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Does the Environmental Kuznets Curve for CO₂ Emissions Exist for Rwanda? Evidence from Bootstrapped Rolling-Window Granger Causality Test

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Abstract: This paper examined the causal relationship between economic growth and carbon dioxide emissions (CO₂) in Rwanda using annual data from 1960–2014. The study was conducted within the framework of the environmental Kuznets curve (EKC) hypothesis using the rolling-window bootstrap Granger causality test approach with a rolling-window size of 15 years. The methodology allows for non-constancy in the parameters of the vector autoregression (VAR) model in the short run as well as in the long run. The study found bi-direction causality between the real gross domestic product (GDP) and CO₂ emissions in metric tons per capita. The results from the rolling-window bootstrap Granger causality test show that GDP negatively influenced CO₂ emissions in the 1976–1977, 1990–1993, 2005–2006, and 2007–2013 sub-sample periods. This result depicts a monotonically decreasing EKC, contrary to the standard EKC relationship. The downward-sloping EKC was explained by the transition of the Rwandan economy from an industrial-based economy to a service-based economy. Further, a feedback effect from CO₂ emissions to the economy was established.

Keywords: carbon dioxide emissions; bootstrap rolling-windows Granger causality; economic growth; environmental Kuznets curve hypothesis; Rwanda

1. Introduction

The alarming rate of environmental degradation has caught the attention of stakeholders, researchers, and policymakers across the globe over the past decades. This is greatly attributable to the fact that environmental pollution not only has repercussions for the economic health of nations and the health of its citizenry but also has spillover effects on other neighboring nations as well. As much as the relationship between the economy and the environment is shrouded in a bit of controversy, there can be no denying the fact that economic growth sometimes comes at a cost to the environment. Recent and past literature on environmental studies has been flooded with attempts to develop policies to account for the seemingly implicit interdependencies between the economy and the environment. History records that formal discussions on the nature of the functional relationship between the economy and the environment began with the work of [1], who, disagreeing with the earlier school of thought that proposed a linear relationship, proposed a non-linear relationship between economic growth and environmental degradation. This new discovery was later formalized by [2] as the environmental Kuznets curve hypothesis, or simply the EKC hypothesis. Expounding on the theoretical underpinnings of the EKC hypothesis, in [3] asserted that environmental pollution worsens initially as the growth of the economy increases and recovers later as the economy develops. Empirical validation of the EKC hypothesis has generated interest among many researchers. To this end, the EKC hypothesis has been tested empirically for a wide variety of environmental indicators

that include but are not limited to deforestation, haze pollution, carbon dioxide, nitrogen oxide, sulfur dioxide, and ecological framework. The EKC hypothesis has been tested for single countries as well as for a panel of countries. The econometric approaches applied to verify the EKC hypothesis have varied, ranging from Ordinary Least Squares (OLS), Auto Regressive Distributed Lag (ARDL), Dynamic Ordinary Least Squares (DOLS), and Fully Modified Ordinary Least Squares (FMOLS) to spatial models. Econometric models that have tested the validity of the EKC for various indicators have produced very mixed conclusions. These mixed conclusions could be ascribed to the various methodologies employed. Econometrically, the validation of the EKC hypothesis requires that in an empirical EKC model with an indicator of environmental pollution as a dependent variable and GDP and its square as independent variables the parameters of GDP and its square should be positive and negative, respectively, and be statistically significant.

