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RESEARCH ARTICLE

Convergence of carbon dioxide emissions in the Americas and its determinants

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Abstract

This paper investigates the convergence behaviour of carbon dioxide emissions for 39 countries in the Americas from 1960-2016. A linear regression test of convergence which looks for conditional sigma convergence is employed, and a clustering algorithm is used to identify convergence clubs. The results show evidence of convergence in the region for the long run. Convergence clubs are identified for the short run. The convergence clubs show some relation to spatial distribution and income level. Possible factors determining the formation of convergence clubs are investigated through logistic regression. Initial level of emissions and energy intensity were found to have the largest impact determining what convergence club a country belongs to. Per capita GDP, trade openness, and renewable energy were all found to be highly significant factors determining what convergence club a country belongs to as well. Different results were found for urbanization's impact in determining the formation of convergence clubs. These findings show that policymakers should promote allocation schemes for carbon dioxide emissions. Policymakers should also aim to reduce carbon footprint based on the economy's structural characteristics.

Keywords: carbon dioxide emissions; emission intensity; convergence; club convergence.
JEL codes: C23; Q54; Q52; Q56; R11.

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1. Introduction

The impact of carbon dioxide emissions on the environment has been a widely studied topic for some time. The literature today indicates that carbon dioxide emissions have a global impact on the climate and the environment. To mitigate harm to animals and humans' way of life, scientists urge for maintaining global warming to 2 degrees Celsius above pre-industrial levels (UNFCCC, 2015) This has led to economists taking interest in the topic, with research focusing on monetizing carbon emissions through carbon markets, the tragedy of the commons, and other policies to reduce emissions.

The environmental Kuznet's curve (EKC) hypothesizes that the relationship between economic development and environmental degradation is represented with an inverted U-shape. This means that economic development is followed by increases in environmental harm until a turning point occurs when economic development is associated with reduced environmental harm. Environmental degradation can take many forms for the EKC, and carbon dioxide emissions are often associated with this relationship. Brock and Taylor (2010) combined the Solow growth model and EKC to form the green Solow model (GSM). The GSM predicts that countries' per capita emissions will converge over time.

Much research has studied the convergence of emissions. The convergence hypothesis holding is important for the acceptance of environmental policy (Aldy, 2006). Countries with high per capita emissions believe that if the GSM prediction of convergence holds, countries with lower per capita emissions will eventually catch up in emissions and make the same sacrifices high emitters have to reduce emissions. Countries with lower emissions similarly believe that over time they will be in the same position as higher emitters, so reducing emissions early is beneficial to reduce the total emissions. If the convergence hypothesis does not hold, low per capita emitters will expect high per capita emitters to shoulder most of the burden of reducing emissions and will be unlikely to partake in international co-operative efforts to reduce worldwide emissions. High emitters will similarly be opposed to implementing environmental regulations knowing that low emitters will not do the same. If countries converge to a level of emissions that maintains global warming to 2 degrees Celsius, the environmental goal is met. However, as stated, if countries converge to a level of emissions that exceeds global warming of 2 degrees Celsius, countries are more likely to cooperate to reach a level of emissions that maintains global warming at 2 degrees Celsius compared to countries which do not converge.

If countries converge to a level of emissions that is unsustainable, co-operating to achieve a sustainable level of emissions is important. Fredriksson et al. (2004) and Davies and Naughton Davies and Naughton (2014) found that proximate countries have the most opportunity for co-operation regarding environmental policy. Studying the convergence of regional groups is then of interest as they have the most opportunity for co-operation. Panopoulou and Pantelidis (2009) studied convergence of regional groups based on the World Bank's regional classifications. Panopoulou and Pantelidis (2009) studied the sub-Saharan Africa (SSA) and the MENA (Middle East and North Africa) regions separately, finding convergence for MENA, but not for SSA. Solarin (2014) expanded on these findings by studying the convergence of the full Africa continent, finding convergence for the full region. As the authors find different convergence behaviour, it indicates that similar income level is not the sole determinant of emissions convergence for a region. Panopoulou and Pantelidis (2009) also studied the convergence of the LAC (Latin America and the Caribbean) region, and other studies have considered smaller parts of the region (see (Robalino-López et al., 2016), and (Apergis et al., 2020)). Research has been done regarding the determinants of CO2 emissions, but the literature of carbon dioxide emissions convergence has generally neglected discussing the determinants of the convergence and convergence clubs.

The purpose of this study is to investigate the cross-country convergence of the Americas. As most studies consider regions with similar income level or economic characteristics, this study expands the research by combining the North America and LAC regions. The Americas is a large geographic area with widely varied economies across the region providing an interesting case for studying regional convergence of emissions for investigating whether spatially proximate countries converge and what factors lead these countries to converge. Spatially proximate countries have the greatest opportunity for cooperation in environmental policy. As the economies vary largely across the Americas, this also shows the importance of economic development for convergence. This study investigates the convergence of 39 countries in the Americas over the period 1960-2016 using data from the World Bank (2020). This study further contributes to the literature by investigating whether initial level of emissions, energy intensity, per capita GDP, openness, renewable energy, and urbanization determine the convergence clubs' formation. This paper also expands on the time periods of previous studies, thus showing if earlier findings of convergence hold to this day.

Three hypotheses are formulated based on earlier findings. First, convergence is expected to be found for the full period, but not for the later years. Second, convergence clubs are expected to be identified and they are expected to show relation to spatial distribution and income level. Third, high levels of per capita GDP, openness, renewable energy, and urbanization are expected to correlate with low-emission convergence clubs, while initial level of emissions and energy intensity are expected to not correlate with low-emission clubs. The results show evidence of cross-country conditional sigma convergence for the full period, and convergence clubs are identified for the later years. There is some relation to spatial proximity for the convergence clubs. Initial level of emissions, energy intensity, per capita GDP, trade openness, and renewable energy use are found to have highly significant effects on what convergence club a country belongs to. Different results were found for Urbanization's impact on the formation of convergence clubs.

The rest of the paper will be structured as follows. Section 2 presents the theory behind convergence of carbon emissions. Section 3 reviews the literature on convergence of carbon emissions. Section 4 describes the methodology employed to investigate convergence, its' determinants, and the data this paper employs. Section 5 presents the empirical findings. Section 6 provides an analysis of the empirical findings. Section 7 concludes with a summary and mentions the policy implications of the results.

2. Background

This section is divided in three parts. First it presents the theory behind carbon emission convergence. Then it describes the different types of convergence present in the literature.

2.1. Carbon dioxide emission convergence

The Solow (1956) growth model predicts that economies' per capita income will converge when population growth rate, savings rate, and the rate of technological progress are controlled for. This implies that poor countries grow faster than richer countries due to diminishing returns to capital, which causes the long run convergence.

The Kuznets curve proposed by Simon Kuznet suggests an inverted U-shape relationship between per-capita income and economic inequality. Economists later adapted this theory when studying the relationship between economic development and environmental degradation. One example of this is Grossman and Krueger (1995), who found an inverted U-shape relationship between the two variables, meaning that environmental damage increases along with increases in development until a turning point occurs when economic development is followed by reduced environmental damage. Many papers discuss the EKC (Environmental Kuznets Curve), and some authors criticize the hypothesis ((Arrow et al., 1995); (Dijkgraaf and Vollebergh, 2005); (Stern et al., 1996)). Reviews of the literature surrounding the EKC hypothesis have different findings. Shahbaz and Sinha (2018) found inconclusive results regarding the EKC estimation for CO2 emissions, while Sarkodie and Strezov (2019) identify an average of $8,910 as the turning point of the EKC in their meta-analysis.

Brock and Taylor (2010) posit that the diminishing returns and technological progress that Solow identified as key to growth is also key for the EKC, forming the GSM (green Solow model). When development begins, there is rapid economic growth which is accompanied by growth in per capita emissions. Technological progress would reduce emissions but takes time to catch up. Diminishing returns eventually take effect, the economy reaches the balanced growth path and begins to decrease in emissions as technological progress catches up. Diminishing returns and technological progress thus cause the EKC, as per capita emissions first rise then falls as per capita income rises. Similar to the Solow growth model, the GSM predicts that countries' per capita emissions will converge. Brock and Taylor (2010) note that regulating pollution increases costs of pollution and reduces it, but policy does not affect the growth rate of pollution. The GSM thus assumes environmental policy to change the level of emissions but not the rate of its' growth. Countries may converge to a level of emissions that is unsustainable. To ensure countries achieve sustainable levels of emissions, policymakers can implement environmental regulation to reduce the level of emissions.

Multilateral agreements are vital for total emissions to be reduced. Emission allocation schemes is one example of such multilateral agreements. Allocation schemes can be implemented in different ways. Aldy (2006) considers the implications of convergence for emission allocation schemes. He notes that countries with lower per capita emissions could expect countries with higher per capita emissions to have more responsibility for dealing with climate change. Although developed countries have higher per capita emissions, involving developing countries in multilateral agreements is important to reducing the total worldwide emissions. Aldy (2006) mentions that allocating emissions on a per capita basis may solve this issue, as developing countries have a larger incentive to partake. The convergence hypothesis holding is important for developed countries' acceptance of an allocation scheme based on per capita emission. If the convergence hypothesis does not hold however, allocating emissions on a per capita basis would likely lead to resource transfers through emissions trading and relocation of emission-intensive industries (Aldy, 2006).

The EU ETS (Emissions Trading System) uses the cap-and-trade model, where a cap is set on the total amount of greenhouse emissions that can be emitted, and the total emissions are divided between members who can buy or receive emissions allowances (European Commission, 2017). The allowances are then traded freely which promotes efficient allocation of emissions as allowances will go to areas where the cost of reducing emissions are the lowest. Zhou and Wang (2016) note that early allocation schemes were ruled by the "fairness principle", that high emitters should shoulder more of the burden in mitigating climate change. However, the "efficiency principle", how much cost is associated with a reduction in emissions, has gained popularity. Emission intensity, GDP produced per emissions unit, is the common marker of efficient carbon usage. Market systems such as the EU ETS function through emission intensity as the member with the most efficient, the lowest, emission to GDP ratio will receive or buy the most units of carbon permits. The "fairness principle" applies to areas other than allocation schemes as countries with lower emissions expect countries with higher to mitigate more of the environmental damage. It is expected that developing countries catch up and eventually make the same sacrifices as developed countries have.

