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DOES ECONOMIC GROWTH INFLUENCE THE REDUCTION OF CARBON DIOXIDE EMISSIONS? EVIDENCE FOR THE UNITED STATES–MEXICO–CANADA AGREEMENT

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ABSTRACT. This study aims to measure the impact of goods and services production on carbon dioxide (CO2) emissions. The research is supported by a theoretical and methodological framework that incorporates a production function with two outputs. This approach makes it possible to demonstrate that emissions tend to reduce with economic growth. The research uses panel data for the North American region. The findings reveal significant differences across countries: the U.S. and Canada demonstrate a stronger emissions-reduction effect compared to Mexico. The findings reveal that in the thirty years since the United States–Mexico–Canada (USMCA) agreement was signed, CO2 emissions have dropped while the economy of the region has grown. The findings emphasize the need for increased coordination among national governments in executing public policies on reducing CO2 emissions, the main gas that causes the greenhouse effect, to mitigate environmental degradation. These results are consistent with the studies conducted for European countries that are members of the Organization for Economic Co-operation and Development (OECD).

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Introduction

The second decade of the 21st century was characterized by significant challenges for the global economy. On the one hand, environmental degradation and the increase in greenhouse gas emissions had consequences for economic activity. On the other hand, economic activity also contributed to emissions. Indeed, carbon dioxide (CO2) production contributes to 60% of anthropogenic origin gases (Cancelo and Díaz, 2002). According to Ritchie (2023), over 80% of CO2 came from developed countries in 2021. This fact calls for research to focus on economic studies in this field.

In 1997, the Kyoto Protocol was adopted at the United Nations Conference on Climate Change (COP3). It established binding targets for industrialized countries in terms of reducing their greenhouse gas emissions. These countries committed to reducing their CO2 anthropogenic emissions by at least 5% below 1990 levels during the first commitment period, which ran from 2008–2012 (Li, 2010). Notably, the European Union went even further, committing to reducing their emissions by 8% (Cancelo and Díaz, 2002), while the United States and Canada committed to about 7% (Bengochea et al., 2001). These commitments were suggested to help mitigate climate change triggered by greenhouse gases.

Likewise, the Paris Agreement, signed under the United Nations Conference on Climate Change (COP21), introduced some challenges for change. Within its framework, countries established long-term objectives to significantly reduce greenhouse gas emissions and offer financing to developing economies to mitigate climate change, strengthen resilience, and improve their capacity to adapt to the effects of climate change.

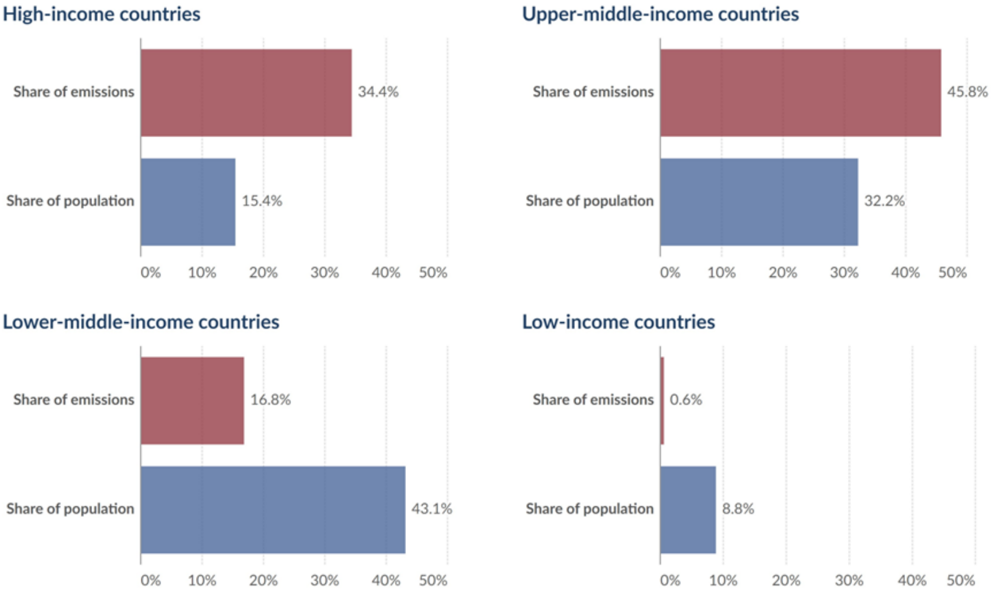

Figure 1. Share of global CO2 emissions and population, 2021
Source: https://ourworldindata.org/inequality-co2

The aim of the study is to measure the impact of goods and services production on carbon dioxide (CO2) emissions. It is supported by a theoretical and methodological framework that incorporates a production function with two outputs, which allows us to demonstrate that emissions tend to reduce with economic growth. The research uses panel data for the North American region, i.e., annual information from 1990–2024 retrieved from the 2023 World Development Indicators database of the World Bank.

In the last decade, the United States' share of global GDP has decreased by just over half a percentage point; however, its contribution is still important at 22.6% in constant 2015 U.S. dollars as of 2023. Meanwhile, China, despite its vigorous economic growth, contributed 18.4% to the world economy in the same year. For this reason, in regional terms, the North American economy continues to maintain economic hegemony due to its contribution to global GDP since it includes the economies ranked 10th and 14th in the world, according to the World Bank (2024). In 2023, North America's contribution to global GDP was 25.55%.

The choice of USMCA countries is particularly relevant from an ecological standpoint, as these economies are ranked among the top 20 global greenhouse gas (GHG) emitters, contributing around 20% of the world's CO2 emissions. Despite the growing body of research on the nexus between economic growth and CO2 emissions, there is a notable lack of studies that focus specifically on USMCA states, which this paper aims to address. A key innovation of this paper is its identification of potential structural differences arising from the unique socioeconomic and cultural characteristics of each country. Thus, the novelty of the article lies in its focus on an economy and region characterized by the greatest economic dynamism due to its contribution to the world economy and the potential implications for carbon dioxide emissions. Methodologically, the study introduces the endogenization of carbon dioxide emissions in the proposed model. The findings reveal that economic growth in this region is associated with a reduction in emissions, which could serve as a motivation for regional and global analyses.