The relationship between economic growth and environmental pollution has been one of the most debatable subjects in modern environmental economics literature due to its significance, both in the past and present. This relationship, best explained by the EKC hypothesis, is quite expanding since the research work of [1,4,5] found evidence in support of the inverted-U-shaped EKC hypothesis for CO₂ emissions, implying that economic growth may be a necessary panacea to solving the ills of environmental pollution. Moreover, [6] examined the validity of the EKC hypothesis in Croatia and found an inverted-U-shaped EKC for CO₂ emissions with a bi-directional causality association between CO₂ emissions and economic growth in the short run, and unidirectional causality was established from the growth of the economy to CO₂ emissions in the long run. [7] investigated the effect of the long-run relationship between trade impacts, growth, and renewable energy use on environmental degradations for the G7 nations. The results from their study confirm the existence of the EKC for CO₂ emissions hypothesis for the G7 nations. Moreover, [8] examined the long-run association among nuclear energy use and CO₂ emissions in France and found an inverted-U-shaped EKC with unidirectional Granger causality from energy use to CO₂ emissions. In a study covering 28 provinces in China, [9] examined the long-run effects of development, energy consumption, trade, and urbanization on pollutants such as emissions, wastewater, and waste solid emissions. The results from the study confirm an inverted-U-shaped EKC for all the pollutants.

In an examination of the relationship between environmental pollutants, economic growth, fossil-fuel energy use, and trade, [10] found that the EKC for CO₂ emissions hypothesis could not be validated. [11] could not validate the EKC for CO₂ emissions hypothesis after examining the long-run causal relationship between CO₂ emissions, economic growth, industrialization, and population in Rwanda. Further, [12] failed to validate the EKC hypothesis for CO₂ emissions in Cambodia. The authors found income and urbanization, energy use, and trade to aggravate CO₂ emissions while corruption control and good governance minimized CO₂ emissions. The long-run association between land consumption and economic development was analyzed by [13]. However, the authors did not find evidence in support of the EKC hypothesis for Ecuador. Finally, [14] examined the validity of an inverted-U-shaped existence by investigating the long-run association between economic growth and pollutant emissions for Canada. The authors found a monotonically increasing EKC, which is contrary to the standard EKC relationship. [15] explored the long-run dynamic relations between economic growth, energy use, population density, trade, and pollutants across Japan, South Korea, Brazil, China, Egypt, Mexico, Nigeria, South Africa, and France, respectively. The estimated outcome revealed an inverted-U-shaped EKC hypothesis for South Korea and Japan but an N-shaped EKC for the remaining countries.

In spite of the robustness of previous econometric models, most of them tested the EKC hypothesis on the full data sample, implicitly assuming that the coefficients of the EKC model are non-time varying over the time period of the study. This hypothesis may be true for the whole sample but not for sub-samples of the data. The violation of this implicit conjecture may affect the reliability of the results generated by the econometric method applied. Furthermore, most of the previous works on the EKC have assumed causality from the economy to the environment without any feedback effect

from the environment to the economy. These studies therefore did not take into account the possibility of feedback from the environment to the economy. To ensure the reliability and validity of the EKC hypothesis, there is a need for a robust methodology that takes into account the shortcomings of previous methodologies. It is in this regard that this paper examines the causal links between economic growth and carbon dioxide emissions in Rwanda during the period 1960–2014 by the application of bootstrap rolling-window bootstrap Granger causality test technique. The advantage of this approach is that it provides the opportunity to determine the causality between economic growth and environmental degradation in sub-sample periods, as compared to standard full-sample Granger causality techniques which examine causality over the study's full-sample period. Thus, the examination of the validity of the EKC hypothesis can be verified more reliably through parameter attainment of each sub-sample period. Further, the rolling-window bootstrap Granger causality test technique allows the examination of feedback from the environment to the economy.