Fredriksson et al. (2004) studied how environmental policy of a country impacts the policy of its' neighbours, finding that strategic interaction exists between policies for US states. Davies and Naughton (2014) similarly considered that countries have incentive to co-operate as cross-border pollution exists, and that spatially proximate countries have opportunity to do so. They investigate the spatial cooperation between countries and find that regional agreements show the highest rate of treaty participation. Investigating the emission convergence of regional groups is interesting as spatially proximate countries have the opportunity to cooperate to ensure convergence to low levels of emissions.

If full-sample convergence does not hold though investigating whether convergence clubs exist is of interest. Aldy (2006) forecast future CO2 emissions, but it should be noted that previous studies typically consider the changes in total global emissions, neglecting the geographic distribution of emissions. Aldy noted that the geographic distribution of emissions impacts environmental agreements to aid the environment. Aldy used convergence and convergence clubs to investigate how emissions converged in the past and investigates whether emissions will converge to a target in the future. Thus, convergence and convergence clubs help in forecasting the distribution of future levels of emissions. If the convergence clubs show a relation to spatial distribution, countries within the clubs have an opportunity to cooperate. Spatially proximate countries can enact policies to reduce total emissions. Examples of such policies are interconnected power grids for distributing energy from renewable sources to neighbouring countries which have less access to energy. This will expand on climate friendly ways of travel between countries such as railways, trade agreements that require certain environmental standards, and spill overs and exchanging environmentally friendly technologies.

It is then relevant to investigate whether spatially proximate countries with different levels of development and economic structures converge in emission levels. The Americas is a large region with a diverse range of economies, which provides an interesting study for the regional convergence of emissions. The Americas region is also interesting with regard to trade policy as many countries across the region are already engaged in trade agreements. The United States-Mexico-Canada Agreement (USMCA), previously North American Free Trade Agreement (NAFTA), is an example of this where environmental and working regulations are required for the agreement. Other regional free trade agreements in the Americas include the Pacific Alliance, Southern Common Market (MERCOSUR), the Andean Community of Nations (CAN), and Dominican Republic-Central America Free Trade Agreement (DR-CAFTA). Expanding on these trade agreements to encompass larger areas will not only aid economic growth in the region but also raise environmental standards to a globally sustainable level. The Free Trade Agreement of the Americas was previously proposed as an Americas-wide reduction of trade barriers but was never implemented. The Central American Electrical Interconnection System (SIEPAC) and the North American Electricity Reliability Corporation (NERC) are examples of interconnected power grids in the Americas. Convergence clubs also allow identifying why a sample of heterogeneous countries does not converge, and whether those reasons are immutable characteristics of a country or facets of an economy that is open to change.

2.2. Types of convergence

The literature mostly regards three types of convergence called beta convergence, sigma convergence and stochastic convergence.

Beta Convergence: Beta Convergence was introduced by Baumol (1986) and refers to the negative relation between the growth rate of a variable and its initial level. This occurs in growth literature when poor countries grow faster than rich countries. As Panopoulou and Pantelidis (2009) note, in the context of CO2 emissions beta convergence can be tested using the cross-country regression:

$$y_i = c + \beta E_{0,i} + u_i \tag{1}$$

where y_i is the average growth rate of CO2 emissions for a country i, $E_{0,i}$ is the starting level CO2 emissions for country i, and u_i is the random error term. We have beta convergence if $\beta < 0$. In terms of CO2 emissions, this occurs when countries with high per capita initial emission levels have lower growth rates than countries with low per capita initial emission levels. Beta convergence has been critiqued by DeLong (1988) and Quah (1993) who demonstrate that (1) often indicates convergence when it doesn't exist. Further, since (1) assumes all countries are converging at the same rates, Quah (1996, 1997) argues that it poorly describes a distribution's dynamics and proposes use of the full cross-country distribution.

There are two types of beta convergence, conditional and unconditional. In growth literature, *unconditional convergence*, also known as *absolute convergence*, is when the growth rate of an economy decreases as it reaches the steady-state equilibrium. In other words, a lower initial GDP yields a higher growth rate than a high initial GDP. *Conditional convergence* occurs when beta convergence exists, but it is conditional on other variables being controlled for. In growth literature, this is exemplified by an economy's GDP per worker converging to a specific long-run level determined by the country's unique structural characteristics. In the context of CO2 emissions, the long-run level of CO2 emissions is determined by an economy's characteristics rather than the initial income per worker.

Sigma Convergence: Sigma convergence was proposed by Barro and Sala-I-Martin (1990) and denotes a decrease in cross-sectional variation of the natural logarithm of a variable over time. In other words, sigma convergence occurs when there is a reduction in a variables' dispersion over time for multi-country samples. In growth literature, this means that the dispersion of per capita income for a group of countries is reduced over time when adjusted for inflation. In emissions literature, this is when the dispersion of per capita carbon dioxide emissions for a group of countries is reduced over time. Sala-i Martin (1996) writes that sigma and beta convergence are related, as beta convergence is a necessary condition to achieve sigma convergence. However, beta convergence is not sufficient for sigma convergence to occur as economies can be affected by random shocks.

Stochastic Convergence: Quah (1990) posited the value of investigating the persistence of shocks on per capita income. Carlino and Mills (1993, 1996) build upon this to introduce stochastic convergence as a time-series concept of convergence. This occurs in growth literature when the difference between real per capita income of an economy compared to another country, or to the sample average follows a zero-mean stationary process. In the context of emission literature, it means that the shocks in the logarithm of per capita CO2 emissions compared to the sample average are temporary. Stochastic convergence is tested through a panel unit root test, where the variable of interest is the logarithm of relative carbon emissions. Stochastic convergence is present when relative carbon emissions are trend stationary. If a unit root exists, it indicates that the effect of a shock is permanent and causes the series to diverge from the sample mean.

Global Convergence is a broad concept of convergence that includes samples with few but distinct economies and samples that considers the convergence of every country. It investigates whether countries grouped by shared characteristics are converging. These characteristics are typically income level or economic characteristics such as oil exporting countries. Some studies also consider regional convergence where countries are grouped by region.

If variables taken from a sample are not converging, divergence is present in the sample and one or more countries are not converging towards a common steady state. When convergence does not exist for a full sample, it is still possible for sub-groups of countries within the sample to converge to different steady states. This is referred to as convergence clubs. Convergence clubs in the growth literature are groups of countries within a sample that trend towards a similar steady state level of income per capita. Convergence clubs tend to occur in the growth literature for countries that share similar initial economic development, so we see convergence clubs for countries with high income per capita and low income per capita.

In summary, beta convergence investigates catch-up processes of per capita carbon dioxide emissions between countries and is a necessary condition to achieve sigma convergence. Sigma convergence looks at the reduction in disparity of per capita CO2 emissions between countries over time, and stochastic convergence looks at whether or not shocks have permanent impacts on the CO2 emissions for an individual country compared to the sample average.

In the emissions literature, convergence clubs are groups of countries within a sample that trend towards a similar steady-state level of emissions. Researchers within the emissions literature generally find convergence clubs with similar economic development or based on geographical proximity. These convergence clubs allow investigating the differences or similarities in emissions between similar economies. This study considers the convergence of two regions that are generally considered separately due to different economic development. The two regions are geographically tied to each other allowing to consider regional group convergence. The literature has neglected investigating the possible factors determining the convergence behaviour of emissions. There is a gap regarding the possible determinants shaping the convergence behaviour of carbon dioxide emissions and the formation of convergence clubs.

3. Literature Review

This section provides an overview of the literature divided into four parts concerning global, group, and club convergence, and a part that mentions the determinants of carbon dioxide emissions and convergence. The section finishes by describing gaps in the literature that this paper intends to fill and what hypotheses arise from earlier findings.

3.1. Global Convergence

Nguyen-Van (2005) studied the convergence of CO2 emissions in a sample of 100 countries over the period 1966-1996. The author found no overall convergence in the sample but did find convergence for industrialized countries. Due to these findings, they speculate that countries that have similar conditions will converge. Aldy (2006) studied convergence in an international sample of 88 countries. The author found no evidence of convergence for the sample but found some evidence of divergence. Aldy further discussed the environmental Kuznet's curve and forecasted future emissions, finding that the world sample will likely diverge further in the next 50 years. Ezcurra (2007) viewed the convergence of per capita carbon dioxide emissions in 87 countries for the period 1960-1999, finding that the sample is converging over the period, however, the convergence process will likely not continue. This may suggest that the per capita emission for a country is tied to inherent characteristics of it.

Westerlund and Basher (2007) investigated the convergence of per capita CO2 emissions for a mix of developed and developing countries with data from 1870-2002. They found strong evidence of overall stochastic convergence in their panel. Although this study only considered 28 countries, it shows some evidence of global convergence as it looked at both developed and developing countries. Panopoulou and Pantelidis (2009) studied the convergence of per capita CO2 emissions for 128 countries over the periods 1960-2003, 1960-1985, and 1975-2003. They found evidence of divergence for the full period and later years studied, but convergence for the early years. Li and Lin (2013) studied the convergence of per capita CO2 emissions for 110 countries over the period 1971-2008, they found no evidence of absolute convergence.

Zang et al. (2018) studied convergence of per-capita carbon dioxide emissions and emission intensity in a sample of 201 countries from 2003 to 2015. The authors found sigma convergence for their global sample. Churchill et al. (2018) studied the convergence of per capita CO2 emissions for a blend of 44 developed and developing countries over the period 1900-2014, finding strong evidence for stochastic convergence. Haider and Akram (2019) investigated the convergence of PCCF (per capita carbon footprint) and PCEF (per capita ecological footprint) in 77 countries over the period 1961-2014. The authors found no overall convergence in their sample for either measurement. Payne and Apergis (2020) provides a survey of the empirical literature on convergence of carbon dioxide emissions.

