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The Effect of Technological Innovation On Co_2 Emissions in OECD Countries: Using Panel Regression

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Abstract

In the last century, energy consumption has grown in parallel with population growth and the extensive use of technology. While increased energy consumption has major environmental consequences due to carbon dioxide (CO_2) emissions, it has also accelerated the search for renewable energy. In this study, we investigated the effect of technological innovations and renewable energy on carbon dioxide emissions. For this purpose, we examined the number of patents and the effects of renewable energy use on the environment of 37 Organization for Economic Co-operation and Development (OECD) countries, which constitute the world's largest economy, between 1990 and 2019, using the panel cointegration method. The empirical results show that the increase in the number of patents has a significant effect on CO_2 emissions, while investment and GDP have a relatively small effect. It was concluded that renewable energy and export trade variables reduce CO_2 emissions.

Key words: Technological Innovation, Renewable Energy CO_2 Emission, Panel Cointegration.

JEL Code: Q55, C01, Q53

1. Introduction

Global warming, which is a symptom of climate change, is one of the most significant environmental problems of the last several decades. Emissions of greenhouse gases continue to be the most significant cause of global environmental pollution. Aside from carbon dioxide emissions from plants, animals and other sources, the typical by-product of energy source use has been substantially linked

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to carbon emissions. CO_2 emissions continue to be detrimental to environmental sustainability and are a key point of contention in the worldwide discussion over climate change. This is due to the fact that CO_2 emissions have remained the most serious danger to the natural ecosystem and human progress throughout history (Bekun et al., 2019).

Human activities and associated energy consumption have recently raised major environmental issues, notably CO_2 emissions. The OECD uses more economic and energy resources than any other organization on a global scale. The rise in carbon dioxide emissions as a result of a wide range of human activities and the massive quantity of energy used has challenged the globe with a slew of tough issues.

Global warming, a result of rising CO_2 emissions, has enhanced the life expectancy of all living things on the planet. As a result, campaigns against global warming have begun on a global scale. The use of renewable energy sources (such as biomass, wind, and solar energy) rather than non-renewable energy that damages the environment has risen to prominence, particularly in the 1990s. Due to the abundance of renewable energy in nature and the fact that it does not produce carbon emissions, it has recently gained a lot of popularity.

OECD countries, which account for a significant portion of CO_2 emissions, it has led some to believe that the drop in CO_2 emissions is related to an increase in technological advancements (patents) over the last ten years. In other words, there have been some studies, however few, that demonstrate that technical improvements are responsible for the reduction in CO_2 emissions. The utilization of renewable energy sources is the other side of this reduction. Renewable energy has been shown in numerous studies to minimize CO_2 emissions. In other words, it's been a topic of debate whether recent reductions in CO_2 emissions in OECD countries are due to technological advancements and renewable energy.

The goal of this study is to examine the influences of renewable energy, patents, and other control variables on CO_2 emissions by looking at data from 37 OECD nations from 1990 to 2019. To accomplish this, cointegration analysis with balanced panel data was used to analyze the long-term connection between the variables in question. In the long run, these variables have been discovered to act in concert. The researchers then concluded that increasing technological innovations using the Fmols approach considerably increased CO_2 emissions for the OECD countries studied, whereas increasing renewable energy consumption decreased CO_2 emissions.

2. Literature Review

As technology advances, a growing number of government officials and academics understand the essential role of creative production in reducing CO_2 emissions. As a result, a growing number of scholars are investigating the influence of mechanical advancement on CO_2 emissions. Several major indicators of mechanical improvement are included in these assessments, including efficiency, research and development, and patent creation. Certain experts use energy proficiency to track technological advancements and the effect of creative development on CO_2 emissions. Despite the fact that numerous researchers have examined the impact of mechanical development on CO_2 emissions at the national, provincial, and global levels, the study has certain limitations. There are considerable disparities in the output development nexus among OECD nations, meaning that the influence of mechanical development on CO_2 emissions would be different and uneven across OECD countries.

