis fails to hold. The core group consists of the $k^*$ provinces that yield the highest value of the log *(t)* regression test statistic.

Step 3: Extention of the initial core group

Step 3.1: Form a complementary core group of all remaining provinces not included in the core group.

Step 3.2: Add one province at a time from the complementary to core group, (Step 3.1) to form the core group. Run the log *(t)* test, if the resulting test statistic is greater than the critical value, form a club candidate group of all provinces passing this test.

Step 3.3: An initial convergence club is obtained if the convergence hypothesis jointly holds for both the core group and the club candidate group. Otherwise, repeat Step 3.2 until convergence criterion is met.

Step 4: Recursion and stopping rule

Form a subgroup of the remaining provinces that are not sieved by Step 3. Perform the log *(t)* test for this subgroup. If the test statistic is greater than $-1.65$, the subgroup forms the next convergence club. Otherwise, repeat Steps 2-3 on this subgroup.

Step 5: Club merging

Perform the log *(t)* regression for all pairs of subsequent clubs and across formed clubs. Merge those clubs fulfilling the convergence hypothesis jointly. Continue the procedure until no clubs can be merged.

## 4 Data source

The data used in the study are from two sources. The first source is Environment and Climate Change Canada (formerly known as the Environment Canada). This data set includes information on greenhouse gas emissions, which comprise of carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride ($SF_6$), and nitrogen trifluoride ($NF_3$)). The greenhouse gas emissions are expressed as Mt $CO_2$ eq. The second source of data is Statistics Canada from which, we collect data on population count. We gather aggregate and sectoral levels data of all 10 Canadian provinces and territories observed between the periods 1990-2014[8]. The sample contains the following provinces and territories: Newfoundland and Labrador (NL), Prince Edward Island (PE), Nova Scotia (NS), New Brunswick (NB), Quebec (QC), Ontario (ON), Manitoba (MB), Saskatchewan (SK), Alberta (AB), British Columbia (BC), Yukon (YK), Northwest Territories and Nunavut (NN). The sectors considered in this study are residential and transportation sectors.

[INSERT FIGURE 1 ABOUT HERE]

Figure 1 shows trends of Canadian's emissions by type of gas. As shown in Figure 1 below, more than 75% of Canada's emission is derived from carbon dioxide emission. Methane accounted for about 15% of total emissions. Looking at the emission trend, we observe in 2014, Canada's emission was down 2% from the 2005 level. This decline was mainly the result of a

[8] Note that for the years preceding 1999, data for Nunavut and Northwest Territories are combined in a single region. After the creation of Nunavut in 1999, Nunavut data are presented separately, but we decided to combine the data for Nunavut and Northwest Territories to make a single series.

drop from carbon dioxide, methane and nitrous oxide emissions. Table 1 provides summary statistics of greenhouse gas emissions at aggregate and sectoral levels. As can be seen, Canada's greenhouse gas emissions totalled 732 Mt CO2 eq in 2014. Quebec and Yukon were the only provinces to report declines in average greenhouse gas emissions during the first decade following the 1990s. Conversely, during the 2003-2014 period, all provinces and territories, except the Prairie Provinces registered decreases in the greenhouse gas emissions. It is worth noting that greenhouse gas emissions in most provinces were increasing during the 1990 to 2002 period, whereas, during the 2003-2014 period a large proportion of Canadian provinces and territories are showing decline in their emissions. Is this trend suggesting emissions are converging across Canadian provinces? The next section provides the results of this investigation.