3.2. Group Convergence

Strazicich and List (2003) studied the stochastic and conditional convergence of CO2 emissions in 21 industrialized countries for the period 1960-1997. The authors found significant evidence of convergence over the period. Aldy (2006) investigated the convergence of per capita CO2 emissions among 23 member countries from the OECD. The author found some evidence of convergence for the OECD, but the evidence for stochastic convergence was mixed.Lee and Chiang (2009) looked at the convergence of per capita CO2 emissions in 21 OECD countries over the period 1950-2002. They found evidence of stochastic convergence for the group.

Panopoulou and Pantelidis (2009) investigated the convergence of per capita CO2 emissions in groups based on both region and income level. They found evidence of convergence for the EMU countries, OECD, and high-income countries. The EMU countries are converging the fastest of the three groups, and the OECD and high-income countries have nearly identical results. The authors also found that middle-income countries are converging, but at a slow rate. Low-income countries, OPEC (Organization of the Petroleum Exporting Countries), and the Economies in Transition are all found to not be converging. Panopoulou and Pantelidis further investigated the convergence of regional groups, finding divergence for Europe and Central Asia, South Asia, and Sub-Sahara Africa. They found evidence of convergence for Middle East and North Africa, East Asia and the Pacific, and Latin America and the Caribbean. The authors noted that the Latin America and the Caribbean region is only slowly converging.

Jobert et al. (2010) investigated the CO2 emission convergence in 22 members of the European Union over the period 1971-2006, and absolute convergence was identified. Li and Lin (2013) studied the convergence of per capita CO2 emissions for the period 1971-2008 in 110 countries, finding that convergence is occurring for countries with similar income level. When they investigated conditional convergence, they found that the relationship between GDP growth and CO2 emission growth varied for the different groups of countries. Notably, increasing GDP per capita also increased per capita CO2 emissions in all country groups except the high-income group which stayed at the steady-state level as GDP per capita increased.

Solarin (2014) investigated the CO2 emission convergence of 39 African countries for the period 1960-2010. The author found evidence of both stochastic and beta convergence for the countries. This is in contrast to the findings of Panopoulou and Pantelidis (2009), showing that something has changed the convergence behaviour. Solarin (2014) considered both North Africa and sub-Saharan Africa in one panel which Panopoulou and Pantelidis (2009) do not. It may also be caused by the increased timespan, meaning that the convergence behaviour has changed over time. Since the papers do not consider the same type of convergence, it could also be that the region is only beta- and stochastically converging and not sigma-converging. Payne (2020) investigated stochastic convergence of per capita CO2 emissions in developing countries. They split the developing countries into low-, middle-, and high-income countries, and found evidence of stochastic convergence for the country panels. Nazlioglu et al. (2021) studied convergence of per capita CO2 emissions in 13 OPEC countries from 1960-2016. Their findings show little evidence of stochastic convergence for the group.

3.3. Club Convergence

Panopoulou and Pantelidis (2009) found divergence for their large international sample and tested for convergence clubs. They identified two convergence clubs in the sample and found evidence of transition between the clubs. Robalino-López et al. (2016) studied the convergence of per capita CO2 emissions, per capita GDP, energy intensity, and emissions intensity for 10 South American countries over the period 1980-2010. The authors did not find overall convergence for the region, but they found evidence of convergence clubs. Zang et al. (2018) studied club convergence of per capita CO2 emissions and CO2 per unit of GDP from 2003 to 2015. They found convergence clubs for groups based on both region and income-level. Haider and Akram (2019) investigated the convergence of PCCF and PCEF in 77 countries over 1961-2014 period, discovering two convergence clubs. They found that the countries with low PCCF and PCEF are converging faster than the countries with high PCCF and PCEF. Apergis et al. (2020) studied the convergence behaviour of emission intensity, energy intensity, and the carbonization index for six Central American countries. The authors identified convergence clubs for each and found Panama to be non-convergent for the carbonization index.

Payne (2020) investigated the existence of convergence clubs in developing countries for per capita CO2 emissions. They split the developing countries into 27 low- and 38 lower middle-income countries and looked for sigma convergence, finding no evidence of overall convergence for either of the samples. They identified convergence clubs for each of the panels, and also found non-convergent countries in each. The authors also combined the two groups to look for convergence clubs within all 65 countries. This sample also showed convergence clubs and non-convergent countries. Payne and Apergis noted that geographical proximity is a common characteristic for countries within the convergence clubs, and that non-convergent countries tend to be island nations.

In a recent study Tillaguango et al. (2021) assess the accelerated process of environmental degradation by studying the convergence of the ecological footprint in Latin America. They investigate the role of the productive structure and find the existence of per capita ecological footprint clubs and the existence of three convergence clubs. They estimate the marginal effects of their determinants. They recommend that the region's environmental policymakers should cooperate to collectively mitigate environmental degradation for achieving sustainable development goals.

3.4. Determinants of Convergence

Choi et al. (2010) studied the relationship between CO2 emissions, economic growth, and free trade with data from 1971-2006 for China, Korea, and Japan. The relationship between economic growth and emissions is different for each country, and little evidence is found supporting the EKC. Similarly, the relation between trade openness and emissions also varies, with Korea showing an inverted U-shape, China a U-shape, and Japan showing a positive relation between the two variables that is decreasing towards the end of the period. Sharma (2011) investigated the determinants of CO2 emissions in a sample of 69 countries and for panels of low-, middle-, and high-income countries for the period 1985-2005. The author found per capita income and urbanization to have statistically significant effects on CO2 emission. They further found that trade openness had no significant effects on CO2 emissions in any of their panels, but that energy consumption significantly impacted CO2 emissions in their high-income panel. Dogan and Seker (2016) studied the determinants of carbon emissions in the OECD countries, investigating real income, energy consumption, financial development, and trade openness in the EKC model. They found that financial development and trade openness reduces CO2 emissions, whereas energy consumption increases it. They further found that as real income increases environmental harm is reduced, confirming the EKC hypothesis. Coskuner et al. (2020) studied socio-economic determinants of CO2 emissions in the OPEC countries for the period 1995-2014. Similar to Dogan and Seker, they confirmed the EKC hypothesis, and found that per capita income has a significant positive effect on emissions. Urbanization and international trade are also found to be significant drivers of CO2 emissions.

Ezcurra (2007) studied convergence in emissions and looked at the explanatory factors of the spatial distribution in per capita CO2 emissions. The author investigated per capita GDP, trade openness, and climatic conditions' (temperature) relation to CO2 emissions and found that per capita GDP and climatic conditions both seem to have a strong impact, but trade openness does not. Camarero et al. (2013) analysed convergence in CO2 emissions per unit of GDP by studying convergence in the determinants of CO2 emissions: the carbonization index (CO2 emissions per unit of energy) and energy intensity (energy per unit of GDP). All three variables of interest are diverging for the 19 countries investigated, and convergence clubs are identified for each variable. The authors found that the convergence behaviour of CO2 emissions per unit of GDP is explained best by the convergence dynamics of the carbonization index rather than energy intensity. Bhattacharya et al. (2020) investigated convergence of 70 countries regarding CO2 emission intensity. The authors note that the convergence literature of CO2 emissions has disregarded two areas of study: the determinants of convergence and forecasting future emissions. Their paper discusses both topics, investigating TFP (total factor productivity), trade openness, renewable energy consumption, urbanization, and industry value added as potential determinants of the convergence behaviour of emissions in their two convergence clubs using a binary logit regression. High TFP, renewable energy consumption, and urbanization all correlate with being part of the low-carbon intensity convergence clubs. Increased trade openness also seems to have some positive relation to joining the low-carbon intensity convergence clubs, while increases in industry value added instead increases the odds of joining a high-carbon intensity club.

Plenty research considers global convergence, and some looks at group convergence based on economic development. Some authors have studied regional convergence. This paper intends to expand the research by investigating the full Americas region, and also expand on the time periods of previous studies to see if earlier findings of convergence hold to this day. Some authors have investigated the factors determining the formation of convergence clubs. This paper also intends to investigate the factors determining the formation of convergence clubs.

Three hypotheses arise from the findings of earlier research. Papers studying very large timespans show signs of convergence for the periods, but most papers considering shorter timespans do not find convergence for large international samples. Panopoulou and Pantelidis (2009) found convergence for the Latin America and Caribbean region for the 1960-2003 period. Robalino-López et al. (2016) failed to find full convergence for 10 countries in South America for the 1980-2010 period but did find convergence clubs. The first hypothesis is that the Americas region is converging over the full period, but not in the later years.

The literature shows many examples of group convergence, where the groups are mostly based on similar income level or development. Some studies also consider groups based on geographic region or economic characteristics. Convergence clubs are increasingly being investigated in the emissions literature, with most researchers finding convergence clubs based on geographic region or income level. The second hypothesis arises from this: convergence clubs will be identified for the short run, and they are expected to show relation to spatial distribution and income level.

Several papers investigate trade openness, per capita income, energy consumption, and urbanization among others as possible determinants of CO2 emissions with varying results. Some researchers have found variables that significantly impact the convergence behaviour of CO2 emissions, such as per capita income, climatic conditions, the carbonization index, renewable energy consumption, urbanization, and trade openness. The third hypothesis is formulated based on these findings, as high levels of per capita GDP, openness, renewable energy, and urbanization are expected to correlate with low-emission convergence clubs. Initial level of emissions and energy intensity are not expected to correlate with low-emission clubs.

4. Methodology

This section presents the methodology employed in the paper. Phillips and Sul (2007) presented the log t-test as a new regression test of convergence. The clustering algorithm was also introduced by Phillips and Sul (2007) as a way to sort data into groups with similar convergence characteristics. The log t-test is used to study the overall convergence in the sample, and the clustering algorithm is used to investigate the existence of convergence clubs in the panel. This section also introduces the logistic regression which is used to investigate the factors determining the formation of convergence clubs. Last, this section presents the data used.

