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Bootstrap ARDL Test on the Relationship among Trade, FDI, and CO_2 Emissions: Based on the Experience of BRICS Countries

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Abstract: We used the Bootstrap Autoregressive Distributed Lagged Model (ARDL) method to test the relationship among BRICS (Brazil, Russia, India, China, and South Africa) countries' trade, foreign direct investment (FDI), and CO_2 emissions. We found that Brazil's CO_2 emissions and FDI have a cointegration relationship with the trade on the lag of one-period. Russia and India and CO_2 emissions and trade have a cointegration relationship with FDI on the lag of one-period. In the long-term, Brazil's FDI has a long-term causal relationship with the trade on the lag of one-period. The trade between Russia and India has a long-term causal relationship with FDI on the lag of one-period. Among other BRICS variables, Russian trade and FDI on the lag of one-period of CO_2 emissions and FDI and CO_2 emissions are on the lag of one-period on trade, which McNown et al. mentioned is the degeneration case #1 in their paper; while China's trade and FDI on the lag of one-period of CO_2 emissions is the country of degeneration case #2. When we examined short-term causality, we found that CO_2 emissions showed a causal relationship with trade, while FDI and CO_2 emissions were less pronounced. Trade has a positive causal relationship with FDI. These variables are different in different situations and in different countries. These results should be related to BRICS countries' FDI, international trade development, and their different CO_2 emission policies.

Keywords: global emission reduction; trade; FDI; BRICS countries; Bootstrap ARDL

1. Introduction

Since the financial crisis in 2008, the growth of the global economy has slowed sharply, and the economic growth of major developed countries has been weak; however, the BRICS countries are still the group with the greatest economic potential at present. These countries are in the process of economic development, and they have many common industrialization processes (The BRICS countries (formerly the four BRIC countries) refer to the five major emerging market countries of Brazil, Russia, India, China, and South Africa. The land area of the "BRIC" countries accounts for 26% of the world's total territory, and its population accounts for 42% of the world's total. With the rapid economic growth of the four countries, their international influence is increasing day by day. https://en.wikipedia.org/wiki/BRICS); however, each country also has its own characteristics. The emerging economies of the BRICS countries are maintaining strong growth. In 2017, the total GDP of the BRICS countries was 188.76 billion U.S. dollars, accounting for 23.3% of the world total. The five countries' trade exports totaled 32.216 billion U.S. dollars, accounting for 18% of the world's total exports. The total net inflow of foreign direct investment (FDI) in the five countries was 307.79 billion U.S. dollars, accounting for 16.5% of the world's net FDI inflow [1]. The rapid development of economic globalization has led to the rapid growth of international trade and has led to a sharp increase in global greenhouse gas emissions. According to the report of the Intergovernmental Panel on Climate Change (IPCC, the Intergovernmental Panel on Climate Change is an intergovernmental organization affiliated with the United Nations. It was established in 1988 in cooperation with the World Meteorological Organization and the United Nations Environment Program. Its membership is limited to those of the World Meteorological Organization and the United Nations Environment Program), in 2019 [2], globally, economic growth and population growth continue to be the two most important drivers of increased carbon dioxide (CO_2) emissions due to fossil fuel combustion. The world has recognized the serious challenges of climate change. The United Nations has developed agreements, such as the United Nations Framework Convention on Climate Change and the Kyoto Protocol, to address greenhouse gas emissions in response to climate change [3]. BRICS countries are playing increasingly important roles in the development of the world economy. At the same time that economic development has received global attention, the total energy consumption of the BRICS countries has also risen rapidly. The resulting pollution problems, such as CO_2 emissions, have also become the focus of global research and attention. For the BRICS countries, FDI and international trade have injected strong momentum into economic growth, but with global warming, these emerging economies are experiencing increasing pressure from public opinion, under the open economy.

The importance of the BRICS countries in the global economy continues to increase. According to World Bank statistics [1], the BRICS countries' contribution to world economic growth from 2008 to 2018 reached 51.3%, which has become an important engine of global economic growth. From 2008 to 2018, the nominal GDP of the BRICS countries rose from 11.8% to 22.3% of the world's total, and the proportion of total trade in the world rose from 11.8% to 16.4%. From 2023 to 2030, the annual growth rate of GDP per capita of the BRICS countries will still be 4.5%, which is much higher than the growth rate of any developed or even other emerging economies. As a result, the projected share of the BRICS countries in world gross domestic product will rise to 37.7%. BRICS countries sustain to enjoy demographic advantages. The total population of BRICS countries in 2018 was approximately 3.16 billion, accounting for 41.57% of the global population, which provided adequate labor protection for BRICS countries [1]. China, Russia, Brazil, and India all have relatively high employment populations. The labor population in China and India has provided huge benefits for economic growth. Judging from the natural population growth rate of BRICS countries, Russia and South Africa are increasing their natural population growth rates; China and India are both large countries with more than 1.3 billion people. Although the natural population growth rate is not high, due to the large population base, the absolute number of newly added populations is still large, and the BRICS countries will still sustain the population advantage in the future. Judging from the growth rate of the real GDP of the BRICS countries from 2006 to 2018, the growth rate of the real GDP of the BRICS countries has slowed down in recent years. The real GDP growth rates of Brazil, Russia, and South Africa have changed from higher to lower than global and only China and India among the BRICS countries have maintained high growth rates. Brazil needs to change its relatively simple economic structure to promote economic transformation through industrialization; Russia needs to gradually reduce its excessive dependence on oil and gas resource exports; India needs to further increase the level of urbanization and industrialization; China is carrying out supply-side structural reforms and expanding the total at the same time of demand, efforts are being made to strengthen supply-side structural reforms; South Africa needs a better economic system, creating more employment opportunities, and reducing the unemployment rate of the population.

In the current globalization context, trade between countries is becoming increasingly close and capital crosses national borders and flows to industries and regions with higher returns. The increase in

FDI provides utilities such as capital, skills, technology transfer, market access, and export incentives, and international trade and free capital flows exacerbate FDI in developing countries. Hoffman et al. [4] argue that in low-income countries, CO_2 emissions affect FDI entry; in middle-income countries, FDI inflows lead to increased CO_2 emissions; and in high-income countries, no causal relationship between FDI and CO_2 emissions is found. Aliyu [5] uses the host country's annual total CO_2 emissions, total known particulate emissions, rising temperatures, and total energy consumption to test "dirty" FDI, resulting in "dirty" FDI outflows. The environmental policies in 11 OECD countries are positively correlated, but FDI inflows do not significantly explain the pollution levels and energy use in 14 non-OECD countries (The OECD stands for the Organization for Economic Cooperation and Development. It's an association of 35 nations in Europe, the Americas, and the Pacific. Its goal is to promote the economic welfare of its members. It coordinates their efforts to aid developing countries outside of its membership. https://www.thebalance.com/organization-economic-cooperation-development-3305871). Cole and Elliott [6] estimate the scale and technical effects of trade on SO_2, NO_x, CO_2, and biochemical oxygen demand (BOD) (SO_2 represents sulfur dioxide; NO_x represents nitrogen oxides; BOD represents biochemical oxygen demand) and conclude that trade technology effects are stronger than economies of scale for SO_2 and BOD, while scale effects are stronger for NOx and CO_2. The effect, that is, the increase in CO_2, caused by the scale effect is greater than the decrease in CO_2 emissions caused by the technical effect.