The paper has the following structure. The next section discusses the literature on the nexus between CO2 emissions and economic activity. In the third section, we review empirical regularities, which justify further investigation of the relationship between economic activity and greenhouse gases. The next section explains our methodology, while the results and discussion of our findings are presented in the fifth section. The last section concludes.

1. Literature review

Various studies have used diverse quantitative techniques to link CO2 emissions with economic activity. Broadly, these studies can be categorized into three groups:

- The first group studied the causality between economic growth and CO2 emissions in different regions.
- The second group studied the relationship between economic growth and emissions.
- The third group studied the long-term effect of emissions in developed countries.

In the first group, one can distinguish Pao and Tsai (2010), who examined the dynamic causal relationships among polluting emissions, energy consumption, and production in BRICS countries. They also identified short-term unidirectional causalities of emissions towards production. By contrast, Bokhtiar, Wieloch, Sumon, Zikovic, and Salah (2023) found that in the BRICS countries, the causality results indicate a reverse relationship between industrial growth, trade openness, and CO2 emissions.

In Turkey, Soytasa and Saria (2009) investigated the causality relationship based on the Granger approach, which considers economic growth, CO2 emissions and energy consumption. Meanwhile, Acaravci and Ozturk (2010a) analyzed the causality relationship between economic growth and carbon emissions and energy consumption. Their outcomes show it is probable that energy conservation policies, such as the rationing of energy consumption and the control of CO2 emissions, adversely affect the real production growth in Turkey.

Apergis and Payne (2010) studied the causal relationship between CO2 emissions, energy consumption, and actual production in Commonwealth countries. They found that short-term dynamics indicate the unidirectional causality of energy consumption and real production growth with its impact on CO2 emissions.

Hossain (2011) empirically examined dynamic causal relationships among CO2 emissions, energy consumption, economic growth, trade opening, and urbanization for a panel of newly industrialized countries (NIC). He found that, over time, primary energy consumption caused most CO2 emissions.

Farhani and Rejeb (2012) researched the relationship between energy consumption, gross domestic product (GDP), and emissions in 15 countries in the Middle East and North African (MENA) region. They revealed that in the long term, there is a unidirectional causality between GDP and CO2 emissions and energy consumption. Meanwhile, Arouri et al. (2012) researched the relationship among CO2 emissions, energy consumption, and real GDP for 12 MENA countries. They found that real GDP shows a quadratic relationship with CO2 emissions for the entire region.

In the second group of studies, which investigated the relationship between economic growth and emissions, Turker (1995) analyzed a panel of 137 countries over 21 years and identified a positive relationship between CO2 emissions and GDP. Narayan and Narayan (2010) studied the evidence for developing countries and revealed that approximately 35% of CO2 emissions from the sample fell in the long term. This means that even though the economies of these countries have grown, their emissions have fallen. Bhattacharyya and Ghoshal (2010) investigated economic growth and CO2 emissions through an optimal environmental pollution planning control exercise. They found that the relationship between rates of CO2 emissions growth and economic development is meaningful for those countries that have a high level of CO2 emissions and population rates. Acaravci and Ozturk (2010b) examine the causal relationship among CO2 emissions, energy consumption, and economic growth in Europe. They found evidence of a long-term relationship among carbon emissions per capita, energy consumption per capita, and real GDP per capita.

Among the third group of studies, which consider the trend of long-term emissions for developed countries and regions, Koop (1998) found that the richest economies adopt technical improvements to reduce CO2 emissions, while the poorest do not. Meanwhile, in their analysis of European Union countries, Bengochea et al. (2001) argued that there are significant differences between more industrialized and less industrialized countries. Those outcomes do not seem to support a uniform policy for emissions control.

The literature contains diverse research on the nexus between CO2 emissions and economic growth. Studies have established causal links between economic growth and CO2 emissions, particularly from GDP to CO2 emissions. They also indicate that in developed countries, emissions tend to decrease in the long term. However, we did not find research for the North American region, specifically the United States–Mexico–Canada Agreement (USMCA), which has been in force for 30 years and integrates Canada, the United States, and Mexico. We consider this to be a gap that should be filled.

2. Empirical regularities

In anticipation of the signing of NAFTA in 1993 and its implementation the following year, Grossman and Krueger (1991) suggested that reducing tariff barriers would affect the environment due to the expanded scale of production, its changing composition, and the techniques that would be employed. They identified that sulfur dioxide and smoke concentrations increase with GDP per capita at low national income levels but decrease with GDP growth at higher income levels.

The Economic Complexity Index proposed by Hausmann and Hidalgo (2011) makes it possible to identify the characteristics of a country's production structure. The index has served as a reference to provide evidence that countries with more complex production structures could reduce their levels of environmental degradation in CO2 emissions, as reported by Đokić and Jović (2017). However, this index, and the literature around it, is limited and mainly devoted to developed countries (e.g., Can and Gozgor, 2017; Gozgor, Lau, and Lu, 2018; Liu, Kim, and Choe, 2019).

In line with Hausmann and Hidalgo (2011), it might be more relevant to analyze complexity rather than the volume of production itself. There may be sectors whose products are of low complexity, with little added value, and often associated with highly polluting technologies. Conversely, other sectors or economies may focus on high-complexity products that require high investments in research and development while using clean technologies.

This logic suggests that factor remuneration of factors and environmental pollution can influence development levels. Sectors with more complex products tend to attract a qualified labor force and offer better compensation, impacting poverty and employment indicators, among others. These sectors may also help reduce pollution levels (Renner, 2018).

On the other hand, the Kuznets environmental curve, a reference since the early 1990s (alongside Grossman and Krueger, 1991), proposes an empirical regularity: a systematic relationship between changes in income and environmental quality (Yandl, Vijayaraghavan, Bhattarai, 2002). However, as Catalán (2014) points out, the empirical evidence for this hypothesis is not definitive. Therefore, further investigation into the relationship between economic activity and greenhouse gases is crucial.