4.1. Log t-test of convergence

We have panel data for the variable X_{it}, where X is the natural logarithm of per capita CO2 emissions, $i = 1, 2, \ldots.., N$, and $t = 1, 2. \ldots\ldots, T$, where N is the number of countries and T the number of time periods considered. The common way to decompose Xit is as follows:

$$X_{it} = g_{it} + a_{it} \tag{2}$$

where g_{it} is a systemic component and a_{it} is a transitory component. To separate common components from idiosyncratic components, Phillips and Sul (2007) transform (2) into:

$$X_{it} = \left(\frac{g_{it} + a_{it}}{\mu_t} \right) \mu_t \tag{3}$$

where X_{it} is decomposed into two time-varying components, μ_t as the common component and δ_{it} as the idiosyncratic component. δ_{it} measures the distance between X_{it} and the common stochastic trend μ_t for a given country i. We can test for convergence using δ_{it}, if an individual i converges to the constant δ. This is done through ratios rather than differences, meaning the common component μ_t is obsolete. Thus, Phillips and Sul further transform (3) into the relative transition parameter:

$$H_t = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}} \tag{4}$$

Here, the common component μ_t is removed. Model (4) measures δ_{it} relative to the panel average, so we can trace the transition path for X_{it} compared to the panel average. Phillips and Sul name two properties inherent to h_{it}. One, h_{it} is defined so that the cross-sectional average is unity. Two, h_{it} converges to unity if δ_{it} converges to δ. This implies that in the long run as $(t \to \infty)$, the cross-sectional variance of h_{it} (H_t) converges to zero, giving us the following:

$$H_t = \frac{1}{N} \sum_{i=1}^{N} (h_i - 1)^2 \to 0 \text{ as } t \to \infty \tag{5}$$

Phillips and Sul note that a decreasing cross-sectional variation is not sufficient evidence to indicate overall convergence, as it could instead point to local convergence for subgroups. To account for this, Phillips and Sul model δ_{it} in semiparametric form as:

$$\delta_{it} = \delta_i + \frac{\sigma_i \xi_{it}}{L(t)t^{\alpha}} \tag{6}$$

where $\sigma_i > 0$ for all i, $t \geq 1$ and ξ_{it} is $iid(0,1)$ across i and weakly dependent over t. $L(t)$ is a slowly varying function that moves towards ∞ as $t \to \infty$, and α is the speed of convergence, or the rate at which H_t moves towards zero. δ_{it} converges to δ_i for all $\alpha \geq 0$ because of this formulation. Knowing this, we can now state the null hypothesis, H_0, and the alternative hypothesis, H_1.

$$H_0 : \delta_i = \delta \text{ and } \alpha \geq 0$$

$$H_1 : \delta_i \neq \delta \text{ for some } i \text{ and/or } \alpha < 0$$

If the null hypothesis holds, there is convergence for all countries. If the null hypothesis is rejected, there is no convergence for some countries. Rejection of the null hypothesis could imply both divergence for the sample and club convergence, meaning that at least one subset of the sample has formed a convergent group at a different factor loading than δ, such as δ_1 and δ_2. We can now perform the regression t-test. First, we form the cross-sectional variance ratio $\frac{H_1}{H_t}$, using H_t and h_{it} as defined in (5) and (4), respectively, and H_1 is H_t at $t = 1$. We then compute a t-statistic for the coefficient $\widehat{b}$ with an estimate of the long-run variance of the regression residuals.

$$\log\left(\frac{H_1}{H_2}\right) - 2\log L(t) = \widehat{a} + \widehat{b}\log t + \widehat{b_t} \text{ for } t = [rT], [rT]+1, ..., T \text{ with } r > 0 \tag{7}$$

Here, $L(t) = log(t)$ and $\widehat{b} = 2\widehat{a}$, where $\widehat{a}$ is an estimate of α in H_0. This regression is performed after a portion r of the sample T is removed. Like Phillips and Sul (2007), Bhattacharya et al. (2020), and Haider and Akram (2019), an r of 0.33 is selected for this study. We test for convergence through a one-sided t-test of $\alpha \geq 0$ using b. As we employ the standard t-statistic t_b, we follow the standard normal distribution and can reject the null hypothesis of convergence at the 5% level if $t_b < -1.65$.

The Phillips and Sul (2007) club convergence methodology is based on a nonlinear time-varying factor model that considers the possibility of transitional heterogeneity or transitional divergence. If there is heterogeneity, standard unit root or cointegration tests are not appropriate for investigating convergence. Phillips and Sul methodology does not depend on a variables' stationarity properties, and as such does not employ stochastic convergence. Further, the methodology broadens the definition of convergence to consider cases of asymptotic cointegration: when two series do not cointegrate but show similar changes over time. The most important property of the methodology is that if the full panel does not converge, different groups of countries can be identified as converging to different steady states and at the same time identify individual non-convergent countries to diverge from the rest.

4.2. Club convergence test

Club convergence can be studied by ordering countries based on economic, social, or geographic characteristics and investigating whether countries with similar characteristics are converging through convergence tests. This paper studies club convergence for the entire sample using Phillips and Sul (2007)'s club convergence algorithm. As previously mentioned, rejection of the null hypothesis of convergence for a panel still leaves the possibility of subgroup convergence in the sample. Phillips and Sul's club convergence algorithm allows identifying subgroups within a panel that are converging towards a common level of per capita carbon emissions. The convergence algorithm consists of the following four steps.

- Step 1. *Last Observation Ordering*: Here we order the panel members based on the last observation in descending order. This is done as the last years of the series will be the strongest indicators of whether there is convergence in the panel.
- Step 2. *Core Group Formation*: We now form a core group of converging countries, Gk. To identify this subgroup, we perform the log t-test on the first $k = 2$ countries from the ordering in Step 1, and if t_{bk} $(k = 2) > -1.65$, they establish Gk. We then perform the log t-test on $k = 3$. If $t_{bk}(k = 3) > t_{bk}(k = 2)$, we add country 3 into Gk. This procedure is repeated providing $t_{bk}(k) > t_{bk}(k-1)$ for all $N > k \geq 2$. Basing the core convergence group on $t_{bk}(k) > t_{bk}(k-1)$

reduces the probability of a type II error, and thus a low false inclusion rate. The subgroup we find where the earlier condition holds is denoted G_{k^*}, where k^* is the size of the core group.

- Step 3. Sieve Individuals for Club Membership: Now we assess every individual country not included in $G_{k^*}(G^c_{k^*})$ for membership in the core group. We do this by taking one country at a time from $G^c_{k^*}$ and add them to G_{k^*}. After calculating the t-statistic from the log-t regression, the country is investigated for membership in G_{k^*} : if $t_b > c$ where c is a chosen critical value, the country satisfies the membership condition and is added to G_{k^*}. After all countries that satisfy the membership conditions are added to the core group, we check that the core group is converging through $t_{\hat{b}} > -1.65$. If $t_{\hat{b}} < -1.65$, we raise c and do this step again until the core group is converging.

- Step 4. Stopping Rule: Here we form a complement group with the countries not selected into the core group from Step 3. We then perform a log t-test for the subgroup to see whether there is convergence ($t_{\hat{b}} > -1.65$). If the results indicate convergence, we can conclude that there are two convergence clubs present in the panel. If the results do not indicate convergence, we perform Steps 1-3 to find whether there are other subgroups of converging countries in the panel. If Step 2 fails to form another convergence group, the remaining countries diverge.

A low c is exclusive and will only allow countries with strong evidence for membership to be included into the core group. This will lead to more reliable groups but will increase the risk of excluding countries from groups they belong to, thus causing many small convergence clubs to form. To remedy this, Phillips and Sul (2009) recommend testing whether some convergence clubs can be merged. This is done through performing a log t-test for a panel that includes two convergence clubs. If $t_{\hat{b}} > -1.65$ for the combined group, we can merge the two groups into one convergence club. This paper employs Du (2017) package for the convergence and convergence club testing. To deal with heteroscedasticity and autocorrelation for the log-t test, the package calculates a conventional heteroskedastic and autocorrelated estimate from the regression residuals.

4.3. Logistic regression

A logistic regression will be implemented to investigate the formation of the convergence clubs identified. The regression models how well independent variables can predict the outcome of the dependent variable (Egerton, 2018). The dependent variable is categorical and most commonly binary but can take other forms. An example of this is a soccer game, where the outcome is "win" or "lose" for a team. "Win" takes the value of 1, and "lose" takes the value of 0 for the dependent variable. Independent variables predicting the outcome of "win" or "lose" could be points scored or possession time of the football. The odds ratio of a logistic regression shows the change in outcome for the dependent variable when a one-unit change in an independent variable has occurred (Egerton, 2018). If points scored increases by one unit, the odds ratio may show 1.20 which indicates one-unit increase in points scored increases the odds of winning the game by a factor of 1.20. If the odds ratio shows 1.0, this means the odds of winning the game does not change based on an increase in the independent variable. If the odds ratio is less than 1.0, the odds of winning the game is reduced when more points are scored. A larger distance from 1.0 indicates a greater association between the independent variable and the outcome of the dependent variable (Egerton, 2018).

Bhattacharya et al. (2020) implemented a binary logistic regression to study the determinants of their two emission intensity convergence clubs. The dependent variable took the value of 0 for the high intensity club and 1 for the low intensity club. Yu et al. (2015) studied convergence clubs in energy intensity and found 4 convergence clubs.

To study the determinants of these clubs they performed an ordinal logit regression with the clubs as the dependent variable, with 1 representing the highest intensity club and 4 representing the lowest intensity. As the results of this paper shows 2 convergence clubs for PCO2 (Per capita carbon dioxide emissions) 1990-2016, and 4 convergence clubs for emission intensity, both a binary and an ordinal logit regression will be implemented. The highest per capita emission club will be denoted as 0 and the lowest as 1. The highest emission intensity club will be denoted as 1, second highest as 2, third highest as 3, and lowest as 4. Since the objective is a low per capita emission and emission intensity, this simplifies the interpretation of the regression results.