Ito (2017) used panel data from emerging nations to look at the link between CO_2 emissions, renewable and nonrenewable energy use, and economic growth. From 2002 to 2011, annual adjusted panel data were utilized in this study from 42 non-industrial nations. A comparison of GMM and PMG has been made by him. The relationship between CO_2 emissions, financial development, the use of petroleum derived energy and ecologically friendly power consumption has been a major focus of his research and work. According to the author's findings, increasing electricity use contributes to a decrease in emissions while still being ecologically beneficial. According to his findings, long-term financial gains can be influenced positively by sustainable electricity consumption. The use of non-inexhaustible energy also has alternative connections.

Bakhsh et al. (2017) examined the relationship between economic development in Pakistan, CO_2 emissions, renewable waste, and foreign direct investment (FDI) using an annual data collection from 1980 to 2014. This examination finds a few fascinating consequences of effect of FDI on ecological contamination in Pakistan through the channels of scale impact, procedure impact and arrangement impact. They discovered that the scale effect indicates that the stock of capital and labor have a favorable effect on Pakistan's economic growth, however pollution has a negative effect. Their empirical findings indicate that, in the case of capital accumulation, economic development and foreign direct investment have a positive and significant effect on the capital stock.

Chen and Lei (2018) investigated the effects of renewable energy and technical innovation on the environment-energy-growth nexus. This study employs a panel quantile regression model to incorporate the effects of renewable energy usage and technological innovation across 30 countries from 1980 to 2014, reexamining the environment-energy-growth nexus. The advantage of this method is that it considers distributional heterogeneity in order to provide a point-by-point depiction of connection between CO_2 outflows and driving variables at various discharge levels. They discover that the influence of various factors on CO_2 emissions vary. The data indicate that the factors affecting CO_2 emissions are different.

Cheng et al. (2019) demonstrated the heterogeneous effects of renewable energy and environmental patents on CO_2 emissions. They employed both panel OLS and panel quantile regression approaches. This study examines the effects of six determinant factors on CO_2 emissions per capita in the BRICS countries from 2000 to 2013 (in particular, sustainable energy supply, environmental license development, financial development, exports, unfamiliar direct venture, and homegrown credit to the private sector). They discovered that the determinant variables' impacts are heterogeneous among quantiles.

Koçak and Ulucak (2019) investigated the effect of energy R&D expenditures on CO_2 emission reduction. They use dynamic panel data to examine the influence of disaggregated energy research and development spending on CO_2 emissions in 19 high-income OECD countries from 2003 to 2015. Their findings indicate that investments in research and development for fossil energy and energy efficiency have an accelerating impact on CO_2 emissions. Additionally, there is no statistically significant association between research and development expenditures for renewable and nuclear energy and CO_2 emissions. Furthermore, they discovered that energy storage technologies make a significant contribution to CO_2 emissions reduction. They used panel data to assess the impact of CO_2 emissions from passenger autos in Europe. Between 1990 and 2015, they examined the strong correlation between traveler car CO_2 emissions and a few parameters in Europe. They presented proof that CO_2 emissions have benefited from global technological improvement and changes in the efficiency of conventional fuels, while increases in monetary mobility, mechanization rate, and the dieselization cycle all have a favorable and significant association. They discovered that car emissions develop around declining inclining patterns and are growing at a rate of 4% per year throughout European nations. They discovered that car CO_2 emissions are sensitive to vehicle loads and, in particular, changes in family usage and that improvements in eco-friendliness predict a significant reduction in CO_2 emissions in the vehicle traveler area.