[INSERT TABLE 1 ABOUT HERE]

## 5 Empirical results

Table 2 reports the convergence results for aggregate per capita greenhouse gas emissions across the Canadian provinces and territories. The top half of Table 2 displays the results for the full sample convergence and the club clustering, while the bottom half presents the result for clubs merging. As can be seen from the first column of Table 2, the estimated value for *beta* for the full convergence is −1.114 and the corresponding *t*-statistic: −77.541. Based on results from the *t*-statistic, the null hypothesis of full convergence can be rejected at the 5% level since the *t*-statistic value is below −1.65. The absence of full convergence does not exclude the presence of convergence clubs. Thus, we implement the club-clustering algorithm to identify provinces that satisfy the convergence clubs criterion. The club clustering algorithm classifies four distinctive convergence clubs, with Saskatchewan and Alberta in the first club; Newfoundland and Labrador, Nova Scotia, New Brunswick and Northwest Territories and Nunavut in the second club; Prince Edward Island, Ontario and British Columbia in the third club and Quebec and Yukon in the fourth. Furthermore, we perform tests to assess whether any of formed clubs can be merged to constitute a larger convergence club. The bottom half of Table 2 reports the testing results. The findings provide no evidence that any subsequent clubs can be merged together to form a larger convergence club.

[INSERT TABLE 2 ABOUT HERE]

Figure 2 plots the relative transition paths of per capita greenhouse gas emissions. The relative transition curves are meant to visually assess whether individual provinces converge relative to the cross-sectional average over time. Full convergence occurs if the paths of all provinces asymptotically approach one. Any point above one indicates that the province's per capita greenhouse gas emissions is above the cross-sectional average and vice versa.

[INSERT FIGURE 2 ABOUT HERE]

As shown in Figure 2, the curves eloquently capture the growth course for each province relative to the sample average. Saskatchewan and Alberta converge to a steady state that is above the cross-sectional average. One possible explanation that can be put forward for the high levels of per capita emissions in these two provinces would be their reliance on coal-fired electricity generation as well as oil sands and heavy oil production. Quebec and Yukon have their steady state way below the national average. The member of the provinces in the second club reach their steady state about the panel average. Prince Edward Island, Ontario and British Columbia, which belong to the third convergent club, have their steady state ending to a point below the sample average.

[INSERT TABLE 3 ABOUT HERE]

Table 3 reports the results for the residential sector's per capita greenhouse gas emissions across the Canadian provinces and territories. Clearly, the null hypothesis of full convergence is rejected at the 5% level. The divergence of per capita greenhouse gas emissions for the whole sample does not, however, rule out the possibility of convergence clubs. The convergence clubs tests results indicate the presence of two convergent clubs and one divergent set of provinces. The first club consists of Prince Edward Island and Alberta. The second club includes Newfoundland and Labrador, Quebec and Manitoba. The divergent set of province is made up of Nova Scotia, New Brunswick, Ontario, Saskatchewan, British Columbia, Yukon, Northwest Territories and Nunavut.

When tested for clubs mergers, the *t*-statistic value for club merging, −23.147, is significantly smaller than −1.65, strongly rejecting the null hypothesis of clubs merging.

[INSERT FIGURE 3 ABOUT HERE]

Figure 3 displays the paths of the relative convergence across Canadian residential sector emissions. The emissions trajectories for the member of first club (Prince Edward Island and Alberta) appear to be increasing with respect to the sample average. The increasing level of greenhouse gas emissions for residential sector in Alberta can be explained by the size of homes in Alberta. In Alberta, homes built between 2000 and 2010 are approximately 37 per cent larger than those built from 1960 to 1980. Larger homes require more energy for heating, thus more emissions to be released.  However, for the case of Prince Edward, Island, it can be explained by Island homes burn fossil fuels like light fuel oil, heavy fuel oil, diesel, and propane to produce heat or electricity. These fuels are known to generate more greenhouse gas emissions. Several additional observations are worth mentioning. In most provinces, greenhouse gas emissions remain steadily constant up to 2004 and then start to increase or decline in certain cases.