The empirical studies performed by increasing numbers of scholars have shown that FDI can improve the environmental conditions of host countries through technological spillover effects. Winkelman et al. [7] combined the data from several countries and analyzed that FDI is conducive to reducing the carbon intensity of host countries and promoting the development of a low-carbon economy in host countries. Based on this type of thinking, some scholars have performed classification tests on the relationship between FDI and different investment environments. The research shows that when the investment location is different in terms of the income level, population factor, opening up, and geographical environment, the FDI's impact on the environment is also significantly different (Kozul-Wright and Fortunato [8]). Therefore, FDI campaigns have promoted rapid economic growth in developing countries. However, while FDI has contributed to economic growth, its potential impact on the environment over the past decade is now being discussed (Baek [9]). FDI is moving towards countries where environmental regulations are relatively less stringent, with lower environmental taxes and lower standards (Seker et al. [10]). In this way, multiethnic countries are shifting their high-pollution industries to developing countries to avoid the high environmental costs in their countries. This indicates that the impact of FDI on the host country's environment may have a threshold effect; that is, as the host country's economy and society continue to develop, the relationship between FDI and the environment also changes.

Over the past three decades, the economies of the BRICS countries have achieved phenomenal growth. These economies account for 21% of world GDP, 40% of world energy consumption, and a large part of global CO_2 emissions, and they will account for more than 40% of the world population in 2018 [11]. However, these economies still rely mainly on traditional energy sources, including ways to increase economic growth and ways to reduce environmental quality. Reducing domestic energy consumption and CO_2 emissions by changing the import and export structure will undoubtedly improve the quality of foreign trade, which will promote the overall economic growth, conserve energy, and reduce emissions. In some industrially developed countries, the so-called development of developing countries has occurred by importing high-carbon products to replace domestic production or directly transferring high-carbon-emission industries to foreign countries through FDI in the country's "pollution shelter". The CO_2 emissions of the BRICS countries accounting for the world's total CO_2 emissions rose from 27.35% in 2001 to 37.78% in 2011. By 2016, the greenhouse gas emissions of the BRICS countries accounted for 41.3% of the world's total. This paper examines the international trade, FDI, and CO_2 emissions of the BRICS countries and their antecedents. From our research, we explore whether developing countries, as represented by BRICS countries, have become a "pollution paradise" for the high-carbon industries of developed countries. We use the Bootstrap Autoregressive Distributed Lagged Model (ARDL) model to explore the impact of BRICS trade on CO_2 emissions. From long-term cointegration relations and long-term, short-term causality, the results are beneficial to BRICS countries seeking a balance between trade and CO_2 emissions. From the perspective of trade and FDI, it is important to study the CO_2 emissions reduction problem of emerging economies and seek new emission reduction paths for the development of low-carbon economies and set global emission reduction targets for the BRICS countries. The BRICS countries have contributed to the development of relevant international trade policies and environmental policies. This paper is structured as follows: the first part is the introduction, the second part is the literature review, the third part is the method, the fourth part is the data period, the fifth part is the empirical results, and the sixth part is the conclusions.

2. Literature Review

With the continuous expansion of trade and the intensification of global warming, since the 1990s, the international community and academia have begun to pay attention to the impact of international trade on climate change. "Trade and carbon dioxide emissions" has become one of the important topics discussed at global climate change conferences. The mechanism of international trade affecting climate change was introduced when Grossman and Krueger [12] explored the impact of the North American Free Trade Area on greenhouse gas emissions; they decomposed the environmental effects of trade into scale effects, structural effects, and technological effects and emphasized that these three effects are mutually influential, i.e., the final total effect is not a simple superposition. The "three-different-effects" analysis helps clarify the path and direction of the influence of international trade on climate change and has become the basic analysis frame for studying the effects of international trade and climate change. Under the framework of the "three effects" analysis, many scholars have performed empirical tests examining the impact of international trade on climate change. The results of the test have two viewpoints; one is that the expansion of trade increases greenhouse gas emissions and exacerbates climate change (Copeland and Taylor [13]; Guo et al. [14]; Lin et al. [15]; Lin [16]).

Another view is that free trade reduces greenhouse gas emissions and slows climate change. For example, Antweiler et al. [17] found that the structural effects of free trade are very small and that a percentage point increase in the production scale will result in a pollution concentration in the sample countries. The degree is increased by 0.25 to 0.5 percentage points, and the technical effect can reduce the pollution concentration by 1.25 to 1.5 percentage points. The three effects will improve the environment as a whole. The study by Peters et al. [18] concluded that international trade is an important factor in explaining changes in CO_2 emissions in many countries. In their study, they find that the stability of CO_2 emissions in developed countries is partly due to increased imports from developing countries. Liddell [19] studied the nature of trade in national emissions and found that internal government policies affect CO_2 emissions, and China and India are countries that especially help reduce CO_2 emissions. Hasanov et al. [20] examined the impact of exports and imports on CO_2 emissions, the impact of long-term and short-term signs of exports and imports on consumption-based CO_2 emissions, and the impact of trade on CO_2 emissions changes that will be fully absorbed within three years. Regionally-based CO_2 emissions are not statistically significant for exports and imports. Different scholars have different indicators, data samples, and research methods when analyzing the impact of trade on greenhouse gas emissions, and the conclusions vary. Managi et al. [21] believe that the impact of trade openness on greenhouse gas emissions depends on the pollutants and country choices. The results show that trade can reduce SO_2 and CO_2 emissions in OECD countries but not in OECD countries. The national situation is the opposite. It can also be seen that the impact of trade on greenhouse gas emissions is a complex, dynamic system process.

In studying the relationship between economic growth and greenhouse gas emissions, Knight and Shore [22] found that during this period, there was some evidence that there was a decoupling between economic growth and regional emissions, but there was no evidence that consumption-based emissions were decoupled. Fernandez-Amador et al. [23] investigated the relationship between per capita real GDP and per capita CO_2 emissions associated with production and consumption activities. They found that both of these income elasticities are dependent on the policies, reflecting the small carbon efficiency gains brought about by economic development. The carbon footprint shows greater income elasticity, and national policy instruments for production can obviously be circumvented by the carbon embodied in intermediate trade. There are three main viewpoints in the academic world about the impact of FDI on the environment. The first viewpoint is the "pollution paradise hypothesis". The core view is that to attract foreign capital inflows, countries will gradually lower their environmental standards and appear to "race to the bottom line". Developed countries have higher environmental standards than developing countries, so the polluting industry will be transferred from developed to developing countries, and developing countries will become "pollution havens" (Walter and Ugelow [24]), Asghari [25], Abdouli et al. [26]), which confirms that FDI caused a decline in the environmental quality of the host country.

The second view is the "polluting halo" effect. The core view is that FDI carrying advanced technology can spread greener and cleaner production technologies to the host country and improve the environmental protection level of its production, thus helping reduce CO2 emissions in the host country (Antweiler et al. [17]; Popp [27]; Poelhekke [28]). The third view is that the impact of FDI on the host country's environment is complex and multidimensional. The two opposite effects of FDI on carbon emissions are affected by the technology spillover effect, absorption capacity and capital accumulation effect of FDI. These effects are different based on different conditions (economic level, industrial structure, environmental policy, investment structure, etc.). Therefore, the environmental effects are uncertain (Kim and Adilov [29]).