Rwanda was selected based on the historical background of its economic transformation after a heavy setback during the 1994 Rwanda genocide. The economy of Rwanda achieved sustained economic growth in the years immediately after the genocide. According to an economic overview report by the World Bank, the economic recovery of Rwanda was characterized by fast development with an average growth of 7.5% for the past decade up to 2018, with per capita GDP growing at 5% per annum. According to the World Development Indicators (WDI) 2019 report, the mean CO₂ emissions in Rwanda since 1960–2014 have been 0.060 metric tons per capita. It is worth noting that CO₂ emissions have shown a fairly steady increase from 1960 to 2014. Additionally, it is predicted by climate change scientists that, between 2015 and 2030, Rwanda's CO₂ emissions will be more than double, rising from 5.3 to 12.1 million tonnes of CO₂ emissions equivalent due to the increasing demand for fossil-fuel energy use by industries and road transport. Given the foregoing scenario of the relationship between economic growth and environmental pollution, this paper seeks to examine the existence of the EKC for CO₂ emissions hypothesis for Rwanda. What are the implications for policy in Rwanda if the hypothesis holds? Are there any feedback effects from the environment to the economy? The paper will be useful for a number of significant reasons. Firstly, to the best of our knowledge, this paper is the first to examine the validity of the EKC hypothesis for CO₂ emissions in Rwanda using the bootstrap rolling-window Granger causality test. Secondly, the rolling-window bootstrap Granger causality methodology employed by our study allowed us to examine whether there were any feedback effects from the environment to the economy. Thirdly, the paper will increase the existing stock of literature on the empirical examination of the EKC for CO₂ emissions in Rwanda and the intellectual and scientific community at large. The results from the study reveal a monotonically downward-sloping EKC hypothesis for Rwanda, implying that economic growth is a natural panacea to reducing CO₂ emissions in Rwanda. Further, the results show evidence of feedback effects from the environment to the economy. The remainder of the paper is organized in the following chronological manner: Section 2 presents the materials and methods for the study, Section 3 presents the results of the study, Section 4 discusses the results of the study, and Section 5 concludes the paper.

2. Materials and Methods

2.1. Theoretical Framework

The EKC hypothesis examined by this paper is premised on the original Kuznets curve theory developed by Kuznets [16], which asserted that income inequality initially increases with income up to an income threshold and diminishes with further increases in income beyond this threshold. The EKC theorizes that as income per capita increases, environmental pollution initially increases with economic growth up to an income threshold and decreases with further increases in income beyond this income threshold. The EKC hypothesis asserts that, in the long run, economic growth becomes a natural panacea to cure environmental ills. The standard EKC is represented as follows:

$$Z_t = \delta_0 + \delta_1 GDP_t + \delta_2 GDP_t^2 + \gamma'X + \varepsilon_1 \quad (1)$$

where Z is a measure of environmental quality. For this paper, Z is CO_2 emissions per capita, GDP gross domestic product per capita, X vector of control variables, and ε error term.

2.2. Estimation Strategy

To investigate the existence of the EKC for CO_2 emissions hypothesis for Rwanda, annual data from 1960–2014 was obtained from the latest version of the World Development Indicators (WDI) database from the World Bank on the two endogenous variables: real gross domestic product per capita (GDP) (measured in constant 2010 US dollars) and CO_2 emissions per capita (CO_2). The natural logarithms of both endogenous variables were taken and used for the analysis. The time period considered by the research was convenient and strategic as it was the longest data period available from the source for the two variables under study. The methodology adopted by this paper was performed in three steps. Firstly, the full-sample bootstrap Granger causality test was performed. In the second step, the coefficients of the vector autoregression (VAR) model used to test for full-sample Granger causality were tested for stability over the sample period. In the event that the parameters of the VAR model in step two prove to be unstable, the bootstrap rolling-window Granger causality test was performed. The three steps are clearly detailed in the next sections.

2.2.1. Full-Sample Bootstrap Granger Causality Testing

The full-sample bootstrap Granger causality test approach deviates from the standard Granger causality test in its test statistics. This is because [17] argued that standard statistics like the likelihood ratio and Lagrange multiplier tests could lack the desired standard asymptotic distributions due to the fact that there are impertinent structural changes that are continuously present in time series and VAR models [18,19]. To solve this problem, [20] proposed a modified Wald test with variables integrated of order one. However, the shortcoming of the modified Wald test is that it still fails in both small and even medium samples. These shortcomings of the general likelihood ratio and Lagrange multiplier tests affect the validity and reliability of the Granger causality test. It was against this background that [21] introduced the critical values of the residual-based (RB) technique which are more effective even when the indicators are not co-integrated. The proposed improvised RB technique is most suitable for standard asymptotic tests for the power and size properties in a small trial corrected Likelihood Ratio (LR) test. This study used the residual-based modified LR statistics. The full-sample bootstrap Granger causality test proceeds by construction of a bivariate VAR (p) as follows:

$$Z_t = \delta_0 + \delta_1 Z_{t-1} + \dots + \delta_p Z_{t-p} + \varepsilon_t \quad t = 1, 2, \dots, T \quad (2)$$

where p represents the optimal lag order chosen by the least value of the Schwarz information criterion (SIC). In the VAR (p) process in Equation (2), Z is a vector denoted by $Z_t = (Z_{1t}, Z_{2t})'$, where Z_{1t} is CO_2 and Z_{2t} is GDP . Applying matrix algebra, Equation (3) is rewritten as follows:

$$\begin{bmatrix} Z_{1t} \\ Z_{2t} \end{bmatrix} = \begin{bmatrix} \partial_{10} \\ \partial_{20} \end{bmatrix} + \begin{bmatrix} \partial_{11}(L) & \partial_{12}(L) \\ \partial_{21}(L) & \partial_{22}(L) \end{bmatrix} \begin{bmatrix} Z_{1t} \\ Z_{2t} \end{bmatrix} + \begin{bmatrix} v_{1t} \\ v_{2t} \end{bmatrix} \quad (3)$$

where $v_t = (v_{1t}, v_{2t})'$ is a zero-mean white noise procedure with a covariance matrix, and $\partial_{12,k} = \partial(L) = \sum_{k=1}^p \partial_{ij,k} L^k$, where $i, j = 1, 2$, and L is the lag operator, defined as $L^k Z_t = Z_{t-k}$. Based on Equation (3) above, the study can test the null hypothesis that environmental pollution (CO_2) does not Granger-cause real (GDP) by imposing zero restrictions $\partial_{12,k} = 0$ for $k = 1, 2, \dots, p$, and the null hypothesis that real GDP does not Granger-cause environmental pollution (CO_2) can be determined by imposing zero restrictions $L_c \partial_{21,k} = 0$ for $k = 1, 2, \dots, p$.

2.2.2. Parameter-Stability Testing

After performing the full-sample bootstrap Granger causality test, a test of stability on the parameters of the full-sample bootstrap Granger causality test is carried out to determine the applicability of its results. The reason is that the parameters of the full-sample bootstrap Granger causality tests are assumed to be constant and stable in the short run as well as in the long run. However, this assumption does not always hold true. In the event that the parameters are unstable, the bootstrap full-sample Granger causality test results become irrelevant. To overcome this limitation, in [22,23] introduced the *Sup-F*, *Ave-F*, and *Exp-F* tests for testing parameter stability in the short run. The *Sup-F* investigates unexpected structural variations in parameters whereas the *Ave-F* and *Exp-F* are used to examine if the parameters of the full-sample bootstrap Granger causality test have evolved gradually over time in trajectory or not. The long-run stability of the parameters of the VAR model was examined using the L_C test from [24,25].