Cheng et al. (2020) investigated how technological innovation helps nations in the OECD reduce CO_2 emissions. This study examined the impact of technological innovation on the CO_2 emissions of OECD nations. Panel regression is used to choose economic growth, fixed investment, and exports as control variables. CO_2 emissions were estimated from 1996 to 2015 using a balanced panel dataset including 35 OECD countries. This is avoided by employing a recently developed panel quantile regression approach with non-additive fixed effects. To correct for skewed results and to increase understanding about the impacts, as data are not often distributed evenly. The empirical evidence over multiple quantiles are heterogeneous. Additionally, the influencing process is reviewed on a regular basis for technical development. Specifically, the OECD nations examine the direct and moderating impacts of technological advancement on CO_2 emissions.

Parker and Bhatti (2020) examined the dynamics and causes of Asia's per capita CO_2 emissions. Asia's economic significance is growing, and over the last two decades, a dramatic shift in the global financial system has occurred. They employ a sequential strategy that is closely related to policy indicators. To begin, the dynamics are analyzed to determine whether they are convergent, and then the drivers of those dynamics are explored. This article dissects the components and causes of such outflows using a sample of fourteen nations from 1971 to 2017. This shift in monetary power has resulted in changes in global instances of energy use and consequent carbon dioxide emissions associated with energy use. The findings indicated that per capita CO_2 emissions, energy intensity, carbonization, and incomes were gradually converging throughout the whole sample.

Pita et al. (2020) investigated variables affecting energy consumption and CO_2 emissions in Thailand's road passenger transport in order to get a better understanding of the critical factors affecting energy consumption and energy-related emissions in Thailand's street passenger transport. This research utilized the additional substance's degradation approach. The LMDI-I file approach was used to analyze the influencing variables between 2007 and 2017. The investigation examined five influencing variables on energy consumption, namely population, country's way of life, purchasing power, travel volume interest, and explicit energy consumption, as well as two additional influencing factors on emission, specifically fuel share and emission factors. The findings indicate that cars, vans, and taxicabs account for the majority of energy consumption and GHG emissions in Thailand's street traveler transport.

Chen and Lee (2020) investigated how technological innovation contributes to CO_2 emission reductions. They used spatial econometric models to examine the influence of mechanical development on CO_2 emissions in 96 countries worldwide from 1996 to 2018. The major commitment is to examine the overflow effects of mechanical development on CO_2 emissions and their heterogeneity, as well as the directing effect of receptiveness. The experimental results first establish that CO_2 emissions and R&D force are geographically connected across nations and that spatial econometric models are better suited for examining this problem. Thus, the findings demonstrate that overflow influence is critical for comprehending the link between mechanical growth and CO_2 emissions, regardless of whether spatial loads and center variables are included. The findings indicate that high-income, high-technology countries not only reduce their own CO_2 emissions but also contribute to the reduction of CO_2 emissions in neighboring countries, whereas middle- and low-income, low-technology, and low-CO_2 emission countries have no direct or indirect effect, and technological innovation actually increases CO_2 emissions in some groups.

Wang and Wei (2020) investigated technological progress and environmental regulation in CO_2 mitigation. They used the panel smooth transition regression to explore the optimal values Innovative advancement and natural guideline are significant instruments for accomplishing CO_2 discharge alleviation targets. They could be viewed as two of a kind for CO_2 decreases both affecting also, contingent upon one another simultaneously. Mechanical advancement can lessen CO2 outflows through upgrading productivity. In any case, effectiveness

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enhancements additionally influence the interest in assets and energy bringing about a bounce back impact. From "Watchman's Hypothesis", A well-thought-out ecological policy may spur progress while lowering CO_2 emissions. The 'Green Paradox,' on the other hand, ensures that global emissions can increase in response to natural guidance. They found that both inventive progress and natural guideline are two-edged blades that have both beneficial and bad effects on CO_2 emission reduction.