Most of the existing research is based on a single perspective of trade or FDI to study its relationship with the environment or CO_2 emissions. In recent years, some scholars have begun to consider the impact of greenhouse gas emissions under the entire open economy and have included foreign trade and FDI in the scope of the investigation. Keho [30] studied the economic communities of West African countries and found that the impact of FDI on CO_2 emissions depends on the degree of trade openness of the host country. With the increase of trade openness in Burkina Faso, Gambia, and Nigeria, the emission reduction effect of FDI is also more obvious, and with the reduction of foreign trade in Ghana, Mali, and Togo, the emission reduction effect of FDI also declines; however, in Benin, Niger, Senegal, and Sierra Leone, the long-term impact of FDI on CO_2 emissions is not significant. Frutos-Bencze et al. [31] investigated the relationship between FDI, trade and industrial emissions from the Central American Free Trade Agreement (CAFTA-DR) from 1979 to 2010. Studies have shown that FDI and trade have a negative impact on selected pollutant emissions, including carbon dioxide, that is, increased emissions. The existing research shows that different scholars have different indicators, samples, and research methods when analyzing the environmental effects of trade and FDI, and the conclusions are not the same. The relationship between the three is complex and multidimensional, and the environmental effects based on different conditions are not the same. It can also be observed that the evaluation of the environmental effects generated by trade and FDI is a complex, dynamic system process. How to reduce the negative effects of the environment and improve the positive effects of the environment in the process of international economic cooperation is a common issue faced by all countries.

3. Methodology

Improving energy and environmental efficiency is an important means to ensure economic growth, as well as to save energy and reduce emissions. As an important source of technological progress, foreign trade is one of the key drivers of energy environment efficiency improvements. Foreign trade provides domestic companies with more opportunities to access and absorb international advanced technologies; however, on the other hand, they have to face global competition, which is conducive to promoting the efficiency of the energy-environment. In terms of global energy consumption and greenhouse gas emissions, China, the European Union, and the United States are the three countries with the world's largest greenhouse gas emissions, and their greenhouse gas emissions account for more than half of global emissions. The top 10 emitters account for nearly three-quarters of the world's total emissions, while the last 100 emitters account for only 3.5% of global emissions. If these major emitters do not take significant actions to reduce greenhouse gas emissions, the world will not be able to successfully address the challenges of climate change (Olivier et al. [32]). In the past 10 years, the energy industry has remained the largest source of greenhouse gas emissions.

In this paper, we use the Bootstrap ARDL to examine the impacts of BRICS's trade, FDI and CO_2 emissions; Bootstrap ARDL uses the principle of self-regression and multiple loop calibrations to make the time series related data close to the expected result that needs to be verified. Before running the Bootstrap ARDL model, it is necessary to know whether the collected data is for the stable state; the general treatment method is to perform the unit root test first. In the time-series analysis, it is necessary to first check whether the data are stationary. The so-called steady-state means that the static statistics, such as the mean and the variance, do not change with time; that is, the self-covariance and the variance are fixed finite constant values that can avoid false regressions. In the time-series analysis, it is necessary to first check whether the data are stationary. The purpose of a unit root test is to determine the integration level of the time-series variables to determine the nature of the time-series. The method begins with Fuller-Fuller (referred to as the DF test) test proposed by Fuller [33] and Dickey and Fuller [34]. The augmented Dickey-Fuller unit root test (ADF) is used in addition to the more common unit root test. Phillips and Perron [35] proposed the PP unit root test because most time-series data are self-related.

3.1. Unit Root Test

The augmented Dickey-Fuller (ADF) unit root test method is based on the least-squares method for three basic regression equations, namely, the standard (no time-interval item with no intercept), intercept mode (with intercept, no trend) and the estimated with intercept trend mode (with intercept and trend terms).

Model 1: No intercept and trend term (random walk):

$$\Delta y_t = \alpha_0 + \alpha_1 y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \tag{1}$$

Model 2: Intercept item with no trend term (random walk with drift):

$$\Delta y_t = \alpha_0 + \alpha Y_{t-1} + \sum_{i=1}^{p} \beta_j \Delta Y_{t-i} + \varepsilon_t \tag{2}$$

Model 3: Intercept item and trend term (random walk with drift and trend):

$$\Delta y_t = \alpha_0 + \alpha Y_{t-1} + \alpha_2 t + \sum_{i=1}^{p} \beta_j \Delta Y_{t-i} + \varepsilon_t \tag{3}$$

where Δ is the first-order difference, α_0 the variable to be discussed is the drift term, t is the trend term of the time trend term, and p is the maximum number of deferred periods, which is the error term.

As long as there is no sequence correlation in the AR (1) process in the DF test, the critical value of the DF test is the same as the threshold of the ADF test (AR(1) represents first-order autoregression coefficient. AR is abbreviating of autoregression, and a parenthesis 1 means first-order). The coefficients of the different terms $\Delta y_{t-1}(i = 1,\ 2,\ \cdots,\ p-1)$ converge to the t-distribution, indicating that the joint significance test of these coefficients will converge to the F-distribution. Therefore, regardless of the value in the model, the coefficients of the different terms can be inferred using traditional statistical checksum statistics. The lag period selection of the AR model is very important for the results of the

ADF test. In practice, there are usually many ways to choose a lag period, such as the information standard method or the lag method.

If the result of the abovementioned ADF unit root test is to reject the null hypothesis H_0, it means that the data of this time series is stationary and there is no unit root phenomenon, also called the $I(0)$ sequence; if the null hypothesis is not rejected H_0: $\alpha_1 = 0$, it means that the data has a unit root and is a nonstationary time series. This test adds the self-deferred term of the interpreted variable to the right side of the regression so that the residual term is closer to the white noise process and the state change of the variable is controlled.

3.2. Optimum Lag Period Test

After completing the unit root test, then the Akaike information criterion (AIC) is determined. The ADF method or the PP method needs to determine an optimal lag period, so the self-related problem of the residual term is corrected to make the residual term a white noise process. However, if too many lag periods are added, the ability to reject the null hypothesis will be reduced; if we add too few lag periods in the model, it will not be able to completely correct the shortcomings of the threshold increase caused by the moving average; therefore, the question is how many lag periods should be added. In a time-series stationary test analysis, the selection of the time-series of lag periods plays a very important role, and different lag periods often affect the results of the final analysis. Therefore, the selection of the number of lag periods is quite important. In this paper, we choose a method widely used in the financial and economics industry; we use the AIC criteria to judge and choose the smallest AIC as the optimal lag period.

The AIC equation is shown in Equation (4), as follows:

$$\text{AIC} = \text{n}ln\ (SSE) + 2P \tag{4}$$

where P represents the number of parameter estimates, n represents the number of observations used, and SSE is the sum of squared errors.