3. Methodological approach

3.1. Theoretical model

This research aims to establish a theoretical foundation for the causal relationship between economic growth and CO2 emissions in USMCA countries. We hypothesize that CO2 emissions tend to decrease as these economies grow. To achieve this, we propose the model below. Our analysis begins with a standard economic function for panel data, which takes the following form:

$$Y_{i,t} = F(K_{i,t}L_{i,t}) \tag{1}$$

Where Y_{it} is the production level achieved by combining production factors: capital, K_{it}, and labor, L_{it}; i represents the *i-th* analysis unit[1], and t represents the *t-th* period.

This production process requires energy as an input. Since the Industrial Revolution, the use of fossil fuels (particularly oil, carbon, and natural gas) has increased significantly to keep pace with production. These fuels are a primary source of CO2, the main contributor to the greenhouse effect. Therefore, we can define a separate function for CO2 emissions:

$$W_{it} = F(K_{i,t}L_{i,t}) \tag{2}$$

Where W_{it} is the production of $CO2_{,it}$ emissions; as before, K_{it} and L_{it} are factors of production for the *i-th* unit of analysis in period t.

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[1] The unit of analysis refers to each unit of the cross section, which could be an enterprise, an industry, region, or country, or any other relevant grouping depending on the question.

Functional form (2) defines W as the ratio between two outputs from a production process: CO2 emissions in kilograms per 2015 USD of GDP ($kgCO2$) and the Gross Domestic Product (GDP) at current prices.

$$W_{it} = \frac{kgCO_{2,it}}{GDP_{it}} \tag{3}$$

Equation (3) represents kilograms of CO2 emissions by a monetary unit of produced GDP for the *i-th* unit of analysis in period *t*. Functional forms (1) and (2) provide an econometric representation defined from a mathematical expression that will be presented later.

3.2. The empirical model

Taking into account the general linear model:

$$Y = X\beta + \varepsilon \tag{4}$$

Where Y is a column vector (size n x 1) containing information associated with the endogenous variable. The information related to explanatory variables is collected in matrix X (size n x k); parameters to be estimated are in vector β (size k x 1), and the perturbations in a vector ε (size n x 1). These assume:

$E(\varepsilon) = 0$; $var(\varepsilon) = E(\varepsilon\varepsilon^T) = \sigma^2 I$, (where I is the identity matrix), implying no autocorrelation and homoscedasticity in perturbations. For parameter estimation, the following function is proposed:

$$W_{it} = F(K_{it}, L_{it})$$

This is a Cobb Douglas-type production function, which can be expressed as :

$$W_{it} = AK_{it}{}^{\beta_1}L_{it}{}^{\beta_2} \tag{5}$$

We can transform the model into a linear relationship between the natural logarithms of the variables, allowing us to estimate elasticities:

$$LnW_{it} = LnA_{it} + \beta_1 LnK_{it} + \beta_2 LnL_{it} + \varepsilon_{it} \tag{6}$$

Where LnW_{it}, LnA_{it}, LnK_{it}, and LnL_{it} are the natural logarithms of CO2 emissions, productivity factor, capital or investment, and labor factor or employment for the unit of analysis i at period t. Additionally $LnA=\beta_0$.

We can also express equation (3) in terms of natural logarithms:

$$LnW_{it} = Ln\left(\frac{kgCO_{2,it}}{GDP_{it}}\right) \tag{7}$$

Substituting equation (7) into equation (6), we obtain:

$$Ln\left(\frac{kgCO_{2,it}}{GDP_{it}}\right) = \beta_0 + \beta_1 LnK_{it} + \beta_2 LnL_{it} + \varepsilon_{it} \quad (8)$$

This is equivalent to:

$$LnkgCO_{2,it} = \beta_{0,it} + \beta_1 LnK_{it} + \beta_2 LnL_{it} + \beta_3 LnGDP_{it} + \varepsilon_{it} \quad (9)$$

Where LnW_{it}, LnK_{it}, LnL_{it} and $LnGDP$ are the natural logarithms of CO2 emissions, capital or investment, labor factor or employment, and GDP; $\beta_0, \beta_1, \beta_2$, and β_3 are the parameters to be estimated, representing the elasticities of the corresponding variables.

The first three elasticities are typical of this kind of production function. β_3 is of particular interest because it represents the sensitivity of CO2 emissions to changes in the production level. If $\beta_3>0$, production and emissions change in the same way. If $\beta_3<0$, it indicates that economic growth causes a decrease in CO2 emissions. The sign next to β_3 is negative because CO2 emissions should decrease in the sampled countries. In this case, the outcome would align with the results obtained by Koop (1998) and Narayan and Narayan (2010), who indicate that countries with technological improvements notice CO2 emissions reduction.

This result would be consistent with the findings obtained by Grossman and Krueger (1991), Koop (1998), Narayan and Narayan (2010), Đokić and Jović (2017), Can and Gozgor (2017), Gozgor, Lau, and Lu (2018), Renner (2018 and Liu, Kim and Choe (2019), regarding the inverse relationship between growth and pollutant emissions. It would also be compatible with the hypothesis of the environmental Kuznets curve and the Economic Complexity Index proposed by Hausmann and Hidalgo (2011).

3.3. Territorial analysis

While the regional analysis of USMCA is valuable because the effects of CO2 emissions transcend geopolitical boundaries, a territorial study could reveal differences among the member countries. Therefore, this research incorporates index numbers and the use of the coefficient of variation. A novelty of this paper is that it identifies the likely existence of structural differences that result from each country's unique socioeconomic and cultural characteristics.

To analyze how CO2 emissions per dollar of production evolve in each USMCA country, we employ index numbers. This allows for a multidimensional comparison of variables and facilitates comparisons with a reference period.

A standard procedure for a single-value index number expressed as a percentage is to assign the reference period a value of 100. Subsequent observations are then presented as percentages relative to the reference point.