Zubair et al. (2020) analyzes the link domestic income, FDI inflows, trade integration, GDP, and capital decreases CO_2 emissions. The discussion on the implications of exchange, pay, FDI, and financial growth on carbon force levels yet progressing in many established and producing economies. Most noticeably, low-pay nations like Nigeria. This investigation employed the straightforward ARDL to cointegration and the Granger causality models to evaluate the since quite a while ago run connections among the variables in Nigeria more than 1980–2018. From the discoveries, they suppose that a since a long time ago run connection holds reliant on ARDL limits testing outcomes. They further establish causation between FDI inflows, capital, and carbon dioxide outflows in Nigeria. Moreover, employing the CUSUM and CUSUM of squares test, they found that fossil fuel byproducts are constant in Nigeria during the time frame studied.

3. Data and Methodology

3.1. Data

The goal of this research is to find out how technological innovation, renewable energy, and other control variables affect CO_2 emissions in OECD countries between 1990 and 2019. Countries used in the analysis are Australia, Austria, Belgium, Canada, Chile, Czech, Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States. To accomplish this study's purpose, we gathered annual data from the World Bank, the World Development Indicators data bank (WDI), and the International Energy Agency (IEA). Table 1 summarizes the definitions of variable.

Table1: Definition of variables.

Variable	Definition	Unit of measurement
CO_2	CO_2 emissions per capita	Tonnes/capita
TE	Export trade values	Million US dollars
INV	Investment	Million US dollars
RE	Renewable energy	Thousand tonnes of oil equivalent
PATENT	Development of PATENT	Number
GDP	GDP per capita	USD

3.2. The Models

The Environmental Kuznets Curve was inspired by Simon Kuznets's 1955 study of the relationship between income inequality and economic growth. This hypothesis claimed that income inequality would increase during the initial stages of economic development and would then decline as growth continued. This relationship between income inequality and economic development has been dubbed an inverted U-curve.

It is called the environmental Kuznets curve (EKC) and it says that the relationship between environmental quality and real output has an inverted U-shaped feature. Environmental degradation first rises until there is a certain level of GDP, and then it starts to fall as GDP rises (Dogan and Turkekul, 2016).

One objective of this study is to determine the dynamic influence on CO_2 emissions of the number of patents and renewable energy. Another objective of this investigation is to determine the accuracy of the EKC hypothesis. The study establishes a multivariate framework as follows:

$$Model\ 1\ CO_2 = \alpha_0 + \alpha_1 GDP + \alpha_2 PATENT + \alpha_3 INV + \alpha_4 RE + \alpha_5 TE$$

$$Model\ 2\ CO_2 = \alpha_0 + \alpha_1 GDP + \alpha_2 (GDP)^2 + \alpha_3 PATENT + \alpha_4 INV + \alpha_5 RE + \alpha_6 TE$$

Where CO_2 represents per capita CO_2 emission, GDP is per capita real GDP, PATENT is number of patents, INV is investment, RE is renewable energy and TE is Export trade values. According to model 2, when $\alpha_1>0$ and $\alpha_2<0$ EKC's validity and accuracy can then be confirmed.

3.3. Panel Estimation Techniques

The empirical technique followed in this study is composed of five basic steps: First, Pesaran cross-section dependence (CD) test, are employed to check for cross-sectional dependence. Second, to test the stationarity of each variable, Im, Pesaran, and Shin (2003) and Fisher type tests panel unit root utilized. Third, the Pedroni (1999, 2004) and Kao (1999) panel cointegration test is used to investigate the cointegrating relationship between all the selected variables.

Testing for the panel unit root and cointegration was done assuming cross-sectionally independent equation errors. While these first-generation tests are still essential, more recent (second generation) advances have attempted to account for residual cross section dependency in panels when both the time dimension and the cross-section dimension are significant, giving a theoretical foundation for their use (Breitung et al., 2008).

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After determining that the variables of interest are not stationary and have the same integration levels, two panel cointegration testing was conducted. Kao and Pedroni cointegration tests are used to explore the cointegration relationship between variables. Before going any further, consider the panel regression model.

$$y_{it} = x'_{it}\beta + z'_{it}\gamma + e_{it} \quad (1)$$

Where y_{it} and x_{it} are same nonstationary level and non-cointegrated. Kao (1999) introduced DF and ADF-type unit root tests for e_{it} as a test for the null of no cointegration for $z_{it} = \{\mu_i\}$.