3.3. Vector Autoregression Model (VAR)

When multivariate time-series models are represented by linear regression, the assumption of causality between variables is implicit. However, due to the delicate operation of economic systems, it is sometimes impossible to distinguish between variables in the model and endogenous variables. Sims [36] proposed a vector autoregressive model (VAR) to solve the problem of structural model identification. Sims believes that over time, the characteristics of the economic activity will be fully reflected in the data, so the data itself can be analyzed directly. It is easy to understand the nature of the economic activity, so people can create structural settings without having to understand the exact relationship of these endogenous variables in economic theory. In the VAR model, all variables are considered endogenous, so there is no need to distinguish between endogenous and exogenous variables. A set of regression equations is used to explore the relationship between variables and each regression equation. The lag term of the variable and the lag terms of other variables are used as explanatory variables. Therefore, the VAR model is more in line with the spirit of time-series analysis; because time-series analysis considers that the lagging term of the variable covers all relevant information.

3.4. Bootstrap ARDL Test

Using the Bootstrap ARDL test model, we can better understand the cointegration state of the time-series in the model, and use Monte Carlo simulation to determine the size and power of the endogenous problem framework. The simulated asymptotic threshold has little effect; if the resampling process is properly applied, the pilot-to-test ratio can be determined, and asymptotic tests in ARDL tests based on size and power characteristics can be performed and eliminated more appropriately. The possibility of inference is uncertain, and it can also describe the extension of the verification framework in the case of alternative degradation, as well as the thresholds generated by Bootstrap ARDL. The Bootstrap ARDL test is based on the Granger causality test. A standard Granger causality test will determine the direction of short-term causality. If y is due to a variable, no consistency can be found between y and x. For the entire relationship, the Granger causality test for x → y should include only the hysteresis difference for x. That is, we test that $\beta > 0$; if there is a cointegration relationship between the variables, it means that the related variables and the independent variables form a stationary linear combination. The hysteresis term can be regarded as $I(0)$, and the Granger causality test of x → y should include the hysteresis difference of x and the hysteresis level of x, that is, $\beta > 0$ and $\delta = 0$. The cointegration method proposed by Pesaran et al. [37] is that Automatic Regression Extended Lag (ARL) can simultaneously handle different time-series variables with different integration orders. ARDL uses critical intervals to detect whether there is a long-term equilibrium relationship. This not only solves the problem of sequence inequality but also processes small sample data and processes time-series changes with different integration orders. The advantage of this model is that it contains both short-term adjustment relations and long-term equilibrium relations, and can correctly describe the relationship between variables. The advantage of the ARDL method is that other cointegration techniques require that all regressions be integrated using the same specification, but under this constraint test, they can be applied regardless of their regression order. Cointegration tests include comparisons of thresholds and F statistics. The ARDL bound test (Pesaran et al. [37]) has a time-series of mixed integral sequences, which can be defined as follows:

$$\Delta y_t = c + \alpha y_{t-1} + \beta x_{t-1} + \sum_{i=1}^{p-1} \gamma \Delta y_{t-1} + \sum_{i=1}^{p-1} \delta \Delta x_{t-1} + \sum_{j=1}^{q} \psi D_{t,j} + \varepsilon_t \quad (5)$$

In the long-term, in the case of weak exogenous regression, these regression factors are not affected by variables. The model does not rule out the existence of a cointegration relationship between regressions. It does not assume that there is no Granger causality for the dependent variable of the regression. The Bootstrap ADRL time-series test methods McNown et al. [38] proposed changes to Pesaran et al. [37] ARDL test model.

The ARDL model is:

$$y_t = a + \sum_{i=1}^{k} \alpha_i y_{t-i} + \sum_{i=1}^{k} \beta_i x_{t-i} + \sum_{j=1}^{l} \psi_j D_{t,j} + \mu_t \quad (6)$$

i and j are the indicators of the lag period, $i = 1, 2,..., k$; $j = 1, 2,..., k$. t represents time $t = 1, 2, ..., T$. The y_t in the equation is the explanatory variable and x_t is the explanatory variable, there is a variable $D_{t,j}$, is a dummy variable. The parameters α_i, β_i are the coefficient values of the interpreted variable y_i and the explanatory variable x_i. The error term is μ_t, and Equation (6) can be rewritten and expanded into the following equation:

$$\Delta y_t = \gamma_0 + \sum_{i=1}^{k-1} \gamma_1 \Delta y_{t-i} + \sum_{i=1}^{k-1} \gamma_2 \Delta x_{t-i} + \sum_{i=1}^{k-1} \gamma_3 \Delta z_{ti} + \sum_{j=1}^{l} \gamma_4 D_{t,j} + \vartheta_1 y_{t-1} + \vartheta_2 x_{t-1} + \vartheta_3 z_{t-1} \quad (7)$$

where $\gamma = 1 - \sum_{i=0}^{k} \alpha_i$; $\vartheta = \sum_{i=0}^{k} \beta_i$; other parameters are the function values of the original parameters in Equation (7).

McNown et al. [38] proposed adding the original ARDL model to a lag period for interpreting the variables. The null hypothesis is H_0: $\vartheta = 0$. The conditions for testing the cointegration relationship by

Pesaran et al. [37] will be more complete. The Bootstrap ARDL test is the cointegration relationship by relying on the following assumptions:

$$H_0 : \gamma = \vartheta = 0,\ H_0 : \gamma = 0,\ H_0 : \vartheta = 0$$

According to Pesaran et al. [37], the cointegration test needs to be the F-test or *t*-test. The following assumptions are made:

$$H_0 :\ \vartheta_1 = \vartheta_2 = \vartheta_3 = 0 \text{ or } H_0 = \vartheta_1$$

However, McNown et al. [38] suggested adding three tests to distinguish between cointegration and non-cointegration. McNown et al. [38] require that cointegration must reject all three virtual hypotheses.

The null hypothesis error term F_1 is tested as H_0: $\vartheta_1 = \vartheta_2 = \vartheta_3 = 0$.

The *t*-test for the lag dependent variable is H_0: ϑ_1.

The F_2 test for the lag independent variable is H_0: $\vartheta_1 = \vartheta_2 = \vartheta_3 = 0$.

Based on three null hypotheses, McNown et al. [38] explain two degenerates of Pesaran et al. [37]. Only the critical value of case #2 is presented. The two degeneration cases are as follows:

- In degenerate case #1, the F_1 test and the *t*-test for the lag dependent variable are significant, but the F_2 test for the lag independent variable is not significant.
- In degenerate case #2, the F_1 test and the F_2 test for the lag dependent variable are significant, but the *t*-test for the lag dependent variable is not significant.

We found that Pesaran et al. [37] ruled out degenerate case # 1, which must be $I(1)$ if they do not consider the integration order of the dependent variables. However, McNown et al. [38] used the Bootstrap ARDL test to solve this problem by using an additional test of lag independent coefficients.

If there is a cointegration relationship between the dependent variable and the independent variable, the above three virtual hypotheses will be rejected at the same time, and the explanatory variable and the explanatory variable are stable linear coincidences. Through the Granger causality test based on the Bootstrap ARDL model, the short-term causality between the three variables of international trade, FDI, and CO_2 emissions.

After testing the long-term relationship, we found that there is no cointegration relationship between y, x, and z. We use Granger causality tests for x and z, which should include the difference in hysteresis for x or z. We test $\gamma_2 = 0$ or $\gamma_3 = 0$ in Equation (7). However, if there is cointegration between the dependent and independent variables, it means that they form a stable linear combination. In this case, the short-term relationship test should include the hysteresis difference of x or z and the hysteresis level of x or z; that is, test γ_2 and ϑ_2 or γ_3 and ϑ_3.