The coefficient of variation helps us understand how the variability of a variable changes over time. It is calculated as the ratio of the standard deviation to the mean expressed as an absolute value. We use this coefficient to investigate whether the inequality gap in the evolution of kilograms of CO_2 emissions indexes per dollar of production is narrowing over time. A decreasing coefficient of variation suggests convergence among countries, while an increasing value indicates divergence. The coefficient of variation (CV) is expressed as:

$$CV = \frac{\sigma}{\mu} \quad (10)$$

Where σ is the standard deviation, and μ is the arithmetic mean of the variable. Therefore, a higher coefficient of variation signifies greater heterogeneity in the variable and could be interpreted as an inequality gap.

3.4. Estimation

The panel data taken into account has annual information from 1990–2024. The output, Y_{it}, is represented by GDP in USD at current prices; the inputs, X_{it}, are incorporated through investment, which is appropriate to Gross Fixed Capital Formation in USD at current prices; and the Labor, L, references to the total labor force. CO2 emissions are expressed in kilograms (kg) per USD of GDP, in USD at current prices. Data are retrieved from the 2023 World Development Indicators of the World Bank (2023). The conforming information for 2022–2024 has been predicted using the methodology of univariate models proposed by Box and Jenkins (1976), Box, Jenkins and Reinsel (1994), and Brown and Holt's exponential smoothing.

The basic framework for this discussion is a regression model expressed as follows:

$$Y_{i,t} = x'_{i,t}\beta + z'_i\alpha + \varepsilon_{i,t}\,.$$

There are K regressors in $x_{i,t}$, *excluding the constant term*. The heterogeneity, or individual effect, is represented by $z'_i\alpha$, where z'_i includes both a constant term and a set of individual or group-specific variables, which may be observable (such as race, sex, and location) or unobservable (such as family-specific characteristics, individual heterogeneity in skills, or preferences), all of which are taken to be constant over time t. In its current form, this model is a classical regression model. If z_i is observed for all individuals, then the entire model can be treated as an ordinary linear model (Greene, 2003).

We will consider three distinct cases:

a) Pooled Regression: When z_i contains only a constant term, ordinary least squares (OLS) provide consistent and efficient estimates of both the common α and the slope vector β.

b) Fixed Effects: When z_i is unobserved but correlated with $x_{i,t}$, the OLS estimator of β becomes biased and inconsistent as a consequence of an omitted variable (Greene, 2003). However, in this instance, the model can be written as:

$$Y_{i,t} = x'_{i,t}\beta + \alpha_i + \varepsilon_{i,t}\,,$$

where $\alpha_i = z'_i\alpha$, encompasses all the observable effects and specifies an estimable conditional mean. This fixed effects approach treats αi as a group-specific constant term in the regression model.

c) Random Effects: When the unobserved individual heterogeneity can be assumed to be uncorrelated with the included variables, the model can be formulated as:

$$y_{i,t} = x'_{i,t}\beta + E[z'_i\alpha] +\_z'_i\alpha - E[z'_i\alpha]' + \varepsilon_{i,t} = x'_{i,t}\beta + \alpha + u_i + \varepsilon_{i,t}\,,$$

This represents a linear regression model with a compound disturbance that can be consistently (albeit inefficiently) estimated using least squares. In this random effects approach, u_i is a group-specific random element, similar to $\varepsilon_{i,t}$, except that for each group, there is a single draw that enters the regression identically in each period. Greene (2003).

Hausman (1978) showed that the difference between the coefficients of fixed and random effects $(\beta_{re} - \beta_{fe})$ can be used to test the null hypothesis that u_i and X variables are uncorrelated. Thus, the null hypothesis of the Hausman test is that random and fixed effects estimators do not differ substantially. If the null hypothesis is rejected, the estimators differ, suggesting that the fixed effects model is more appropriate. Conversely, if the null hypothesis is not rejected, indicating no bias concerns, the random effects model is preferred for efficiency as there are fewer estimated dummies. Table 1 shows the rejection of this hypothesis.

Table 1. Hausman Test

Coefficients: model 1				Coefficients: model 2			
(b)	(B)	(b-B)	sqrt(diag(Vb-VB))	(b)	(B)	(b-B)	sqrt(diag(Vb-VB))
Fixed	Random	Difference	Standard Error (SE)	Fixed	Random	Difference	Standard Error (SE)
0.777	0.141	0.635	-	0.946	0.522	0.424	-
0.994	0.086	0.908	0.174	0.859	0.125	0 .734	0.168
-1.379	-0.275	-1.104	-	-1.556	-0.697	-0.859	-

b = consistent under Ho and Ha;	b = consistent under Ho and Ha;
B = inconsistent under Ha, efficient under Ho;	B = inconsistent under Ha, efficient under Ho;
Test: Ho difference in coefficients not systematic	Test:Ho:difference in coefficients not systematic
chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)	chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
=83.46	=150.25
Prob>chi2=0.000	Prob>chi2=0.000
(V_b-V_B is not positive definite)	(V_b-V_B is not positive definite)

Source: Authors' elaboration using STATA-16 software

When verifying the assumptions of the regression model, we found issues with contemporary correlation, heteroscedasticity, and autocorrelation. Since the models considered here are extensions of the classical regression model, Table 2 shows the tests used to validate the assumptions underlying the stochastic disturbance term.

Table 2. Assumptions of the classical regression model

Assumption	Test	Null hypothesis	Decision: Model 1	Decision: Model 2
No autocorrelation	Wooldridge test for autocorrelation in panel data	H_0: no first-order autocorrelation	reject	reject
Homoscedasticity test	Modified Wald test for groupwise heteroskedasticity in fixed effect regression model	H_0: $\sigma_i^2=\sigma^2$, for all i	reject	reject
Contemporary correlation test	Breusch-Pagan LM test of independence	H_0: No contemporary correlation	reject	reject

Source: Authors' elaboration using STATA-16 software.

Given these findings, the identified issues are jointly corrected using Panel Corrected Standard Errors (PCSE) estimates (Greene, 2012; Maddala and Lahiri, 2009; Davidson and MacKinnon, 1999; Griffiths et al., 1985).