Fixed effects residuals can be used to generate DF-type tests.

$$\hat{e}_{it} = \rho\hat{e}_{it-1} + v_{it} \quad (2)$$

H_0: ρ = 1 can be used to test the null hypothesis that no cointegration has occurred.

If there is no cointegration, the ADF test statistic can be generated as follows:

$$ADF = \frac{t_{ADF} + \frac{\sqrt{6N}\hat{\sigma}_V}{2\hat{\sigma}_{0v}}}{\sqrt{\frac{\hat{\sigma}_{0v}^2}{2\hat{\sigma}_v^2} + \frac{3\hat{\sigma}_v^2}{10\hat{\sigma}_{0v}^2}}} \quad (3)$$

As a result of sequential limit theory, the asymptotic distributions N (0, 1) of the random variables $DF_\rho, DF_t, DF_\rho^*, DF_t^* and\ ADF$ are equal to the standard normal distribution N (0, 1).

Pedroni (1999, 2004) developed a number of tests for the null hypothesis of cointegration in a panel data model with significant heterogeneity (Baltagi, 2008).

There are two types of test statistics considered by Pedroni: the "Panel Statistic," which is comparable to a homogeneous alternative's unit root statistic, and the "Group Mean Statistic," which is a heterogeneous alternative's unit root test analog (Breitung et al., 2008).

Heterogeneous coefficients panel regression model is considered by Pedroni (1999, 2004).

$$y_{it} = \alpha_i + \gamma_i t + \beta'_i x_{it} + u_{it,} \quad (4)$$

Where $\{y_{it}\}$ and $\{x_{it}\}$ are scalar and have k × 1 I (1) dimensions. In order for the functional central limit theorem to apply, $\{y_{it}\}$ and $\{x_{it}\}$ must meet the requirements and be independent over i (Baltagi, 2015). Pedroni proposed three distinct sets of test statistics for panels with heterogeneous compositions (Tatoğlu, 2017).

3.4. Data Used in the Application

We used fixed investment, economic growth, export trade, and renewable energy supply as control variables, as well as the square of economic growth. The mathematical formulation is as follows for the aim of examining the impact of technological innovation and other control factors on CO_2 emissions in OECD nations.

$$ln\mathrm{CO_2} = \mathrm{f(lnINV, lnGDP, lnGDP2, lnRE, PATENT, TE)} \quad (5)$$

Where ln is the natural logarithm, INV, GDP, GDP^2, RE, PATENT, and TE express investment, economic growth, square of economic growth, development of PATENT, renewable energy supply, and GDP multiplied, and export trade values, respectively.

4. Empirical Results

4.1. Cross–Sectional Dependence

The CD test, derived by Pesaran, 2004, is used to test the inter-unit correlation. Pervasive cross-sectional dependence, in which all units in the same cross-section are correlated, can be found in panel data. This is frequently attributed to the influence of some unobserved common factors that are common to all units and affect them all, albeit in different ways. As previously said, one of the most crucial diagnostics that a researcher should look at before undertaking a panel data analysis is cross-sectional dependence. It is known that the Pesaran CD (2004) test gives better results in the Breusch Pagan LM test when N>T.

The Result of unit roots and Pesaran CD test are listed in Table 2 From this table, The CD test does not detect cross-sectional dependence. As a result, the first-generation test has been chosen. IPS and Breitung were used to determine the stationary state of the variable "CO_2" and another. Where, IPS (2003) and Breitung (2000), which allow each unit to have its own autocorrelation coefficient and correct for inter-unit autocorrelation by taking the difference from the cross-sectional mean were used. All series are non-stationary at the level stated in all tests.

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Table 2: Cross- Sectional Dependences and Unit Root Test.