The independent variables whose effects will be investigated in the logit regression are:

- *Initial (Initial level of PCO2 or CO2/GDP)*. The club convergence hypothesis as stated by Galor (1996) says that economies with similar structural characteristics will converge in the long-run as long as they initially have similar conditions. Later research has found evidence to support this, such as Bhattacharya et al. (2020) who found that increasing initial emission intensity of an economy reduces the odds of being in a low-intensity convergence club. This makes it an appropriate variable to include when looking at the possible factors determining the formation of convergence clubs. An increase in Initial is expected to reduce the odds of joining the low emissions club.
- *Etensity (Energy Intensity, energy per unit of GDP)*. Since energy consumption is an important variable explaining the carbon emissions of a country, the amount of energy consumed to create one-unit of GDP may also be a variable of interest. Camarero et al. (2013) found that energy intensity did not adequately explain the formation of convergence clubs based on emissions intensity. As a lower value of energy intensity is the target, meaning that an economy generates more GDP per unit of energy, an increase in Etensity is expected to reduce the odds of joining the low emissions club.
- *GDP (Per capita GDP)*. Many studies have found per capita GDP to have a significant correlation to CO2 emissions. As such, it is an appropriate variable to include when studying the determinants shaping convergence clubs. Ezcurra (2007) found per capita GDP to have a strong impact on the formation of convergence clubs. If the EKC holds, increasing GDP at a low level will increase emissions, whereas increasing GDP at a high level will reduce them. An increase in GDP is expected to increase the odds of joining the low per capita emission club, but only to a small degree. An increase in income level tends to increase the emission efficiency of an economy. Because of this, the same results are expected as for emission intensity, but the odds are expected to be higher.
- *Openness (Trade share of GDP)*. Similar to GDP, many studies discuss trade openness as a driver of CO2 emissions, and the literature is divided on whether it has a positive or negative effect. Bhattacharya et al. (2020) found differing results regarding trade openness as a determinant of their CO2 convergence clubs. An increase in Openness is expected to reduce the odds of joining the low-emission club, but this effect is not expected to be significant, as earlier research suggests.
- *Renewable (Renewable energy share of total energy)*. Energy consumption has been studied as a determinant of CO2 emissions and has been found a major driver increasing emissions (Sharma,2011;Dogan and Seker,2016) Renewable energy is a good way to reduce the emissions from energy consumption. Bhattacharya et al. (2020) found renewable energy to increase the odds of joining a low-emission club, and the same results are expected for Renewable.

- *Urbanization (Urban population share of total population)*. Urbanization has had differing results in the literature as well, which is understandable as urbanization has many different effects. Positively, more people in a smaller space can reduce emissions through shifting away from private vehicles to more sustainable options, but negatively, it takes more people away from food sources which requires larger transport times. Coskuner et al. (2020) found urbanization to be a significant driver of CO2 emissions. Bhattacharya et al. (2020) found that an increase in urban population increases the odds of belonging to a low-emissions club. An increase in Urbanization is expected to increase the odds of joining a low-emission club, but by a small factor.

4.4. The data

Studying differences in total carbon emissions between countries is inappropriate because of differences in size of population and economy, so instead this study will investigate convergence and convergence clubs for per capita CO2 emissions (metric tons) and emissions intensity (kg of CO2 emissions per 2010 US$ of GDP). These emissions include those produced during consumption of solid, liquid and gas fuels and gas flaring (World Bank, 2020). Further, data for Energy Intensity (ratio between energy supply and GDP, MJ/$2011 PPP GDP), GDP per capita (2010 US$), Trade openness (sum of exports and imports of goods and services as share of GDP),Renewable energy (as share of total energy consumption), and Urban population (as share of total population) will be used to investigate the formation of the convergence clubs identified. All data is collected from the World Development Indicators (World Bank, 2020).

The 39 countries investigated are from the Americas observed for the time period 1960-2016 for per capita CO2 emissions and 37 countries for emission intensity for the period 1990-2016. The countries included in this analysis are shown in Table 1. As there is only data for the 1990-2015 period for several of the independent variables, only this period can be investigated through logistic regression. For this reason, both per capita emissions and emission intensity will be tested for convergence in the 1990-2016 period. Per capita emissions will be tested for the 1960-2016 and 1975-2016 periods as well. The change in convergence behaviour over time may be relevant for policy implications. 1975 as the starting point was chosen as it is between 1960 and 1990. Table 2 displays the correlation between the variables included in the logistic regression. Problematic variables are Urbanization, GDP, and Renewable, who all show high levels of correlation to other variables.

5. The Results

This section presents the empirical results. The section is divided in three parts. The first part presents the convergence testing. The second and third parts investigate convergence clubs and their determinants.

5.1. Convergence testing

The log-t regression test of convergence is performed for the full 1960-2016 period. Table 3 shows the results of the log-t test, with a t-statistic of $17.2601 > -1.65$, we cannot reject the null hypothesis of convergence at the 5% level. To investigate this further, the relative transition paths (h_{it}) are calculated for all countries. The relative transition paths of all countries in the sample should converge to the same constant over time as it was designed to tend to unity. Figure 1 displays the relative transition paths, which shows a general convergence trend over time as the transition paths are moving towards similar but different steady states. As the later years of a sample are most indicative of whether convergence is

Table 1: *Countries included in analysis, 1960-2016.*

Country	GDP	Country	GDP	Country	GDP
Antigua and Barbuda	13917	Argentina	10239	Aruba	26231
Bahamas, The	27705	Barbados	16099	Belize	4216
Bermuda	90062	Bolivia	2425	Brazil	10965
British Virgin Islands*		Canada	50193	Cayman Islands**	78611
Chile	14777	Colombia	7633	Costa Rica	9509
Cuba	6550	Dominica	7055	Dominican Republic	6550
Ecuador	5176	El Salvador	3382	Grenada	9220
Guatemala	3413	Guyana	5429	Haiti	1265
Honduras	2111	Jamaica	4761	Mexico	10183
Nicaragua	1895	Panama	11107	Paraguay	5089
Peru	6262	St. Kitts and Nevis	17057	St. Lucia	8786
St. Vincent and the Grenadines	6686	Suriname	7912	Trinidad and Tobago	15696
USA	52643	Uruguay	14124	Venezuela, RB	14025

Note: GDP = GDP per capita in 2016
* = Not Included in Emission Intensity analysis, missing data for income level
** = Not included in Emissions Intensity analysis, Income Level for 2015

occurring, the large timespan could lead to false indications of convergence. To see how the convergence behaviour has changed over time for per capita emissions, the 1975-2016 period is tested as well.

The regression for the period 1975-2016 has a t-statistic of 56.1940 (see Table A1), which is larger than -1.65 and as such we do not reject the null hypothesis and find convergence at the 5% level. The convergence speed for this shorter period is slower than the full period. The log-t test for the period 1990-2016 has a t-statistic of -7.4881 and a negative convergence rate meaning that there is divergence present in the region for the later years. This shift from convergence during the long-run to divergence in the short-run corresponds to earlier research. The green Solow model predicts convergence of emissions over time, so the likely cause for divergence in the short-run is differences in the catch-up mechanics, namely diminishing returns and technological progress. The convergence of emissions intensity is investigated for 37 countries over the period 1990-2016 as well. The log-t convergence test shows similar results to the same period for per capita CO2 emissions. The null hypothesis is rejected, so there is divergence present in the sample for emission intensity.

5.2. Convergence clubs and determinants testing PCO2

Since there is convergence present for per capita CO2 emissions in the periods 1960-2016 and 1975-2016, those periods cannot be tested for club convergence. However, as divergence is found in the period 1990-2016 for both PCO2 and emission intensity, we can test if groups of countries in the sample are converging towards common steady states using the clustering algorithm. Doing this for the PCO2 sample reveals three convergence clubs of 8, 17, and 14 countries each (see Appendix A.2, Table A5). As mentioned previously, the selected c value is conservative, so the convergence clubs are reliable but we may be excluding countries from a group they belong to. This is solved by the club merging test. The club-merging test finds that convergence clubs 1 and 2 can merge (see Appendix A.2, Table A6), so for PCO2 1990-2016 we find 2 convergence clubs: one with 25 countries and one with 14 (see Table A1).

Table 2: *Correlation matrix for logistic regression variables*

	Initial1	Inital2	Etensity	GDP	Openness	Renewable	Urbanization
Initial	1.0000	1.0000					
Etensity	0.4255	0.3204	1.0000				
GDP	0.8249	-0.0347	0.1728	1.0000			
Openness	-0.2203	0.0603	0.1505	-0.1452	1.0000		
Renewable	-0.4267	-0.2906	0.2119	-0.4044	-0.0054	1.0000	
Urbanization	0.3681	0.0541	-0.1894	0.4106	-0.5459	-0.2809	1.0000

Note: Initial1 = Initial level of per capita emissions, Initial2 = Initial level of emission intensity, Etensity = Energy Intensity, GDP = GDP per capita, Openness = Trade share of GDP, Renewable = Renewable energy share of total energy, Urbanization = Urban population share of total population.

Table 3: *Convergence testing results*

	$\widehat{b}$	Std Dev	t-statistic
PCO2 1960-2016	1.2210	0.0707	17.2601
PCO2 1975-2016	0.6657	0.0118	56.1940
PCO2 1990-2016	-0.1181	0.0158	-7.4881
CO2/GDP 1990-2016	-0.2940	0.0450	-6.5358

Note: The table displays the convergence testing results. PCO2 = Per capita carbon dioxide emissions. CO2/GDP = Emission Intensity. $\hat{b}$ is 2 times speed of convergence. kq (r) = 0.33.

The average emissions for Club 1 is higher than for Club 2 in both periods, but the average for Club 1 has decreased over time while Club 2's average has increased (see Table A1). Club 1 also has a higher income level than Club 2 both in 1990 and 2016, but both clubs have increased in GDP per capita over time. Table A2 also shows the convergence rates of the clubs, and Club 1 is converging the fastest of the two. Figure 2 displays the convergence clubs graphically. Club 2 looks to be centred around Central America and the Caribbean, but with some countries in South America as well. Club 1 has a more diverse distribution which is understandable as it contains a larger portion of the sample.