[INSERT TABLE 4 ABOUT HERE]

Table 4 shows the results of the log (*t)* convergence test and clustering procedure for the transportation sector. The first column reports the result for testing the hypothesis that all provinces converge to a single steady state while that of the remaining columns report the results obtained when we apply the clustering algorithm. First, the null hypothesis of overall greenhouse gas emissions convergence is rejected at the 5% level. With respect to convergence clubs, the algorithm classifies provinces into four convergence clubs and only one set of diverging club is found. The first club comprises of Saskatchewan, Northwest Territories and Nunavut, the second club contains Newfoundland and Labrador and Alberta, the third club is formed by New

Brunswick, Manitoba and Yukon and the last club identified consist of Quebec, Ontario and British Columbia. The divergence group contains Prince Edward Island and Nova Scotia. Then, we conducted a test to determine whether any of the original clubs can be merged to form larger convergence clubs. The test result suggests that the third and fourth convergence clubs can be merged to form a larger convergence club as the *t*-statistic is 4.212 which is significantly greater than the 5% level of −1.65. Therefore, the third and fourth clubs are the only club that pass the merging test to form separate convergence club.

[INSERT FIGURE 4 ABOUT HERE]

We also present a graph showing the relative emissions convergence of the transportation sector. As can be seen below, the relevant relative transition curves, displayed in Figure 4, corroborates the converging behaviour of the identified convergence clubs. The member of the club belonging to the first club, Saskatchewan, Northwest Territories and Nunavut are trended upward and have their steady state converging toward a point well above the national average. The second club has its steady state converging to a point exceeding the cross-sectional average. The merged club (3rd three and 4th club) exhibits constant trends in its relative per capita greenhouse gas emissions.

The relative transition curves show us graphically the formation of the convergence clusters. Nevertheless, to have a sense not only at the formation of the convergence clusters, but also at the spatial agglomeration of each clubs, we show the geographical connection between the members of the convergence clubs.

[INSERT MAP 1 ABOUT HERE]

Map 1 displays the geographical distribution of the clubs for aggregate, residential and transportation. It is worth to note that the figures in Map 1 are plotted based on the convergence-clustering algorithm testing results. Firstly, convergence club for aggregate seem to be spatially concentrated at least for the first two clubs. For instance, Alberta and Saskatchewan do not only share oil sands and heavy oil production but also share geographical connection. The provinces in the second club are also connected on geographic lines. A closer look over the geographical distribution of the clubs in the residential sector show also a geographical link for the set of divergent four provinces in western regions. With respect to the spatial connection of the transportation sector, it can be observed that the provinces in the first and the fourth clubs are also geographically connected.

## 6 Conclusion

In this paper, we examined the environmental convergence hypothesis among Canadian provinces and territories. To serve this objective, we apply the testing approach of Phillips and Sul (2007, 2009). This methodology uses a non-linear factor model with a common and an idiosyncratic component allowing for technical progress heterogeneity across provinces. More specifically, we investigate whether per capita GHG emissions converge at aggregate and sectoral level for the period 1990 to 2014.

First, the testing results reject the null hypothesis of full convergence at aggregate as well as sectoral levels. To investigate the existence of segmentation in per capita GHG emissions across Canadian provinces and territories. We apply the clustering procedure to the aggregated and sectoral level data, the application of the convergence clubs testing identifies groups of provinces and territories that converge to different equilibria in aggregated per capita GHG emissions. The first club comprises of Saskatchewan and Alberta; these two provinces are the country's largest emitters. Indeed, in 2013, 91% of oil produced in Canada is from Alberta and Saskatchewan, which explain in part the above national average emissions for these two provinces. The province of Newfoundland and Labrador, Nova Scotia, New Brunswick and Northwest Territories and Nunavut form the second group. The third group comprises of Prince Edward Island, Ontario and British Columbia and finally, Quebec and Yukon come in the fourth club.

In terms of per capita GHG emissions convergence for residential sector, the club convergence algorithm identifies the presence of two convergent clubs and one divergent set of provinces. With respect to the convergence of per capita GHG emissions for transportation sector, the clustering algorithm classifies provinces in four convergence clubs and one set of diverging province.

Therefore, we argue that the presence of multiple convergent clubs suggests that to achieve the emissions reduction targets, the federal and provincial governments should design specific environmental policy that equitably share the burden of GHG emissions among provinces that enable sustainable development, while reaching the national emission reduction goals.

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