Variable	CO_2	GDP	INV	RE	Patent	TE
Cross-sectional dependence test						
Pesaran (2004)	0.326	-0.474	-0.456	1.338	-0.766	-2.304
CD test						
Unit root test						
IPS (2003)						
Level	0.450	0.802	0.607	1.280	7.032	0.127
First Difference	-9.31***	-9.286***	12.82***	-15.698***	-8.28***	-6.30***
Breitung (2000)						
Level	1.495	-1.377	-1.639	1.127	5.305	3.688
First Difference	-5.443***	-9.174***	-5.050***	-4.115***	-1.651***	-4.445***

Note: ***, **, * denotes signifance level at the %1, %5, %10 levels

4.2. Panel Co-integration Results

The results of the Pedroni (2004) panel co-integration are shown in Table 3. From this table, the Ho hypothesis is established as "there is no cointegration." The lag length was chosen according to the AIC criteria. The panel v, (rho in table), t, and ADF statistics, as well as the group t ADF statistics, were computed. According to all test statistics except the panel v statistics at the 95% confidence level, the Ho hypothesis was rejected and a cointegration relationship was found between the CO_2, GDP, PATENT, INV, RE, and TE (Model 1) variables. According to all test statistics at the 95% confidence level, the Ho hypothesis was rejected and a cointegration relationship was found between the CO_2, GDP, GDP^2, PATENT, INV, RE, and TE (Model 2) variables.

Table 3: Pedroni 2004 Test Results.

	Constant Only	**Constant and Trend**	**Constant Only**	**Constant and Trend**
Pedroni (2004)	Model 1		Model 2	
Panel v-Stat.	6.1474	0.08267	4.0262	6.5341
Panel rho-Stat.	-2.9156	-3.7872	-1.9674	-4.9423
Panel PP-Stat.	-2.8142	-4.6106	-2.3176	-5.5282
Panel ADF-Stat.	-3.0870	-2.5431	-3.6608	-5.3681
Group rho-Stat.	-4.8054	-5.6866	-5.8491	-6.6222
Group PP-Stat.	-2.1100	-6.1180	-3.8000	-8.2565
Group ADF-Stat.	-4.6954	-2.7993	-5.309	-4.8513

Note: The table values for 1%, 5% and 10% margin of error are 2,576, 1,960 and 1,645, respectively. Statistical inferences were made at 95% confidence level (with 5% margin of error).

The results of the Kao panel co-integration are shown in Table 4. From this table, the hypothesis is established as "there is no cointegration." The lag length was chosen according to the AIC criteria. The cointegration model is the same for all units, the unit averages are modeled but the trend is not modeled; the autoregressive parameter is the same for all panels; and estimations are made. In the table, there are non-parametric adjusted versions (Modified Dickey-Fuller t and Dickey Fuller t) of test statistics (Unadjusted Modified Dickey-Fuller t and Unadjusted Dickey Fuller t) of the DF test using autocorrelation versus the Newey-West covariance estimator, respectively). According to all tests at the 95% confidence level, the H0 hypothesis was rejected and the existence of a cointegration relationship between the CO_2, GDP, PATENT, INV, RE, and TE variables was concluded.

Table 4: Kao Co-integration Test.

	Model 1	**Model 2**
Modified Dickey-Fuller t	-8.82234***	-7.06022***
Dickey-Fuller t	-7.03092***	-6.65157***
Augmented Dickey-Fuller t	-3.74351***	-3.27051***
Unadjusted modified Dickey-Fuller t	-8.09811***	-8.21622***
Unadjusted Dickey-Fuller t	-6.83968***	-7.01258***

Note: ***, **, * denotes signifance level at the %1, %5, %10 levels.

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4.3. Panel Estimation Results

The estimation method for panel cointegration that is used by default. We retain the settings for pooled estimation using Fully modified OLS (FMOLS) identical because they match to the estimates. Table 5 shows the result of FMOLS estimate processes.