PCSE estimates are applicable for linear cross-sectional time-series models where the parameters are estimated using either OLS or Prais–Winsten regression. When calculating the standard errors and the variance-covariance estimates, PCSE assumes that the disturbances are, by default, heteroskedastic and contemporaneously correlated across panels (StataCorp, 2019).

If autocorrelation is specified, the parameters are estimated using the Prais–Winsten method. When autocorrelation with panel-specific coefficients of correlation is specified, each panel-level ρ_i is computed from the residuals of an OLS regression (StataCorp, 2019). When autocorrelation with a common coefficient of correlation is specified, the common correlation coefficient is computed as across all panels $\rho=(\rho_1+\rho_2+\rho_3+\ldots+\rho_m)/m$, where ρi is the estimated autocorrelation coefficient for panel i and m is the number of panels. The covariance of the OLS or Prais–Winsten coefficients is $Var(\beta) = (X'X)^{-1}X\Omega X(X'X)^{-1,}$ where Ω is the full covariance matrix of the disturbances (StataCorp, 2019).

When the panels are balanced, we can write Ω as $\Omega = \Sigma_{mxm} \otimes IT_ixT_i$, where Σ is the m by m panel-by-panel covariance matrix of the disturbances, and $\otimes$ is the Kronecker product. PCSE estimates the elements of Σ as $\Sigma_{i,t} = \varepsilon'_i \varepsilon_j / T_{i,j}$, where ε'_i and $\varepsilon_{j,j}$ are the residuals for panels i and j, respectively, which can be matched by period, and where $T_{i,j}$ is the number of residuals between panels i and j that can be matched by period. When the panels are balanced (each panel has the same number of observations, and all periods are common to all panels), $T_{i,j} = T$, where T is the number of observations per panel (StataCorp, 2019).

4. Results and discussion

The access to World Bank data, which unifies indicators across countries, allowed us to build a database in a panel and estimate a set of models to measure the effect of production on CO2 emissions. The outcomes from the final model show that investment and employment increase CO2 emissions. Interestingly, production growth appears to discourage CO2 emission increase.

Table 3. Model 1. Estimation of the CO2 production function with panel data, 1990–2021. Estimation method: Panel Corrected Standard Errors (PCSE).
Dependent variable: Ln (kg per 2015 US$ of GDP), 1990–2021

Group variable: country		Number of obs=96
Time variable: year		Number of groups=3
Panels: correlated (balanced)	Obs per group:	
Autocorrelation: common AR(1)		Min: 32
Sigma computed by casewise selection		Avg: 32
Estimated covariances: 6		Max: 32
Estimated autocorrelations: 1		R-squared: 0.94
Estimated coefficients: 37		Wald chi2(5): 154.44
		Prob > chi2: 0.00

ln(co2usdll)	Coef.	Std. Err.	t-stat	p-value	[95% Conf. Interval]	
ln(GFCF)	0.247	0.090	2.740	0.006	0.070	0.425
ln(labor)	0.712	0.096	7.420	0.000	0.524	0.900
ln(gdp)	-0.416	0.123	-3.380	0.001	-0.658	-0.175
Country						
Mexico	-0.635	0.101	-6.280	0.000	-0.833	-0.436
USA	-1.226	0.112	-10.980	0.000	-1.445	-1.007
year						
1991	0.027	0.014	1.940	0.053	0.000	0.054
1992	0.027	0.015	1.770	0.077	-0.003	0.057
1993	0.014	0.018	0.750	0.455	-0.022	0.049
1994	0.008	0.018	0.430	0.666	-0.027	0.043
1995	-0.001	0.020	-0.060	0.950	-0.041	0.039
1996	-0.020	0.019	-1.060	0.287	-0.058	0.017
1997	-0.044	0.019	-2.290	0.022	-0.083	-0.006
1998	-0.060	0.019	-3.080	0.002	-0.098	-0.022
1999	-0.097	0.021	-4.550	0.000	-0.138	-0.055
2000	-0.104	0.024	-4.360	0.000	-0.151	-0.057
2001	-0.118	0.025	-4.700	0.000	-0.167	-0.069
2002	-0.116	0.026	-4.410	0.000	-0.168	-0.065
2003	-0.118	0.028	-4.260	0.000	-0.172	-0.063
2004	-0.147	0.029	-5.050	0.000	-0.204	-0.090
2005	-0.152	0.031	-4.830	0.000	-0.213	-0.090
2006	-0.186	0.033	-5.620	0.000	-0.251	-0.121
2007	-0.193	0.035	-5.500	0.000	-0.262	-0.124
2008	-0.215	0.036	-5.920	0.000	-0.286	-0.144
2009	-0.238	0.034	-7.100	0.000	-0.304	-0.172
2010	-0.242	0.038	-6.410	0.000	-0.316	-0.168
2011	-0.234	0.040	-5.770	0.000	-0.313	-0.154
2012	-0.279	0.040	-7.000	0.000	-0.358	-0.201
2013	-0.313	0.041	-7.570	0.000	-0.394	-0.232
2014	-0.337	0.042	-8.080	0.000	-0.419	-0.255
2015	-0.377	0.038	-9.930	0.000	-0.451	-0.303
2016	-0.413	0.037	-11.110	0.000	-0.486	-0.340
2017	-0.432	0.039	-11.040	0.000	-0.509	-0.356
2018	-0.478	0.040	-11.870	0.000	-0.557	-0.399
2019	-0.488	0.042	-11.740	0.000	-0.570	-0.407
2020	-0.536	0.041	-13.130	0.000	-0.616	-0.456
2021	-0.600	0.043	-14.040	0.000	-0.683	-0.516
_cons	-7.515	0.761	-9.880	0.000	-9.006	-6.024
rho	0.697					

Source: Authors' elaboration using data from The World Bank (2023).