2.2.3. Sub-Sample Rolling-Window Causality Testing

In the presence of instability of the short- and long-run parameters of the full-sample bootstrap Granger causality test, the results generated lose their significance and become unreliable. This problem is resolved by employing the rolling-window bootstrap Granger causality test introduced by [21]. This procedure is performed by splitting the entire sample data into sub-samples based on a fixed rolling-window size. The sub-samples are then scrolled gradually from the start of the whole time-series data to the end. The following chronological steps are applied for the rolling-window bootstrap Granger causality test. Firstly, assume that the whole length of the time-series data used for the study is given by T . Secondly, given a fixed-sized rolling with l observations, the whole sample data of length T is converted into a sequence of $T-l$ sub-samples, specifically $\theta-l+1, \theta-l, \dots, T$, for $\theta = l, l+1, \dots, T$. To obtain the results of the rolling-window bootstrap Granger causality test, all the observed probability values and LR statistics are chronologically summarized. To determine the effect of GDP on CO_2 , the average of the entire bootstrap estimates of $N_b^{-1} \sum_{k=1}^p \hat{\partial}_{12,k}^*$ is obtained. The average of the entire bootstrap estimates yields the effect of CO_2 to GDP. The exact number of bootstrap repetitions used is denoted by N_b , while $\hat{\partial}_{12,k}^*$ and $\hat{\partial}_{21,k}^*$ are the bivariate estimation from the VAR (p) in Equation (3). Following [21], the study adopts a 90% confidence interval, in addition to the corresponding lower (5th quantile) and upper bounds (95th quantile) of $\hat{\partial}_{12,k}^*$ and $\hat{\partial}_{21,k}^*$.

3. Results

The application of the full sample and rolling-window bootstrap Granger causality tests require the variables employed in the VAR model in Equation (3) to be integrated of order one. To this end, the variables are tested for stationarity using the augmented Dickey–Fuller (ADF) unit root test by [26] and the Philip–Perron (PP) unit root test by [27]. The results of the unit root tests conducted are displayed in Tables 1 and 2 below.

Table 1. Augmented Dickey–Fuller (ADF) and Philip–Perron (PP) unit root tests in levels.

Variable	ADF (Null: Variable Has a Unit Root)		PP (Null: Variable Has a Unit Root)	
	Test statistic	Critical value at 5%	Test statistic	Critical value at 5%
CO_2	−1.7152	−3.497	−1.7091	−3.4953
GDP	−2.120		−1.9915	

Source: Authors.

From Table 1, it can be observed that the null hypothesis of non-stationarity cannot be rejected at the 5% level of significance. However, from Table 2 above, the null hypothesis of non-stationarity can be rejected at the 5% level of significance. The results from the ADF and PP unit root tests in Tables 1

and 2 reveal that the two variables, *GDP* and *CO₂*, are integrated of order one. The results of the unit root test imply that the requirement for the application of the full-sample and rolling-window bootstrap Granger causality test is satisfied. Firstly, the full-sample bootstrap Granger causality test based on Equation (3) is performed. The optimal lag for the VAR, system was selected based on the minimum SIC. The results are shown in Table 3 below.

Table 2. ADF and PP unit root tests in first differences.

Variable	ADF (Null: Variable Has a Unit Root)		PP (Null: Variable Has a Unit Root)	
	Test statistic	Critical value at 5%	Test statistic	Critical value at 5%
<i>CO₂</i>	−6.9126	−3.497	−7.0049	−3.497
<i>GDP</i>	−8.8549		−9.3478	

Source: Authors.

Table 3. Full-sample bootstrap Granger causality testing results.

Tests	H ₀ : GDP Does Not Granger-Cause CO ₂		H ₀ : CO ₂ Does Not Granger-Cause GDP	
	Statistics	<i>p</i> -Value	Statistics	<i>p</i> -Value
Bootstrap Likelihood Ratio (LR) test	0.688	0.686	1.029	0.686

Notes: *p*-values are calculated using 10,000 bootstrap repetitions. Source: Authors.

The results of Table 3 above show that both null hypotheses were rejected at the 10% level of significance. The null hypothesis that GDP does not Granger-cause CO₂ emissions is rejected, and the null hypothesis that CO₂ pollution does not Granger-cause GDP economic growth is also rejected. Consequently, it can be concluded from our test result of the full-sample bootstrap causality test that causality neither runs from the growth of the economy GDP to CO₂ emissions nor vice versa. However, the reliability and validity of the result of the full-sample bootstrap Granger causality test depend on the stability of the parameters of the VAR model in the short run and in the long run. The full-sample bootstrap Granger causality result may give misleading results in the presence of unstable parameters. According to [28], there is a high level of likelihood of structural change in the VAR system such that the co-efficients of the model may not be stable over time, and thus making the outcomes of the full-sample bootstrap Granger causality test among two variables unreliable. As a result, the *Sup-F*, *Ave-F*, and *Exp-F* tests of [22,23] were employed to examine the short-run stability of the cointegrated VAR model, and also the *L_C* testing of [24,25] was applied to explore the long-run stability of the VAR model.