4. Data Period

In this paper, we use CO_2 emissions, trade and FDI data for BRICS countries. The trade and FDI data have been adjusted to prices in 1980, which means we used the 1980 deflator, while the CO_2 emissions are based on the per capita CO_2 emissions in BRICS countries. The CO_2 emissions are calculated by dividing the CO_2 emissions by the metric tons per capita for the current year. The data on CO_2 emissions, international trade (including imports and exports) by the percentage of GDP and FDI (foreign direct investment, net inflows, by the percentage of GDP) come from the International Monetary Fund. We have a note here that the data on IMF of CO_2 emissions is available only in 2014, and the data from 2014 to 2018 comes from the Global Energy & CO_2 Status Report 2017, 2018, 2019 published by the International Energy Agency (IEA). Since the Bootstrap ARDL is performing operations, the variable must be a stable sequence of $I(0)$ or $I(1)$, otherwise false regression will occur. At the time of the unit root test, the data presents $I(2)$, and we abandon the data and use the data of CO_2 emissions. The BRICS data is not uniform, the Brazilian data are from 1975 to 2018, the Russian data are from 1992 to 2018, the Indian data are from 1975 to 2017, the Chinese data are from 1982 to 2018, and the South African data are from 1970 to 2018.

5. Empirical Results and Discussion

5.1. Empirical Results

Table 1 shows the statistical descriptions of the three variables of CO_2 emissions; countries the augmented Dickey-Fuller (ADF) unit root test are applied to the trade and FDI in the BRICS to verify the stationary of each time-series. Table 2 is the unit root test result of the level term, and Table 3 is the unit root test result of the first-order difference term. We cannot reject the null hypothesis that all series have a unit root of 10% significance level when using the ADF test. Since the Pesaran boundary ARDL test (Pesaran et al, [37]) allows modeling variables with different integration orders, we continue to estimate models for all economies. If the dependent variable is static, the new Bootstrap ARDL test for degenerate case #1 also prevents incorrect inference and therefore does not cointegrate with the other two series. Table 4 reports the estimation and testing of Equation (6) using the Bootstrap ARDL. Each ARDL equation passes all diagnostic tests for autocorrelation, non-normality, and heteroscedasticity. These lag lengths were determined using the Akaike information criterion (AIC). Diagnostic tests, such as the Jarque Bera test, LM test, and ARCH test, are performed in the post-estimation to check the normality, autocorrelation, and heteroscedasticity of the residuals. Each ARDL equation passes all diagnostic tests for autocorrelation, non-normality, and heteroscedasticity. F_1*, F_2*, and *t** refer to a critical value of the 0.10 significance level, generated by the Bootstrap ARDL procedure proposed by McNown et al. [38].

Table 1. Description of statistics.

Economies	Brazil			Russia			India			China			South Africa		
Variables	**CO_2**	**TRA**	**FDI**	**CO_2**	**TRA**	**FDI**	**CO_2**	**TRA**	**FDI**	**CO_2**	**TRA**	**FDI**	**CO_2**	**TRA**	**FDI**
Mean	1.754673	0.210544	0.020079	11.57713	0.558724	0.017814	0.940178	0.274436	0.007802	4.067414	0.382184	0.028084	8.497800	0.526731	0.008309
Median	1.749501	0.203944	0.015254	11.51359	0.517061	0.016893	0.898163	0.226194	0.005950	2.820568	0.372102	0.030399	8.647141	0.523117	0.004790
Max	2.612934	0.296783	0.050341	13.97997	1.105771	0.045027	1.961458	0.557937	0.036205	7.946870	0.644789	0.061869	9.979458	0.728654	0.059789
Min	1.275133	0.143909	0.001287	10.12730	0.461934	0.001746	0.404751	0.122193	−0.000297	1.566740	0.179211	0.002097	6.785930	0.374875	−0.008405
Std. Dev	0.357300	0.046883	0.015048	0.918029	0.129364	0.012532	0.449012	0.148388	0.008933	2.253928	0.130330	0.016675	0.930114	0.077086	0.011911
Skewness	0.647122	0.200940	0.458010	0.582980	2.965699	0.595385	0.760020	0.635443	1.156480	0.635025	0.335337	0.049052	−0.060876	0.084575	1.978112
Kurtosis	2.427507	1.686156	1.790895	3.020905	12.97000	2.382151	2.611596	1.899792	3.758870	1.771486	2.308199	1.981967	1.839234	2.672987	8.531169
Variables	44	44	44	27	27	27	43	43	43	37	37	37	49	49	49

Note: The descriptive statistics are based on the differences of each variable. CO_2 represents carbon dioxide emission; TRA represents international trade and FDI represents foreign direct investment.

Table 2. Unit root test (Level).

Countries	Test Variable	DF		ADF			PP		
		Intercept	Trend and Intercept	Intercept	Trend and Intercept	None	Intercept	Trend and Intercept	None
Brazil	CO_2	−0.6329 (1)	−2.3934 (0)	−0.6265 (0)	−2.5547 (1)	0.8005 (1)	−0.7928 (2)	−2.3149 (2)	0.9759 (2)
	TRA	−1.2113 (0)	−2.5886 (0)	−1.2198 (0)	−2.3678 (2)	0.3810 (0)	−1.2699 (1)	−2.8640 (1)	0.4740 (3)
	FDI	−1.0126 (0)	−2.3973 (0)	−1.0956 (0)	−2.4737 (1)	−0.0221 (0)	−1.13876 (2)	−2.5625 (2)	0.0010 (1)
Russia	CO_2	−1.6946 * (0)	−2.6186 (0)	−2.8511 * (0)	−4.3426 ** (0)	−0.6771 (0)	−2.8808 ** (2)	−4.8080 *** (2)	−0.6410 (1)
	TRA	−0.9969 (1)	−2.5975 (1)	−2.6537 (1)	−3.4774 * (1)	−0.2570 (1)	−6.4353 *** (2)	−6.3301 *** (2)	−2.0606 ** (1)
	FDI	−1.7647 * (0)	−1.8077 (0)	−1.9507 (0)	−1.5379 (0)	−0.9990 (0)	−1.8485 (3)	−1.3257 (3)	−0.8689 (3)
India	CO_2	−0.1660 (3)	−2.4747 (3)	0.8472 (0)	−1.8302 (1)	−1.0962 (3)	0.8014 (3)	−1.9884 (3)	−1.2414 (3)
	TRA	−0.2129 (0)	−1.3726 (0)	−0.7201 (0)	−2.0240 (2)	0.9629 (0)	−0.8285 (3)	−1.7466 (3)	0.6866 (3)
	FDI	−1.3729 (0)	−2.9294 * (0)	−1.5809 (0)	−2.9687 (0)	−0.8247 (0)	−1.5124 (1)	−2.9688 (0)	−0.7603 (2)
China	CO_2	−0.0298 (1)	−1.6977 (1)	0.0203 (1)	−1.8699 (1)	1.4095 (1)	0.6820 (3)	−1.5150 (3)	3.2573 (3)
	TRA	−1.3465 (1)	−1.7590 (1)	−1.8972 (1)	−1.4719 (1)	−0.0037 (1)	−1.5780 (2)	−1.0660 (2)	0.0803 (2)
	FDI	−1.3937 (0)	−1.8836 (1)	−2.2193 (1)	−1.8492 (1)	−0.6685 (0)	−1.9454 (1)	−1.4165 (3)	−0.7318 (2)
South Africa	CO_2	−1.3971 (0)	−1.4843 (0)	−1.8347 (1)	−1.6389 (0)	−0.0819 (0)	−2.2456 (3)	−1.7301 (2)	−0.0898 (2)
	TRA	−1.8026 * (0)	−2.3211 (0)	−2.0346 (0)	−2.2730 (0)	0.1631 (0)	−2.0786 (2)	−2.3501 (2)	0.1999 (2)
	FDI	−1.3244 (3)	−1.5904 (3)	−1.5027 (0)	−2.1591 (3)	−1.0221 (3)	−4.9309 *** (0)	−5.7532 *** (0)	−3.6719 *** (1)