A logistic regression is estimated to investigate the formation of the convergence clubs. As there are 2 convergence clubs for PCO2 1990-2016, a binary logistic regression will be used where the dependent variable is a binary variable taking the value of 0 or 1, where 0 is the club that has converged to the higher level of emissions and 1 is the club that has converged to the lower level of emissions. As Club 1's average PCO2 for 2016 is 5.147 and Club 2's 2016 average is 3.800, Club 1 is declared 0 and Club 2 is declared 1. Four regressions are performed, the first including all variables, the second excluding Urbanization, the third excluding Renewable, and the fourth excluding GDP. Urbanization, Renewable, and GDP are excluded as they highly correlate to other variables.

Table A2 displays the results for the logit regression. The Likelihood ration test of the logit regres-

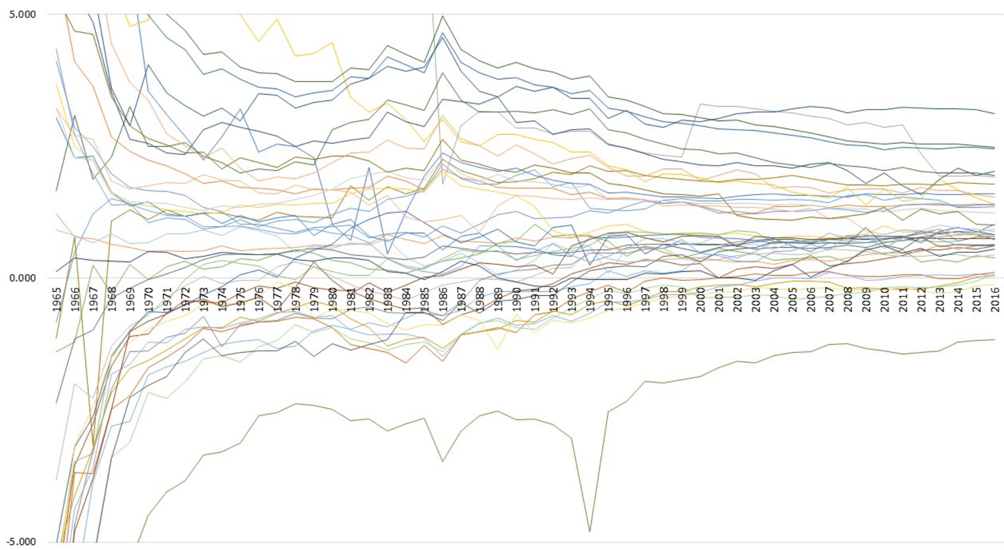

Figure 1: *Relative transition paths (hit) for per capita emissions 1960-2016*

Note: The figure shows the relative transition paths of all countries for per capita emissions.

sion shows how well a model predicts the dependent variable. The larger the value, the better fit of the model. Regression 1 has the largest value at 424.85.

The p-value indicates that the model fits significantly better than a model with no predictors. Regression 2 has a smaller likelihood ratio value, and Regression 3 has the smallest. Removing a variable from the model makes the fit worse. Renewable is the most important to the fit of the model, and Urbanization is the least important.

Openness and Renewable both increase the odds of joining a low emission convergence club in each regression, and the factor does not change much across the regressions. GDP and Urbanization both reduce the odds of joining the low emission convergence club across the regressions, GDP does so to a small degree. Increasing Initial has different impact on the convergence club a country joins for the different regressions. Increasing Initial increases the odds of joining the low emission club for Regression 1 and 2. Increasing Initial reduces the odds of joining the low emission convergence club for Regression 3 and 4. Similarly, Etensity reduces the odds of joining the low emission club in Regression 1, 2, and 4, but increases the odds in Regression 3.

5.3. Convergence clubs and determinants testing CO2/GDP

Implementing the clustering algorithm for emission intensity reveals 4 convergence clubs of 26, 3, 6 and 2 countries respectively. The club-merging test finds that no clubs can merge (see Appendix A.3, Table A7), so the final results are 4 convergence clubs. Table A3 shows the convergence rate of each club, which shows that Club 1 is converging the fastest of the clubs. Club 4's convergence rate is the slowest, and the club is converging at a negative rate. This along with the t-statistic of -1.468 shows that although the club has converged over the period, the convergence is tenuous, and the club is likely to diverge in the future.

The initial and final emission intensity of each club also shows that Club 3 has the lowest average for both periods, Club 1 has the second lowest and Club 2 has the highest average. Club 2's average is skewed as Trinidad and Tobago has a significantly larger emission intensity than the other two members of the club, and the average for the club excluding Trinidad and Tobago would be lower than Club 1's. To investigate whether the convergence clubs are determined by spatial distribution, they are illustrated in Figure 3. As Club 1 contains 26 countries, it is no surprise that the spatial distribution is large and diverse with representation across the entire region studied except North America. Club 2 is centred around North America as 2 of the 3 countries are from there. Club 3 contains 2 countries in Central America, 3 in South America, and one from the Caribbean. Club 4 contains one country from North America and one from South America, Bermuda and Uruguay. Bermuda and Uruguay's convergence is interesting as Bermuda has increased in emissions intensity over the period studied, and Uruguay's has reduced.

A logit regression is estimated to investigate the formation of the convergence clubs. Four regressions are performed again. The results for all four regressions are displayed in Table A4. All independent variables are found to be significant at the 1% level in each regression, except GDP in Regression 2. The odds ratio does not change much across the regressions. Increasing Openness, Renewable, and Urbanization all increase the odds of joining a low-emission intensity convergence club in each regression. Increasing Initial, Etensity, and GDP all reduce the odds of joining a low-emission intensity convergence club in every regression. For the fit of the model, we see that Regression 1 has the largest likelihood ratio, Regression 4 the second largest and Regression 3 the lowest. This means that removing a variable makes the model fit worse, and that removing GDP has the smallest impact on the model fit compared to Renewable and Urbanization.

6. Discussion of the Results

This section provides discussion regarding the strength and limitations of the methodology employed in this study and the results gathered in Section 5.

6.1. Methodology

Some countries in the Americas had to be excluded from the convergence testing of both PCO2 and emission intensity due to lack of data. Further, all countries studied did not have complete datasets available for every independent variable in the logit regression. Some periods are excluded for some countries in the regression. A removing of countries without complete datasets for all independent variables have implications for investigating the convergence of the region. The aim of this study was to investigate the convergence behaviour for the full Americas region, so the choices made reflect this. There is still a sufficient number of observations for the analysis of determinants to be of interest. The data for convergence testing is for the period 1990-2016, while the data for determinants is not available 2016. This may have impacted the results for the logit regression. However, as mentioned previously the primary focus of this study was to investigate the convergence behaviour of the region, and the later years of a sample are most indicative of whether convergence is occurring. Excluding 2016 for the convergence testing would result in different convergence behaviour that would be less accurate to today. The convergence testing was prioritized, but the results for the logit regression are likely to hold up as 767 observations make up a good sample size.

The Phillips and Sul (2007) methodology allows for the possibility of transitional heterogeneity or transitional divergence. If there is heterogeneity, unit root or cointegration tests are not appropriate for investigating convergence. In other words, the methodology does not rely on the assumption of trend stationarity or stochastic nonstationary, so it does not consider stochastic convergence. Unit root or cointegration tests suffer from small sample problems (Cochrane, 1991), so this is a positive. Phillips and Sul (2007) also show that two series can converge even if they are not cointegrated. This expands convergence to encompass cases of similar transitional behaviour even if cointegration does not exist. The selected r of 0.33 has positives and drawbacks. When r increases, larger portions of the sample are removed which causes the test power to decline. However, the rejection rate decreases when r is increased, reducing the risk of falsely rejecting the null hypothesis in case of a low convergence rate. As T (time period studied) is reduced, false rejection rates increase, so a higher r is necessary to maintain a low level of false rejection rates for shorter time periods (Phillips and Sul, 2007). The selected r of 0.33 is fitting for the 26-year period studied for 1990-2016 and is also employed by other researchers (Phillips and Sul, 2007; Bhattacharya et al., 2020; Haider and Akram, 2019). It may be appropriate to adjust the r for the larger T of the 1960-2016, and 1975-2016 periods. An r of 0.29 was tested for the 1960-2016 period, and an r of 0.3 was tested for the 1975-2016 period. The results for those periods are not sensitive to the r being adjusted, so an r of 0.33 has been applied throughout the study for consistency.

The logit regressions showed the likelihood ratio test value reducing as variables were removed, which is normal as the ratio typically increases with more variables. In the case of PCO2 for 1990-2016, removing Urbanization from the regression reduced the likelihood ratio value by very little, and removing Renewable reduced the likelihood ratio the most. This indicates that Renewable and GDP have a larger impact on the predictive power of the model than Urbanization. This is likely because Urbanization is highly correlated to several of the other variables included. GDP similarly does not seem important to the predictive power of convergence clubs for emission intensity. For per capita emissions, GDP significantly increases the likelihood ratio value of the model, but the effect it has on convergence club formation is low. This indicates that GDP itself may not be the driver of convergence behaviour for per capita emissions, but rather, it correlates with factors that do drive convergence behaviour. Regression 1 and 2 have the best fit for per capita emissions, and Regression 1 and 4 for emission intensity.

6.2. Empirical results

Per capita CO2 emissions are fully converging in 1960-2016 and 1975-2016. This shows that over a long-time span, the countries studied are converging in per capita CO2 emissions. This confirms the first hypothesis. The region is diverging for the 1990-2016 period and two convergence clubs are identified, one with 24 countries and one with 14. Emission intensity is diverging as well, and four clubs are found with 26, 3, 6, and 2 countries respectively. As the sample contains many island nations, some non-convergent countries were expected but no countries are. Haiti was particularly expected to be non-convergent. Haiti is an island nation and has the lowest income in the sample, and Payne (2020) found Haiti non-convergent in their investigation of convergence for developing countries.