Table 4 above presents the result of the parameter-stability tests. The *Sup-F* test shows the existence of structural changes in CO₂ and GDP and the VAR system in general at the 1% level of significance. Similarly, the result of the *Ave-F* test confirmed that there is a change in the parameter of both variables as well as the VAR system as a whole. The result of the *L_C* test shows instability of the parameters in the long run.

Table 4. Parameter-stability tests' results. VAR: vector autoregression.

Tests	GDP		CO ₂		VAR System	
	Statistics	<i>p</i> -Value	Statistics	<i>p</i> -Value	Statistics	<i>p</i> -Value
Sup-F	61.4072 ***	0.0000	112.0838 ***	0.0000	27.2181 **	0.0376
Ave-F	27.0638 ***	0.0000	19.1292 ***	0.0000	14.7639 *	0.0804
Exp-F	27.3602 ***	0.0000	52.3531 ***	0.0000	10.3959 **	0.0408
<i>L_C</i>					3.9145 ***	0.0050

Notes: ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively. Source: Authors.

4. Discussion

As a result of the instability of the parameters of the VAR model in Equation (2), the results of the full-sample bootstrap Granger causality test are unreliable and invalid and hence the rolling-window bootstrap Granger causality test methodology is applied. The residual-based modified LR and the probability values of bootstrapped observed LR statistics estimation were carried out using the rolling window for all sub-sample periods from 1960 to 2014. Following the simulation exercises of [29,30], this study selected a rolling-window size of 15. The null hypothesis of the rolling-window bootstrap Granger causality test was the same as that of the full-sample bootstrap Granger causality test, i.e., CO₂ does not Granger-cause GDP, and GDP does not Granger-cause CO₂. The bootstrapped probability values of the null hypothesis that GDP does not Granger-cause CO₂ and the null hypothesis that CO₂ does not Granger-cause GDP are shown in Figures 1–3, respectively. Both null hypotheses were tested at the 10% level of significance.

Figure 1. Probability values of Bootstrap statistic testing of the null hypothesis that GDP does not Granger-cause CO₂.

Figure 2. Estimated bootstrap Sum of rolling-window coefficients for the impact of GDP on CO₂.

Figure 3. Probability values of Bootstrap statistic testing of the null hypothesis that CO₂ does not Granger-cause GDP.

From Figure 1, it can be observed that the null hypothesis that GDP does not Granger-cause CO₂ is rejected in the 1976–1977, 1990–1993, 2005–2006, and 2007–2013 sub-sample periods. To determine the nature of the effect of GDP on CO₂ in each of the sub-sample periods, the paper constructs the sum of the bootstrapped rolling coefficients. This is displayed in Figure 2 above. The effect of GDP on CO₂ emissions is negative in the 1976–1977, 1990–1993, 2005–2006, and 2007–2013 sub-sample periods. The result generally implies that GDP affects CO₂ emissions negatively in the sub-sample periods in which GDP affects CO₂ emissions. This result portrayed economic growth as a solution to improve environmental quality rather than causing environmental pollution. The results from Figure 2 show that the EKC for CO₂ emissions for Rwanda is monotonically decreasing, which is contrary to the standard EKC theory which asserts an inverted-U relationship between environmental degradation and economic growth. The results of this study on the shape of the EKC for CO₂ emissions confirms the findings of [31–34], who found a monotonically decreasing EKC for CO₂ emissions. The results, however, contrast the findings of [35–39], who found an inverted-U-shaped EKC for CO₂ emissions. There are several reasons to explain the downward-sloping EKC for CO₂ emissions for Rwanda. Since independence up to the 1994 genocide period, economic growth in Rwanda was mainly based on agricultural products [40]. After the genocide, the Rwandan government transitioned to a knowledge- and services-based economy instead of moving from agrarian to industrialization [41]. The success story of fast economic growth in the last two decades in Rwanda was characterized by improvement in the services sector which led to the decrease of environmental pollution in the presence of expanding economic growth. In the sub-sample periods in which GDP caused CO₂, the share of the service sector in GDP was consistently increasing. It is a stylized fact that the manufacturing and construction sectors, which are key components of the industrial sector, have been globally found to be the worst culprits in terms of aggravating CO₂ emissions. Thus, with the transformation of the Rwandan economy from an industrial-based to a service-based economy over recent years, it is not surprising that the increased economic growth in Rwanda was accompanied by decreasing levels of CO₂ emissions.