Note: The parentheses are optimal lag order based on Akaike Information Criterion (AIC). The asterisks ***, ** and * indicate the 1%, 5%, and 10% significance levels. The numbers in parentheses represent the lag period. CO_2 represents carbon dioxide emission; TRA represents international trade and FDI represents foreign direct investment.

Table 3. Unit root test (1st difference).

Countries	Test Variable	DF		ADF			PP		
		Intercept	Trend and Intercept	Intercept	Trend and Intercept	None	Intercept	Trend and Intercept	None
Brazil	CO_2	−5.0336 ***	−5.0768 ***	−3.6905 ***	−3.6428 **	−4.9210 ***	−5.0201 ***	−4.9538 ***	−4.9319 ***
		(0)	(0)	(1)	(1)	(0)	(1)	(1)	(2)
	TRA	−5.3430 ***	−3.2128 **	−5.0928 ***	−5.0320 ***	−6.0212 ***	−5.9957 ***	−5.9336 ***	−5.9790 ***
		(0)	(2)	(1)	(1)	(0)	(3)	(3)	(3)
	FDI	−2.8456 ***	−6.3611 ***	−4.2871 ***	−4.2869 ***	−4.2443 ***	−6.3308 ***	−6.3021 ***	−6.3146 ***
		(3)	(0)	(1)	(1)	(1)	(1)	(1)	(1)
Russia	CO_2	−3.5899 ***	−4.4551 ***	−4.0413 ***	−4.3871 ***	−4.1583 ***	−3.9863 ***	−4.3657 ***	−4.1267 ***
		(0)	(0)	(0)	(0)	(0)	(2)	(1)	(2)
	TRA	−2.2641 **	−3.6403 **	−6.0093 ***	−6.3020 ***	−6.2013 ***	−6.8559 ***	−6.3020 ***	−7.2557 ***
		(0)	(0)	(1)	(0)	(1)	(0)	(0)	(0)
	FDI	−4.4046 ***	−4.9660 ***	−4.4654 ***	−4.8319 ***	−4.5613 ***	−5.3454 ***	−5.6396 ***	−5.4813 ***
		(1)	(1)	(1)	(1)	(1)	(2)	(2)	(2)
India	CO_2	−2.4580 **	−2.8021	−2.8501 *	−2.7638	−0.8202	−6.0063 ***	−6.0452 ***	−2.7427 ***
		(2)	(2)	(2)	(2)	(2)	(3)	(3)	(3)
	TRA	−5.5535 ***	−5.5584 ***	−5.4869 ***	−5.4206 ***	−5.3058 ***	−5.5228 ***	−5.4584 ***	−5.4017 ***
		(0)	(0)	(0)	(0)	(0)	(2)	(2)	(3)
	FDI	−7.2646 ***	−7.2868 ***	−7.2694 ***	−7.1686 ***	−7.2934 ***	−7.3006 ***	−7.1962 ***	−7.3091 ***
		(0)	(0)	(0)	(0)	(0)	(3)	(3)	(3)
China	CO_2	−2.5805 **	−2.8038	−2.6334 *	−2.7061	−1.8443 *	−2.6334 *	−2.7061	−1.7443 *
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(2)
	TRA	−4.1256 ***	−4.3638 ***	−4.2114 ***	−4.4000 ***	−4.2076 ***	−4.2114 ***	−4.3660 ***	−4.2076 ***
		(0)	(0)	(0)	(0)	(0)	(0)	(2)	(0)
	FDI	−4.7446 ***	−5.0024 ***	−4.6760 ***	−4.9273 ***	−4.7391 ***	−4.5900 ***	−4.7548 ***	−4.6601 ***
		(0)	(1)	(0)	(1)	(0)	(3)	(3)	(3)
South Africa	CO_2	−2.1699 **	−6.5316 ***	−6.5824 ***	−6.7470 ***	−6.6576 ***	−6.5830 ***	−6.7472 ***	−6.6579
		(0)	(0)	(0)	(0)	(0)	(2)	(1)	(2)
	TRA	−6.8214 ***	−6.8469 ***	−6.7791 ***	−5.2783 ***	−6.8269 ***	−6.8483 ***	−6.7594 ***	−6.8980 ***
		(0)	(0)	(0)	(0)	(1)	(3)	(3)	(3)
	FDI	−3.7053 ***	−3.8300 ***	−4.4338 ***	−4.3831 ***	−7.7339 ***	−4.4338 ***	−4.3831 ***	−4.4900 ***
		(3)	(3)	(3)	(0)	(0)	(1)	(3)	(3)

Note: The parentheses are optimal lag order based on Akaike Information Criterion (AIC). The asterisks ***, ** and * indicate the 1%, 5%, and 10% significance levels. The numbers in parentheses represent the lag period. CO_2 represents carbon dioxide emission; TRA represents international trade and FDI represents foreign direct investment.

Table 4. Cointegration analysis.