Convergence club 4 for emission intensity is composed of Bermuda and Uruguay. The countries are converging at a negative rate and has a poor t-statistic. The club does not seem stable and the countries are likely to diverge in the near future and they may then be non-convergent. It is interesting to consider why they may be exhibiting non-convergent behaviour. Uruguay has a very low emission intensity compared to the other countries studied and has reduced it significantly during the period. This is possibly due to its large expansion of renewable energy, increasing from 44.81% of total energy consumption in 1990 to 58.02% in 2015. Compared to the sample average, which was 30.90% in 1990 and 22.28% in

2015, this is a significant difference. Bermuda has more than tripled its emission intensity from 0.11 in 1990 to 0.37 in 2016. Most countries studied show decreases in emission intensity, so Bermuda differs from the sample. Further, Bermuda is not only an island nation, but is also more geographically isolated than the Caribbean islands. This correspondsto Payne (2020) results, who find that non-convergent countries tend to be geographically isolated countries.

There is a relation between geographical proximity and club formation for Club 2 of PCO2 and Club 2 and 3 of emission intensity. Every convergence club does not show a relation to geographical proximity, so evidence for the second hypothesis is mixed. Apergis et al. (2020) found Panama to be the only country exhibiting non-convergent behaviour in their study of 6 Central American countries. The results of this paper similarly show Panama exhibiting different convergence behaviour than the other Central American countries. All Central American countries are in the same convergence club for per capita emissions except Panama, and all Central American countries are in the same emission intensity club except Costa Rica and Panama. There is no strong connection between free trade agreements and convergence clubs, as the convergence clubs either include countries which are not members of a free trade agreement or exclude countries in the agreements.

The average emissions of Club 1 of PCO2 is higher than Club 2, and Club 1 has a higher income level. Club 1's PCO2 has decreased from 1990 to 2016 while Club 2's PCO2 has increased, and both clubs' average income level has increased. This could imply that Club 1 has reached the turning point of the EKC and is now reducing their emissions, while Club 2 has not yet reached the turning point and is increasing emissions along with increases in income level. This would correspond to the average of \$8,910 that Sarkodie and Strezov (2019) found as a turning point in their meta-analysis, as the average income level of Club 2 is \$5,907 in 2016.

Increasing GDP reduces the odds of joining the low per capita emission club. Although the effect is significant at the 1% level, it is very minor. An increase in GDP was expected to increase the odds of joining the low-emissions club, but as it was expected to be small these results are similar. It is possible that most countries have yet to reach the turning point, or that countries have surpassed it but are not following the EKC. Small island nations' economies are generally different from larger countries, so rich island countries like Aruba, Bahamas, and Barbados could have different turning points compared to the rest of the sample.

Initial level of emissions has mixed results for per capita emissions across the 4 regressions. However, Regression 1 and 2 seem to be the best models out of the four. Increasing Initial in Regression 1 and 2 increases the odds of joining a low emission convergence club. The opposite is found for emission intensity. An increase in initial level strongly reduces the odds of being in a low-intensity convergence club. The results for per capita emissions were not as expected. It is likely because the period is too short for the decrease in emissions from developed countries to overtake the increase in emissions for developing countries. The results for Etensity, Renewable, and Openness are as expected for both PCO2 and emission intensity. Renewable is highly significant and increases the odds of being in the low-emission clubs. Renewable is important for the predictive power of the PCO2 regressions, which is seen in the large reduction of the likelihood ratio test value in Regression 3. The findings for Openness show that increasing openness increases the odds of joining a low per-capita or emission intensity club. Earlier research has found both positive and negative effects for increasing trade openness, so this is further evidence of positive effects of joining a low emission convergence club for openness.

The results for Urbanization were as expected for emission intensity. The results for Urbanization's impact on PCO2 was mixed. The significance level of Urbanization varies for the different PCO2 regressions, and the likelihood ratios is only slightly impacted when Urbanization is removed from the PCO2 model. This implies that Urbanization is not important to be included in the model, so is not significant in predicting the convergence behaviour of per capita emissions. The third hypothesis is mostly confirmed although the results for initial level of emissions were different from the expected for per capita emissions, and urbanization's significance was varied.

7. Conclusion

Earlier research has neglected investigating the factors determining the convergence behaviour of CO2 emissions. This paper expands the literature by investigating the convergence behaviour of carbon dioxide emissions in the Americas and the factors determining the formation of convergence clubs. This paper shows that the region is conditionally sigma converging in the long-run, and convergence clubs are identified for the short-run. Some evidence is found suggesting that spatial proximity plays a role in the formation of convergence clubs. Some evidence is also found supporting the environmental Kuznets curve hypothesis. Initial level of emissions, energy intensity, per capita GDP, trade openness, and renewable energy were all found to be highly significant in determining the formation of convergence clubs. Evidence for urbanization's significance on club formation was divided.

The environmental consequences of carbon emissions are causing policymakers and researchers to look for ways of dealing with the growth in emissions. The success and acceptance of environmental regulations are strongly dependent on the convergence hypothesis holding for carbon emissions between countries due to the fairness principle. This paper provides evidence that per capita carbon emissions and emission intensity are converging in the long run, but not converging in the short run for the Americas. Policymakers should expand on free trade agreements in the region that emphasize strong environmental standards for members. Policymakers should also promote emission allocation schemes that reduce total emissions towards a level that maintains global warming to 2 degrees Celsius. Proximate countries have the opportunity to cooperate on policies such as interconnecting power grids for distributing clean energy from renewable sources across borders.

The convergence hypothesis states that countries with identical structural characteristics will converge over time given similar starting conditions. This paper shows that initial conditions are important in determining the convergence behaviour of a country. However, structural characteristics of an economy such as renewable energy consumption, and trade openness are also found to significantly impact the convergence behaviour of a country. The Paris Agreement aims to limit global warming to 2 degrees Celsius above pre-industrial levels and hopes to achieve this by allowing each country to determine their own contributions (UNFCCC, 2021). Policymakers should determine their own contributions based on national structural characteristics and aim to reduce per capita emissions and emission intensity by improving these conditions where possible. Areas with ample opportunity to expand renewable energy should do so, and areas with possibility of increasing trade openness should take those opportunities. Future research should investigate stochastic convergence for the region to see if these findings hold up or if they are biased based on the type of convergence. Future research should also further investigate the determinants of emission convergence by looking at unique economic or geographic conditions of a country.

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A. Appendix

A.1. Tables and Figures

Table A1: *Convergence clubs for PCO2 1990-2016*

Club 1	$\widehat{b}$	t-stat			Club 2	$\widehat{b}$	t-stat		
$N = 25$	0.230	4.436			N=14	0.030	1.131		
Country	GDP 1990	GDP 2016	PCO2 1990	PCO2 2016	Country	GDP 1990	GDP 2016	PCO2 1990	PCO2 2016
Antigua & Barbuda	11080	13917	0.677	5.896	Belize	2842	4216	0.477	1.542
Argentina	6245	10239	2.383	4.619	Colombia	4467	7633	1.021	2.030
Aruba	25357	26231	204.620	8.426	Costa Rica	4884	9509	0.369	1.638
Bahamas, The	29687	27705	3.749	4.725	Dominican Republic	2695	7026	0.316	2.429
Barbados	13004	16099	0.746	4.465	El Salvador	2143	3382	0.224	1.128
Bermuda	76016	90062	3.551	9.486	Guatemala	2293	3413	0.326	1.060
Bolivia	1356	2425	0.274	1.958	Haiti	1383	1265	0.074	0.275
Brazil	7983	10965	0.649	2.242	Honduras	1561	2111	0.302	1.058
Br. Virgin Islands*			3.774	7.245	Jamaica	4283	4761	0.903	2.830
Canada	36555	50193	10.770	15.090	Nicaragua	1126	1895	0.300	0.887
Cayman Islands**		78611	1.398	8.732	Paraguay	3547	5089	0.160	1.093
Chile	5933	14777	1.658	4.713	St. Lucia	7087	8765	0.164	2.302
Cuba	4219	6550	1.918	2.495	Suriname	6086	7912	1.503	3.077
Dominica	4513	7055	0.183	2.520	Trinidad & Tobago	5823	15695	3.044	31.845
Ecuador	3716	5176	0.388	2.496	Average	3587	5907	0.656	3.800
Grenada	4609	9220	0.245	2.428					
Guyana	2260	5429	1.154	3.090					
Mexico	7790	10183	1.670	3.943					
Panama	4061	11107	0.880	2.654					
Peru	2650	6262	0.805	1.857					
St. Kitts and Nevis	9917	17057	0.214	4.616					
St. Vincent and the Grenadines	3505	6686	0.136	2.010					
USA	36059	52643	16.000	15.502					
Uruguay	6878	14124	1.702	1.976					
Venezuela, RB	12909	14025	7.009	5.501					
Average	13752	21114	10.662	5.147					

Note: The table displays the convergence clubs identified for per capita carbon emissions for the 1990-2016 period. GDP = GDP per capita. $\hat{b}$ is 2 times the speed of convergence. *= British Virgin Islands has missing data for GDP. **= Cayman Islands GDP missing for 1990, 2015 rather than 2016