Table 4. Model 2. Estimation of the CO2 production function with panel data, 1990–2024. Estimation method: Panel Corrected Standard Errors (PCSE_.
Dependent variable: Ln (kg per 2015 US$ of GDP), 1990–2024

Group variable: country		Number of obs=105
Time variable: year		Number of groups=3
Panels: correlated (balanced)	Obs per group:	
Autocorrelation: common AR(1)		Min: 35
Sigma computed by casewise selection		Avg: 35
Estimated covariances: 6		Max: 35
Estimated autocorrelations: 1		R-squared: 0.94
Estimated coefficients: 40		Wald chi2(5): 879.17
		Prob > chi2: 0.00

ln(co2usdll)	Coef.	Std. Err.	t-stat	p-value	[95% Conf. Interval]	
ln(GFCF)	0.319	0.071	4.48	0.000	0.179	0.459
ln(labor)	0.735	0.085	8.58	0.000	0.567	0.903
Ln(gdp)	-0.510	0.093	-5.460	0.000	-0.693	-0.327
Country						
Mexico	-0.671	0.093	-7.230	0.000	-0.853	-0.489
USA	-1.238	0.106	-11.650	0.000	-1.446	-1.030
year						
1991	0.031	0.013	2.380	0.017	0.006	0.057
1992	0.034	0.014	2.360	0.018	0.006	0.062
1993	0.022	0.017	1.330	0.184	-0.011	0.055
1994	0.014	0.017	0.860	0.389	-0.018	0.047
1995	0.011	0.018	0.590	0.554	-0.025	0.046
1996	-0.011	0.018	-0.630	0.527	-0.046	0.023
1997	-0.038	0.018	-2.060	0.040	-0.074	-0.002
1998	-0.055	0.019	-2.950	0.003	-0.092	-0.019
1999	-0.091	0.020	-4.480	0.000	-0.130	-0.051
2000	-0.096	0.022	-4.290	0.000	-0.141	-0.052
2001	-0.109	0.023	-4.650	0.000	-0.155	-0.063
2002	-0.105	0.024	-4.330	0.000	-0.153	-0.058
2003	-0.106	0.025	-4.170	0.000	-0.156	-0.056
2004	-0.136	0.027	-5.030	0.000	-0.188	-0.083
2005	-0.140	0.029	-4.820	0.000	-0.198	-0.083
2006	-0.176	0.031	-5.660	0.000	-0.237	-0.115
2007	-0.183	0.033	-5.540	0.000	-0.247	-0.118
2008	-0.205	0.034	-6.000	0.000	-0.272	-0.138
2009	-0.227	0.031	-7.230	0.000	-0.288	-0.165
2010	-0.227	0.034	-6.570	0.000	-0.294	-0.159
2011	-0.216	0.037	-5.890	0.000	-0.288	-0.144
2012	-0.264	0.037	-7.200	0.000	-0.336	-0.192
2013	-0.296	0.038	-7.850	0.000	-0.370	-0.222
2014	-0.320	0.038	-8.410	0.000	-0.395	-0.245
2015	-0.364	0.035	-10.290	0.000	-0.433	-0.295
2016	-0.400	0.035	-11.530	0.000	-0.468	-0.332
2017	-0.417	0.036	-11.520	0.000	-0.488	-0.346
2018	-0.463	0.037	-12.430	0.000	-0.536	-0.390
2019	-0.471	0.038	-12.350	0.000	-0.546	-0.396
2020	-0.518	0.037	-13.920	0.000	-0.591	-0.445
2021	-0.583	0.039	-14.830	0.000	-0.660	-0.506
2022	-0.617	0.043	-14.190	0.000	-0.702	-0.532
2023	-0.647	0.045	-14.490	0.000	-0.734	-0.559
2024	-0.685	0.046	-14.960	0.000	-0.775	-0.595
_cons	-7.195	0.722	-9.960	0.000	-8.610	-5.779
rho	0.750					

Source: Authors' elaboration using data from The World Bank (2023).

Traditional inputs like investment and employment show a positive and statistically significant relationship with CO2 emissions over the 1990-2021 period. Conversely, GDP growth has a negative and statistically significant impact on CO2 emissions. A one percentage point increase in GDP is associated with a 0.41% reduction in CO2 emissions. For the traditional inputs of investment and employment, forecasts extend until 2024, with parameter estimates remaining positive and significant across all levels of statistical significance. Likewise, the GDP parameter retains statistical significance at all levels, with an increase of one percentage point reducing the production of CO2 emissions by 0.51%. This outcome suggests a gradual reduction in CO2 emissions within the USMCA countries.

Including dummy variables in both models helps identify possible differentiated effects between countries and captures temporal variations. The statistical significance of the parameter values highlights differences between countries. It also reveals an inverse relationship, indicating that the United States has a more significant emissions-saving effect than Mexico. Over time, starting in 1997, there has been a statistically significant inverse relationship with CO2 emissions, indicating an emissions-saving trend in the North American region.

These results are consistent with those obtained by Grossman and Krueger (1991), Koop (1998), Narayan and Narayan (2010), Đokić and Jović (2017), Can and Gozgor (2017), Gozgor, Lau and Lu (2018), Renner (2018) and Liu, Kim and Choe (2019) concerning the inverse relationship between economic growth and CO2 emissions. Additionally, they are consistent with the Kuznets environmental curve hypothesis and the Economic Complexity Index proposed by Hausmann and Hidalgo (2011).

The territorial analysis of CO2 emissions per dollar of production, included in Appendix A-1 and shown in Figure 2, reveals the temporal evolution of emissions. Figure 1 demonstrates a decreasing trend for each country, indicating that both the United States and Canada are effectively reducing their emissions per dollar of production. While Mexico is making progress, it is at a slower rate.