GDP and Carbon emission relationships are positive. This indicates that 1% increase in GDP will increase CO_2 emission by 2.4969%. INV and Carbon emission relationships are positive. This indicates that 1% increase in INV will increase CO_2 emission by 0.050961%, RE and Carbon emission relationships are negative. This indicates that 1% increase in RE will decrease CO_2 emission by -0.713790%.

Table 5: FMOLS Result.

Variables	Model 1	Model 2
Patent	44.1234***	44.281***
	(0.0034)	(0.0004)
RE	-0.71379***	-0.9281***
	(0.0035)	(0.0010)
INV	0.05096***	0.0336***
	(0.0036)	(0.0007)
TE	-0.07047***	-0.0007
	(0.021	(0.0005)
GDP	2.4969***	8.2319***
	(0.0012)	(0.0017)
GDP^2		0.0192***
		(0.0003)

Note: ***, **, * denotes signifance level at the %1, %5, %10 levels.

According to Model 1 and Model 2 as shown in Table 5, the effect of the development of PATENTs (technological innovation) on CO_2 emissions is positive, indicating that technological innovation is not worthwhile for the mitigation of carbon emissions in the selected OECD countries. Similar results are also provided by Chenge at al. (2021). Models 1 and 2 demonstrate the effect of investment on lowering carbon dioxide emissions. The positive impacts of investment can be attributed to the decreasing investment in environmental infrastructure investment that has occurred in OECD countries. Renewable energy as expected exhibit a negative statistically significant relationship with CO_2 emissions, 1% increase in renewable energy will decrease by 0.71%. This can be assigned to the capability of renewable energy and its diminishing marginal effects. Similar results are also found by Chang et al. (2021) and Chenge et al. (2019) who proved that impacts of renewable energy on CO_2 emission in the developing countries and at all quantiles. The impacts of export trade are negative are shown in table. Similar results are also found by Muhammad at al. (2020). GDP and Carbon emission relationships are positive. This indicates that 1% increase in GDP will increase CO_2 emission by 8.232%. GDP^2 and Carbon emission relationships are positive. This indicates that 1% increase in GDP^2 will increase CO_2 emission by 0.019253%. There is no statistically significant support for the EKC hypothesis in the FMOLS specifications.

5. Conclusions

As a contribution to the energy-related literature on global warming and environmental pollution in the light of renewable energy use and technological innovations, this study explores the empirical relationship between technological innovations, renewable energy, trade, investments, GDP, and CO2 emissions, taking into account the EKC hypothesis. Between 1990 and 2019, we conducted research with 35 OECD countries using panel unit root, panel cointegration, and panel estimation techniques. To assess the cross-sectional dependence in the estimate equations, the Pesaran (2004) test was applied. Since there is no cross-sectional dependence, the series' stationarity was confirmed using the IPS (2003) and Breitung (2000) tests. Pedroni (2004) and Kao cointegration tests were used to analyze the series' long-term relationship. The long-term coefficients were estimated using FMOLS methods.

We established two different models to examine the effects of renewable energy and renewable energy on CO_2. In the first model, the effect of renewable energy, investment and GDP on CO_2 emissions was statistically significant and positive. On the other hand, it was seen that renewable energy and trade had a statistically significant and negative effect. In the second model, in addition to the first model, the square of GDP is added to the model. In the second model, the number of patents, investment GDP and the square of GDP were statistically positive and significant. Although the trade variable was statistically significant in the first model, it was not statistically significant here. In other words, although it reduced the amount of CO_2 emissions in the short term, this effect was reversed in the long term.

As a result, technological innovations have been shown to have a considerable impact on environmental pollution while having no effect on carbon dioxide emissions for OECD countries. Renewable energy, on the other hand, has been seen to diminish the amount of carbon dioxide, as expected. GDP and investment raised CO_2 emissions, whereas trade decreased them. We included the squared GDP model in the model to evaluate the EKC hypothesis, and we found no evidence to support the EKC hypothesis in our analysis.

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