From Figure 3 above, the bootstrap P-values of the null hypothesis that CO₂ does not Granger-cause GDP are observed. At a 10% level of significance, the null hypothesis that CO₂ does not Granger-cause GDP is rejected in the 1989–1994 sub-sample period. From Figure 4, the sum of the bootstrap rolling-window coefficients reveals that the effect of CO₂ on GDP in the 1989–1994 sub-sample is positive. This implies the existence of feedback effects from CO₂ emissions to economic growth.

Figure 4. Estimated bootstrap Sum of rolling-window coefficients for the impact of CO₂ on GDP.

5. Conclusions

This paper examined the causal relationship between economic growth and CO₂ emissions in Rwanda using annual data from 1960 to 2014. The study was conducted within the framework of the EKC hypothesis. Firstly, the study conducted the full-sample bootstrapped Granger causality test and found no existence of causality between economic growth and CO₂ emissions. Next, the parameters of the VAR model were tested for stability. The study found that the parameters of the VAR model are unstable, making the results of the full-sample bootstrapped Granger causality test unreliable. As a result, the rolling-window bootstrap Granger causality test, using a rolling-window size of 15 years, was employed, revealing bi-directional causality between the real GDP and CO₂ emissions in metric tons per capita. The results from the rolling-window bootstrap Granger causality test show that GDP negatively influenced CO₂ emissions in the 1976–1977, 1990–1993, 2005–2006, and 2007–2013 sub-sample periods. This result depicts a monotonically decreasing EKC, which is contrary to the standard EKC relationship. The downward-sloping EKC was explained by the transition of the Rwandan economy from an industrial-based economy to a service-based economy. CO₂ emissions were found to affect GDP positively in the 1989–1994 sub-sample period, implying a feedback effect from the environment to the economy.

5.1. Recommendations

From the results of the rolling-window bootstrap Granger causality test, it is observed that economic growth ameliorates CO₂ emissions in Rwanda. This implies that economic growth is a natural panacea to solving the menace of CO₂ emissions pollution in Rwanda. The study, therefore, recommends policies to expand economic growth. However, it is strongly recommended that the expansions in economic growth should be driven by the service sector as overtime Rwanda has transitioned from an industrial economy to a service-based economy. Economic growth in Rwanda in recent years has therefore been driven by the service sector. The service sector is also an emitter of CO₂ emissions as is the industrial sector. By continuous implementation of policies that expand the growth of the service sector, economic growth will be achieved at a very low cost to the environment in terms of CO₂ emissions. Moreover, the study recommends that manufacturing firms in Rwanda should be made to strictly comply with the newly developed green manufacturing policies, such as the National Strategy for Transformation (NSTI) and the Green Growth and Climate Resilience Strategy (GGCRS). This will ensure that manufacturing firms cut down on waste and emissions during their production processes. This will ensure that economic growth in Rwanda comes at a very little cost to the environment.

5.2. Limitations

This paper is limited only by the nature and time span of the data employed. Monthly or quarterly data will yield better and robust results. However, due to the unavailability of monthly and quarterly data, annual data was used.

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