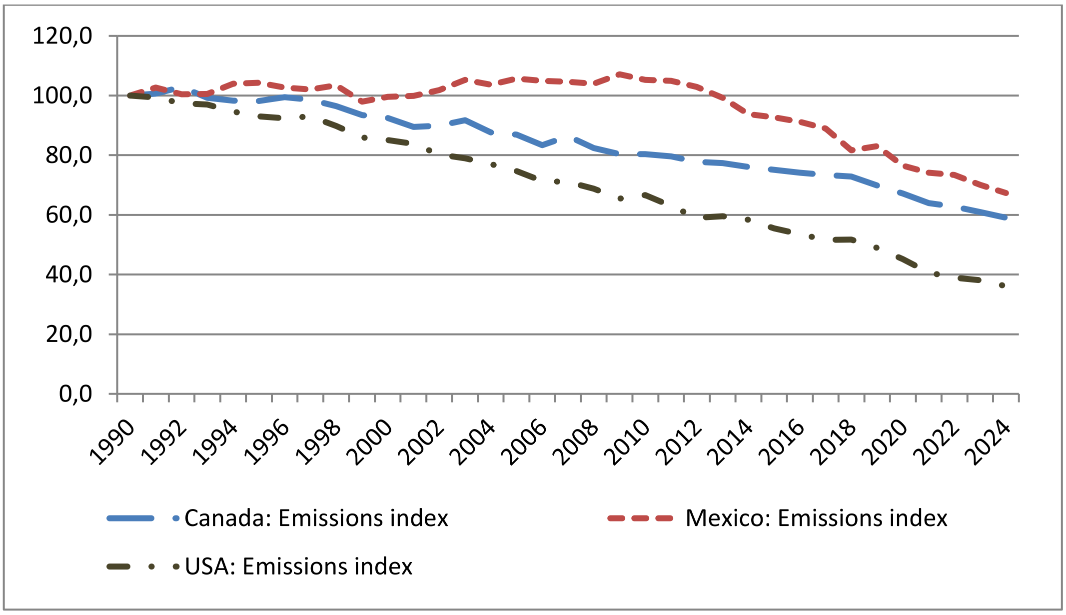

Figure 2. The evolution of the CO2 emissions index per dollar of production
Source: Authors' elaboration based on World Development Indicators, The World Bank (2023).

The coefficient of variation is included in Appendix A-2 and shown in Figure 3. It shows that in the analyzed period, the coefficient of variation increases from the enactment of the

NAFTA agreement. This trend leads to the conclusion that there is a divergence in the reduction of pollutant emissions per dollar of production in the NAFTA countries.

Remarkably, the economic crisis of the early 1990s and 2008 show that these phenomena have a positive effect in reducing the inequality gap of CO2 emissions in the three studied countries.

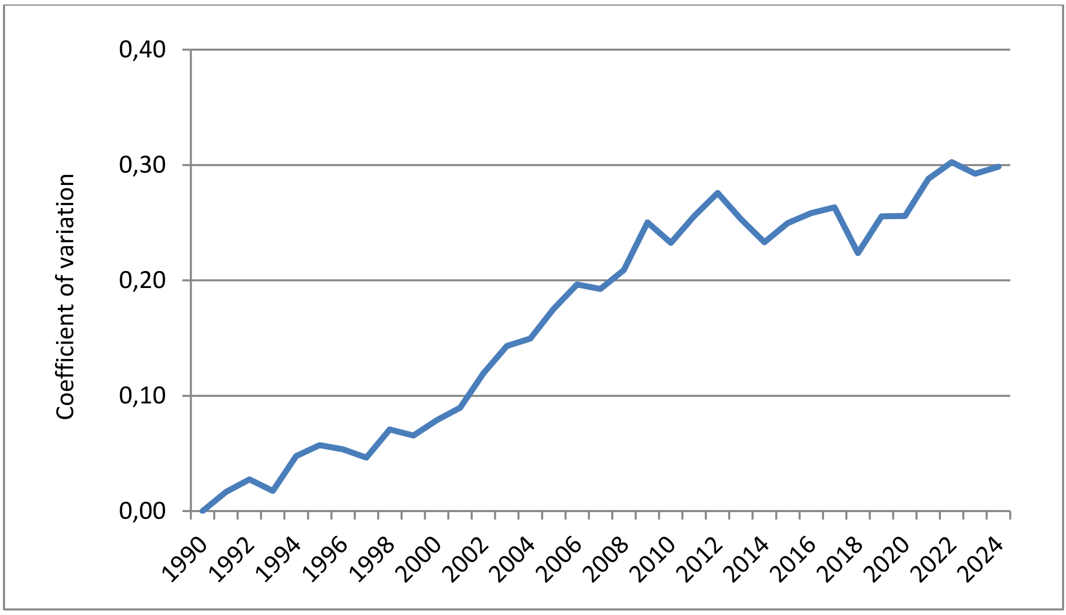

Figure 3. The evolution of the coefficient of variation of CO2 emissions index per dollar of production
Source: Authors' elaboration based on World Development Indicators, The World Bank (2023).

The results reinforce Koop's (1998) findings, which indicate that the wealthiest countries present technical advances that result in CO2 emission efficiencies. They also support Grossman and Krueger's (1991) proposition that reducing tariff barriers within NAFTA would affect the environment due to expanded economic activities from the diversified forms of production. In particular, their research reveals that concentrations of sulfur dioxide and smoke increase with GDP per capita at low national income levels but decrease with GDP growth at higher income levels.

The results are also consistent with the Economic Complexity Index, proposed by Hausmann and Hidalgo (2011). It serves as a reference to provide evidence that countries with more complex productive structures could reduce their levels of environmental degradation in CO2 emissions, as reported by Đokić and Jović (2017).

In line with the environmental Kuznets curve, a systematic relationship between changes in income and environmental quality is identified, as reported in Yandl, Vijayaraghavan, and Bhattarai (2002). However, as noted by Catalán (2014), the empirical evidence for the Kuznets' environmental hypothesis is not definitive. For this reason, further investigation of the relationship between economic activity and greenhouse gases is necessary. It is in that sense that this paper contributes to the contemporary understanding of the relationship between economic activity and CO2 emissions in North America.

Conclusion

Based on the findings, it is possible to conclude that CO2 emissions have been reduced thirty years after the North American trade integration due to the region's economic growth.