Countries	Period	Dependent Variable| Independent Variable	Lag Specification	F1	F1 *	t	t*	F2	F2 *	Dummy Variables	Cointegration Status
Brazil	1975–2018	(CO_2|TRA|FDI)	(1, 2, 0)	0.877	3.173	−1.416	−2.076	0.566	3.096	D97, D10	No-cointegration
	1975–2018	(TRA|FDI|CO_2)	(1, 0, 0)	6.134	4.276	−3.716	−1.903	8.501	5.282	D00	**Cointegration**
	1975–2018	(FDI|CO_2|TRA)	(1, 0, 0)	2.308	3.311	−1.483	−2.168	3.307	3.134	D97	No-cointegration
Russia	1992–2015	(CO_2|TRA|FDI)	(1, 0, 0)	4.455	4.152	−3.249	−2.581	2.911	4.512	No	**Degenerate case #1**
	1992–2018	(TRA|FDI|CO_2)	(1, 0, 1)	5.276	5.189	−3.917	−3.397	4.018	7.021	D96	**Degenerate case #1**
	1992–2018	(FDI|CO_2|TRA)	(1, 0, 0)	5.221	3.714	−7.890	−2.753	13.750	3.102	D03, D14	**Cointegration**
India	1975–2017	(CO_2|TRA|FDI)	(1, 0, 0)	7.108	3.234	−1.998	−2.006	9.689	3.652	D86, D95, D08	No-cointegration
	1975–2017	(TRA|FDI|CO_2)	(1, 2, 0)	0.232	3.870	−0.737	−0.824	0.339	2.923	D93, D04	No-cointegration
	1975–2017	(FDI|CO_2|TRA)	(1, 0, 0)	5.469	4.007	−3.638	−2.740	8.202	4.615	D95, 06, D12	**Cointegration**
China	1982–2018	(CO_2|TRA|FDI)	(1, 0, 0)	9.756	4.673	−2.699	−3.277	13.713	6.048	D95, D06, D11	**Degenerate case #2**
	1982–2018	(TRA|FDI|CO_2)	(1, 0, 0)	0.954	3.923	−1.512	−2.145	0.455	4.420	D92, D00, D14	No-cointegration
	1982–2018	(FDI|CO_2| TRA)	(1, 0, 0)	1.382	5.212	−1.810	−3.426	0.469	5.826	D92, D12	No-cointegration
South Africa	1970–2018	(CO_2|TRA|FDI)	(1, 0, 0)	2.351	3.959	−1.665	−2.830	1.951	4.849	D81, D90, D04, D12	No-cointegration
	1970–2018	(TRA|FDI|CO_2)	(1, 0, 0)	1.650	13.979	−2.064	−1.322	0.753	14.623	D06	No-cointegration
	1970–2018	(FDI|CO_2|TRA)	(0, 0, 0)	8.981	11.363	−5.170	−9.546	1.119	3.106	D97	No-cointegration

Note: CO_2 represents carbon dioxide emission; TRA represents international trade and FDI represents foreign direct investment. F_1 is the F statistic for the coefficients of $y(-1)$, $x_1(-1)$ and $x_2(-1)$; F_2 is the F statistic for the coefficients of $x_1(-1)$ and $x_2(-1)$; t denotes the t statistic for the coefficient of $y(-1)$. D97 means a dummy variable for the year 1997; other years are 0. t is the t-statistics for the dependent variable, and F is the F-statistics for the independent variable. F, t_1, t_2 and F*, t_1*, t_2* are the critical values at the 10% significance level, generated from the bootstrap method suggested by McNown et al. (2018).

This paper examines FDI of the BRICS countries, whether there is a long-term (cointegration) economic relationship between trade and CO_2. Many believe that an outward-looking strategy to promote trade and/or encourage FDI contributes to the reduction of CO_2 emissions in the BRICS countries. If these outward-looking strategies result in long-term reductions in actual CO_2 emissions, then there should be a long-term cointegration relationship between these variables. In addition, this long-term relationship must exist in a case where CO_2 is a dependent variable. The study used a newly developed cointegration test, i.e., the Bootstrap ARDL, to study the long-term relationship between FDI in the BRICS economies, trade, and CO_2.

We conducted Bootstrap ARDL empirical tests on CO_2 emissions, trade, and FDI in the BRICS countries. From Table 4, we find that Russia's trade and FDI on CO_2 emissions, as well as FDI and CO_2 emissions to trade are degenerate case #1. In international trade, manufacturing is concentrated in developing countries, and final consumption is common in developed countries. The CO_2 emissions of developing countries due to the consumption of products produced by developing countries can be regarded as the CO_2 emissions transferred by developed countries to developing countries by outsourcing the production links in the industrial chain. The globalization of international trade has caused countries to not set up high-polluting industries in their own countries. Therefore, the increase in FDI reflects that local industries may be dominated by high-energy-consuming and high-polluting industries. Russia's data show that the three related variables of CO_2 emissions, trade, and FDI have a high correlation in the BRICS countries in the long-term, regardless of whether they are independent variables or dependent variables. The growth of Russia's economy places great pressure on the demand for energy, raw materials, and transportation. For the long-term, high-energy-consuming industries are still basic industries. With the continuous advancement of industrialization, the demand for high-energy-consumption products for large-scale infrastructure construction has continued to increase. With the continuous increase in the production of high-energy-consumption products, CO_2 emissions have also continued to increase.

China's FDI, lag of one period of CO_2 emissions, and trade are degenerate case #2. This may indicate that FDI has a long-term development relationship with China's economic development, because China is mainly an export-oriented economy, and FDI affects CO_2 emissions. The long-term relationship between CO_2 emissions and trade is a reasonable phenomenon, and the empirical results can explain this phenomenon; China's international trade process is usually accompanied by a shift in CO_2 emissions. That is, developed countries must implement higher environmental protection policies, and industries with high pollution and high energy consumption must be transferred to developing countries. To prioritize economic development and attract foreign investment, low environmental protection standards are usually established, which fundamentally change trade growth at the expense of high CO_2 emissions, accelerate the transition to a new strategy for low carbon trade, change the structure and quantity of exports, and change high CO_2 emissions, high energy consumption, and the number of resource-based primary products being exported. The trade industrial structure guides the transformation and upgrading of processing trade, eliminates backward production capacity, and encourages the export of low-energy-consuming products. Brazil's FDI and CO_2 emissions have a cointegration relationship with the lag of one-period of trade; for Russia and India's trade and CO_2 emissions; there is a cointegration relationship with the lag of one-period of FDI. Among the BRICS countries, South Africa's economic data are as follows: South Africa ranks lowest in the tangible food supply, and the labor force fell by more than 3% in 2008, while India's workforce has grown by nearly 3%. South Africa's manual labor costs are higher than those in India and China. Workers in South Africa are paid more than those in Brazil, China, and India. South African workers are more productive than those in Russia, Brazil, China, and India.

In Table 5, we show that Russia and India have significant long-term causality in trade and FDI, and both have positive causality; Brazilian FDI and trade also have significant long-term causality. We find that although these variables have a cointegration relationship, there is no long-term causal relationship in the case of CO_2 emissions and trade in Brazil. In Russia and India, CO_2 emissions and

FDI have no long-term causal relationship in the lag of one-period. Countries with higher per capita income levels are still in countries with lower per capita income levels. The inflow of FDI has reduced the pressure on CO_2 emissions to a certain extent; trade dependence has positively reduced the CO_2 emissions of the heavier BRICS countries. Regarding the impact of FDI in developed countries, there is a significant relative relationship between trade and CO_2 emissions. One way to use the motivational guidance method is to generate a data set for key-value use that is valid and suitable for a particular ARDL test.

Table 5. Causality test (long-run).

Countries		CO_2	TRA	FDI
		F-statistics (*p*-value) (sign)	**F-statistics (*p*-value) (sign)**	**F-statistics (*p*-value) (sign)**
Brazil	TRA	0.006403/ [0.9368] (+)	/	**8.949400 ***/[0.0055] (+)**
Russia	FDI	0.029751/ [0.8648] (+)	**27.11592 ***/ [0.0000] (+)**	/
India	FDI	1.652010/ [0.2096] (+)	**12.41976 ***/ [0.0015] (+)**	/

Note: CO2 represents carbon dioxide emission; TRA represents international trade and FDI represents foreign direct investment. The asterisks ***, **, and * indicate 1%, 5%, and 10% significance levels, (+), (–) the positive and negative signs, respectively. Additionally, the parentheses [.] are p-value and sign for the coefficients. The case of non-cointegration and its causality test involved only lagged differenced variables. The bold value represents Granger causality's significant results.