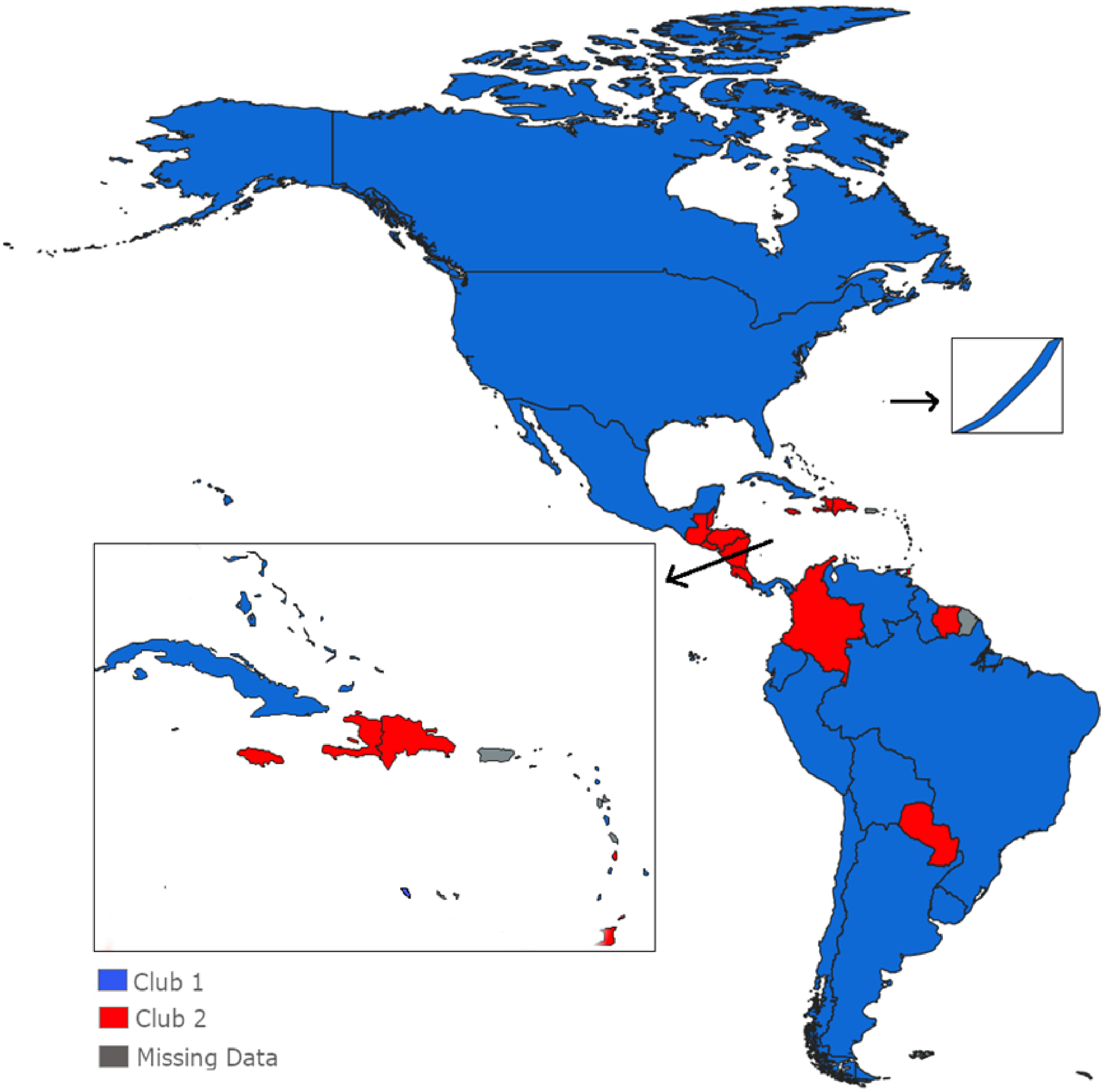

Figure 2: *PCO2 1990-2016 convergence club's spatial distribution*

Note: The figure maps the spatial distribution of the per capita emissions 1990-2016 convergence clubs. Shapefile created by Tapiquén (2015)

Table A2: *Logit regression for PCO2 1990-2016 convergence clubs*

	Regression 1	Regression 2	Regression 3	Regression 4
	Odds Ratio	Odds Ratio	Odds Ratio	Odds Ratio
Initial	1.4043**	1.3355**	0.6429*	0.7880***
	(0.1932)	(0.1813)	(0.0759)	(0.0718)
Etensity	0.7181*	0.7583*	1.1790**	0.9416
	(0.0664)	(0.0661)	(0.0894)	(0.0817)
GDP	0.9997*	0.9996*	0.9997*	
	(0.0000)	(0.0000)	(0.0000)	
Openness	1.0163*	1.0201*	1.0064**	1.0099**
	(0.0038)	(0.0034)	(0.0032)	(0.0035)
Renewable	1.0796*	1.0753*		1.0697*
	(0.0093)	(0.0087)		(0.0084)
Urbanization	0.9806**		0.9977	0.9718*
	(0.0092)		(0.0083)	(0.0075)
Likelihood Ratio Test	424.85	420.73	320.13	376.39
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Observations	767	767	767	767

Note: The table shows the results for the binary logit: regression for per capita emissions for the 1990-2016 period. The dependent variable is a binary variable taking the value of 0 for the highest per capita emissions club and 1 for the lowest per capita emissions club. Standard error in () and p-values of the Likelihood ratio test in []. * = 1% significance level, ** = 5% significance level, *** = 10% significance level.

Table A3: *Convergence clubs for emission intensity*

Club 1	$\widehat{b}$	t-stat	
$N = 26$	0.342	4.386	
Country	GDP 2016	CO2/GDP 1990	CO2/GDP 2016
Antigua & Barbuda	13917	0.41	0.42
Argentina	10239	0.55	0.45
Aruba	26231	0.31	0.32
Barbados	16099	0.28	0.27
Belize	4216	0.58	0.37
Bolivia	2425	0.62	0.81
Chile	14777	0.42	0.32
Cuba	6550	0.74	0.38
Dominica	7055	0.18	0.36
Dominican Republic	7026	0.48	0.35
Ecuador	5176	0.44	0.48
El Salvador	3382	0.22	0.33
Grenada	9220	0.23	0.28
Guatemala	3413	0.25	0.32
Guyana	5429	0.68	0.57
Haiti	1265	0.1	0.22
Honduras	2111	0.34	0.5
Jamaica	4761	0.73	0.59
Mexico	10183	0.49	0.39
Nicaragua	1895	0.54	0.47
Peru	6262	0.36	0.3
St. Kitts and Nevis	17057	0.27	0.27
St. Lucia	8786	0.16	0.26
St. Vincent and the Grenadines	6686	0.21	0.3
Suriname	7912	0.71	0.39
Venezuela, RB	14025	0.52	0.44*
Average	8311	0.41	0.39

Club 2	$\widehat{b}$	t-stat	
$N = 3$	0.053	2.911	
Country	GDP 2016	CO2/GDP 1990	CO2/GDP 2016
Canada	50193	0.43	0.3
Trinidad & Tobago	15696	2.39	2.03
USA	52643	0.54	0.29
Average	39510	1.12	0.87
Club 3	$\widehat{b}$	t-stat	
$N = 6$	0.254	3.613	
Country	GDP 2016	CO2/GDP 1990	CO2/GDP 2016
Bahamas	27705	0.24	0.17
Brazil	10965	0.18	0.2
Colombia	7633	0.39	0.27
Costa Rica	9509	0.19	0.17
Panama	11107	0.28	0.24
Paraguay	5089	0.14	0.21
Average	12001	0.24	0.21
Club 4	$\widehat{b}$	t-stat	
$N = 2$	-0.185	-1.468	
Country	GDP 2016	CO2/GDP 1990	CO2/GDP 2016
Bermuda	90062	0.11	0.37
Uruguay	14124	0.19	0.14
Average	52093	0.15	0.25

Note: The table displays the members of each convergence club for emission intensity. GDP = GDP per capita. *Venezuela's final CO2 is in 2014 rather than 2016. Number of countries in a club noted with (). is 2 times the speed of convergence

Figure 3: *Emission intensity convergence club's spatial distribution*

Note: The figure illustrates the spatial distribution of the convergence clubs for emission intensity. Shapefile created by Tapiquén (2015)

Table A4: *Logit regression for emission intensity convergence clubs*

	Regression 1	Regression 2	Regression 3	Regression 4
	Odds Ratio	Odds Ratio	Odds Ratio	Odds Ratio
Initial	0.0060*	0.0116*	0.00002*	0.0181*
	(0.0052)	(0.0096)	(0.0001)	(0.0138)
Etensity	0.3072*	0.2613*	0.4949*	0.2756*
	(0.0342)	(0.0295)	(0.0388)	(0.0291)
GDP	0.9999*	0.9999	0.9999*	
	(0.0000)	(0.0000)	(0.0000)	
Openness	1.0333*	1.0203*	1.0251*	1.0332*
	(0.0038)	(0.0030)	(0.0034)	(0.0037)
Renewable	1.0646*	1.0628*		1.0769*
	(0.0082)	(0.0075)		(0.0076)
Urbanization	1.0609*		1.0602*	1.0473*
	(0.0089)		(0.0083)	(0.0078)
Likelihood ratio test	575.52	518.21	498.11	561.35
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Observations	767	767	767	767

Note: Table shows the results from the ordinal logit regression for emissions intensity. The dependent variable is an ordinal variable taking the value of 1 for the highest emission club, 2 for the second highest, 3 for the third highest and 4 for the lowest emission intensity club. The standard error in (). Likelihood ratio test p-value in []. * = 1% significance level, ** = 5% significance level, *** = 10% significance level.

A.2. Per capita emissions results

Table A5: Per capita emissions convergence clubs before merging test.

Club 1 (8)	Club 2 (17)		Club 3 (14)	
Country	Country	Country	Country	Country
Antigua and Barbadua	Argentina	Aruba	Belize	Colombia
Canada	Bahamas	Barbados	Costa Rica	Dominican Republic
Chile	Bermuda	Bolivia	El Salvador	Guatemala
Dominica	Brazil	Cayman Islands	Haiti	Honduras
Panama	Cuba	Ecuador	Jamaica	Nicaragua
Peru	Grenada	Guyana	Paraguay	St. Lucia
USA	Mexico	St. Kitts and Nevis	Suriname	Trinidad and Tobago
British Virgin Islands	St. Vincent and the Grenadines	Uruguay		
Venezuela, RB				

Note: This table displays the convergence clubs for per capita emissions before the club merging test has been performed.

Table A6: Club merging test for per capita emissions.

	$Log(t)$	Std Err	t-statistic
Club 1+2	0.2299	0.0518	4.4362
Club 1+3	-0.1667	0.0117	-14.2076

Note: This table displays the results of the club merging tests for the per capita emissions convergence clubs.

A.3. Emission intensity results

Table A7: Club merging test for emission intensity.

	$Log(t)$	Std Err	t-statistic
Club 1+2	-0.1120	0.0468	-2.3909
Club 2+3	-0.4571	0.0167	-27.3742
Club 3+3	-0.2841	0.0532	-5.3435

Note: This table displays the results of the club merging tests for the per capita emissions convergence clubs.