The results show that traditional economic inputs, such as investment and employment, are positively correlated with CO2 emissions, while GDP growth has a negative effect, suggesting that higher GDP reduces CO2 emissions. A 1% increase in GDP is associated with a 0.51% decrease in CO2 emissions.

The findings reveal significant differences across countries: the U.S. and Canada demonstrate a stronger emissions-reduction effect compared to Mexico. Notably, Mexico was not obligated to reduce emissions under the Kyoto Protocol, while the United States and Canada, which are also part of the region, have created a spillover effect in terms of CO2 generation.

The study also reveals a general decline in CO2 emissions per dollar of production, particularly in the U.S. and Canada, with Mexico making slower progress. Thus, we recommend a proactive public policy that aims to achieve a higher reduction. Moreover, since 1994, there has been a divergence in the emissions index per monetary unit of production among the three countries, indicating an increasing inequality gap that is influenced by differing environmental protection measures.

Therefore, the findings emphasize the need for increased coordination among national governments in executing public policies on reducing CO2 emissions, the main gas that causes the greenhouse effect, to mitigate environmental degradation. Additionally, the paper notes a divergence in emission reduction rates post-NAFTA, influenced by the economic crises of the 1990s and 2008.

Our results are consistent with Bhattacharyya and Ghoshal (2010), who investigated the relationship between economic growth and CO2 emissions. They found that the relationship between CO2 emissions growth rates and economic development is significant for those countries with high CO2 emissions and population growth rates. Likewise, we agree with Acaravci and Ozturk (2010b), who examined the causal relationship between CO2 emissions, energy consumption, and economic growth in Europe. They found evidence of a long-term relationship between carbon emissions per capita, energy consumption per capita, and real GDP per capita. However, our results differ from Turker (1995), who analyzed a panel of 137 countries over 21 years and identified a positive relationship between CO2 emissions and GDP (we found an inverse relationship).

In line with our results are Narayan and Narayan (2010), who studied the evidence for developing countries and revealed that approximately 35% of the CO2 emissions in their sample fell in the long term. This implies that despite economic growth in these countries, their emissions have decreased. Finally, our results coincide with Koop (1998), who found that richer economies adopt technical improvements to reduce CO2 emissions while poorer ones do not. His results suggest that richer countries show technical progress that allows them to reduce carbon dioxide emissions, but poorer countries do not.

Our results align with previous research on the environmental Kuznets curve, which posits that environmental degradation initially increases with economic growth but eventually declines at higher income levels. Our study also supports the hypothesis that economic complexity, as suggested by the Economic Complexity Index, is linked to lower environmental degradation. The paper underscores the need for further investigation into the connection between economic activity and greenhouse gas emissions, particularly in the context of North America's evolving economic and environmental landscape.

A possible limitation of this paper is that it does not consider all the regions of the world or all the countries. Nonetheless, due to the magnitude of the GDP of the region analyzed, it contributes significantly to regional analysis. Additionally, the paper does not consider an important factor related to the presidential change in the United States in January 2025 and its implications for fossil fuel use, CO2 emissions, and climate change.

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APPENDIX

Appendix A-1. Kilograms of CO2 emissions index per dollar of production

Year	Canada	Mexico	USA
1990	100.0	100.0	100.0
1991	100.6	102.7	99.3
1992	102.9	100.5	97.4
1993	99.2	100.5	97.0
1994	98.2	104.0	94.6
1995	98.1	104.3	93.1
1996	99.5	102.7	92.4
1997	98.6	102.0	93.0
1998	96.4	103.4	89.8
1999	93.5	97.9	86.0
2000	92.5	99.6	85.0
2001	89.5	99.9	83.8
2002	89.9	101.9	80.2
2003	91.7	105.3	79.0
2004	87.7	103.6	77.1
2005	86.9	105.7	74.7
2006	83.4	105.0	71.4
2007	86.4	104.6	71.0
2008	82.4	104.0	68.7
2009	80.4	107.1	65.5
2010	80.3	105.2	66.7
2011	79.7	104.9	63.0
2012	77.8	102.9	59.0
2013	77.4	99.3	59.5
2014	76.0	93.8	58.3
2015	75.1	92.7	55.5
2016	74.1	91.2	53.6
2017	73.4	89.0	51.6
2018	72.9	81.6	51.7
2019	69.8	83.1	49.0
2020	67.2	76.5	45.2
2021	63.9	74.2	40.7
2022	62.8	73.4	38.9
2023	61.0	70.0	38.1
2024	59.0	67.3	36.1

Source: Authors' elaboration based on World Development Indicators, The World Bank (2023).

Appendix A-2. Coefficient of variation

Year	Standard deviation of the emissions index	Arithmetic mean of the emissions index	Coefficient of variation
1990	0.00	100.00	0.00
1991	1.69	100.88	0.02
1992	2.74	100.25	0.03
1993	1.74	98.91	0.02
1994	4.72	98.95	0.05
1995	5.62	98.49	0.06
1996	5.27	98.22	0.05
1997	4.55	97.86	0.05
1998	6.83	96.55	0.07
1999	6.05	92.46	0.07
2000	7.28	92.38	0.08
2001	8.16	91.09	0.09
2002	10.84	90.67	0.12
2003	13.16	91.99	0.14
2004	13.37	89.47	0.15
2005	15.64	89.12	0.18
2006	17.01	86.59	0.20
2007	16.82	87.35	0.19
2008	17.78	85.04	0.21
2009	21.11	84.33	0.25
2010	19.55	84.06	0.23
2011	21.10	82.51	0.26
2012	22.04	79.91	0.28
2013	19.93	78.73	0.25
2014	17.73	76.07	0.23
2015	18.58	74.44	0.25
2016	18.85	72.96	0.26
2017	18.78	71.31	0.26
2018	15.37	68.73	0.22
2019	17.19	67.28	0.26
2020	16.11	62.96	0.26
2021	17.16	59.60	0.29
2022	17.66	58.38	0.30
2023	16.47	56.35	0.29
2024	16.17	54.16	0.30

Source: Authors' elaboration based on World Development Indicators, The World Bank (2023).