In Table 6, we show the test of short-term causality for the BRICS countries. Brazil's trade has a positive causal relationship with the lag of one-period of FDI (2.631094), indicating that Brazil's trade growth has a positive impact in the short-term. The Brazilian government's "import substitution strategy" is to first establish a joint venture factory by attracting foreign investment and then subsidize the middle class to buy domestic industrial manufactured goods, thereby promoting economic growth. This is because foreign investment in Brazil is mainly concentrated in technology-intensive sectors, such as the automotive, electromechanical equipment and appliance industries. To attract capital, the Brazilian government raised the minimum wage standard by only 50% when the accumulated inflation rose by more than 100% within a few years. This has resulted in more than one-third of the Brazilian workforce receiving only the minimum wage; thus, the purchasing power is declining.

Table 6. Causality Test.

Countries		CO_2	TRA	FDI
		F-statistics (*p*-value) (sign)	**F-statistics (*p*-value) (sign)**	**F-statistics (*p*-value) (sign)**
Brazil	CO_2	/	0.636901/ [0.5983] (–)	0.358891/ [0.7832] (+)
	TRA	1.800154/ [0.1886] (–)	/	0.025480/ [0.8741] (+)
	FDI	2.412634/ [0.1068] (–)	**2.631094 */ [0.0885] (+)**	/
Russia	CO_2	/	0.528510/ [0.6727] (–)	**7.650304 ***/ [0.0060] (–)**
	TRA	1.231427/ [0.3238] (+)	/	2.744058/ [0.1014] (+)
	FDI	0.812713/ [0.3851] (+)	8.617539 **/ [0.0125] (+)	/
India	CO_2	/	**2.606520 **/ [0.0761] (–)**	**2.02648 ***/ [0.0001] (–)**
	TRA	2.019237/ [0.1516] (–)	/	**8.173146 ***/ [0.0016] (+)**
	FDI	0.157213/ [0.8553] (–)	2.072647/ [0.1454] (–)	/
China	CO_2	/	1.781738/ [0.1888] (–)	0.485598/ [0.6968] (+)
	TRA	**2.461789 */ [0.0977] (+)**	/	1.070561/ [0.3878] (–)
	FDI	0.496611/ [0.6892] (+)	0.225741/ [0.8772] (–)	/
South Africa	CO_2	/	**3.159647 */ [0.0839] (+)**	0.001429/ [0.9701] (+)
	TRA	0.019913/ [0.9803] (+)	/	**3.831021 **/ [0.0313] (+)**
	FDI	0.818108/ [0.4938] (–)	1.054974/ [0.3823] (+)	

Note: CO_2 represents carbon dioxide emission; TRA represents international trade and FDI represents foreign direct investment. The asterisks ***, **, and * indicate the 1%, 5%, and 10% significance levels, (+), (–) the positive and negative signs, respectively. Additionally, the parentheses [.] are *p*-value and sign for the coefficients. The case of non-cointegration and its causality test involved only lagged differenced variables. The bold value represents Granger causality's significant results.

In the short-term causal relationship, in Russia, FDI has a negatively significant (7.650304) causal relationship to the lag of one-period of CO_2 emissions, indicating that FDI contributes to the reduction of CO_2 emissions; in terms of trade and FDI, in Russia, as in Brazil, there is a positive significant causal relationship (8.617539). In the short-term, India's trade and FDI have negative causal relationships with CO_2 (2.606520, 2.02648, respectively) and FDI has a positive causal relationship with trade (8.173146). China's short-term CO_2 emissions are positively significant in the lag of one period of FDI (2.461789). According to The International Energy Agency (IEA) Global Energy & CO_2 Status Report, 2018 [11] shows that global CO_2 emissions have reached record highs for two consecutive years, i.e., increasing by 1.4% in 2017 and expanding to 1.7% in 2018, the highest growth rate since 2013, after a lapse of five years. Among them, the power generation sector accounts for approximately 2/3 of the increase in emissions. The IEA analysis is one of the reasons for the expansion of the use of coal-fired power generation in developing countries causing the carbon dioxide increase in Asia. The value is one-third of the increased CO_2 emissions since 2017 using coal. China accounted for nearly 30% of the total emissions, reaching 9.481 billion tons, an increase of 2.5%. In the short term, South Africa's trade has a significant positive effect on the lag of one-period of CO_2 emissions (3.159647) and FDI has a significant positive correlated effect in the lag of one-period of trade (3.831021).

5.2. Discussion

Carbon dioxide emissions policies must be based on the social, economic, and regulatory conditions of the BRICS countries and work to maximize the benefits and risks of low-carbon investments. To support global efforts to combat climate change, the BRICS partners at the United Nations Conference on Trade and Development (UNCTAD) proposed a partnership to establish a synergistic link between investment promotion and climate change mitigation and encourage low-carbon investment to promote sustainable growth and development (UNCTAD is a permanent intergovernmental body established by the United Nations General Assembly in 1964. Its headquarters are in Geneva, Switzerland. UNCTAD is part of the United Nations Secretariat. It reports to the UN General Assembly and the Economic and Social Council, but it has its own membership, leadership, and budget. It is also part of the United Nations Development Group. https://unctad.org/en/Pages/aboutus.aspx). The main content and efforts are as follows [39]: (1) Establish the International Low-Carbon Technical Assistance Center. The Low Carbon Technical Assistance Center can support developing countries, especially the least developed countries, in formulating and implementing national strategies and action plans to mitigate climate change and participate in capacity building and institution building. The center can help recipient countries meet development challenges and realize development aspirations, including benefiting from low-carbon foreign investment and related technologies. (2) Develop a clean investment promotion strategy. This includes developing an enabling host country policy framework and implementing effective promotion plans. International financial institutions and home countries need to support low-carbon investment promotion strategies. Specific measures include foreign investment promotion, investment guarantees, and credit risk guarantees. (3) Support and promote clean technologies. This includes the development of supportive frameworks to promote cross-border technology flows, i.e., the establishment of linkages between multinational companies and local companies, to achieve maximum spillover effects, to enhance the ability of local companies to become part of global value chains, and to enhance the multinational absorption. Develop cleaner technology capabilities in developing countries and encourage partnerships to promote technology transfer between countries. (4) Unify the company's greenhouse gas emissions disclosure practices. This includes establishing global uniform standards for corporate greenhouse gas emissions disclosure, improving the disclosure of foreign companies' activities in the value chain, and mainstreaming best practices in emissions disclosure through existing corporate governance oversight mechanisms. (5) Ensure that FDI helps mitigate climate change. This includes the introduction of climate-friendly provisions in future international investment agreements and the achievement of multilateral understandings to ensure that existing international investment agreements and the dynamics of global and national policies on climate change are consistent.

From the report of Word Bank in 2018 [1], Brazil experienced a period of economic and social progress from 2003 to 2014. More than 29 million people have been lifted out of poverty and the phenomenon of inequality has been greatly reduced. Economic activity shrank sharply in 2015 and 2016, with GDP falling by 3.6% and 3.4%, respectively. The economic crisis is the result of falling commodity prices and the country's limited ability to carry out the necessary fiscal reforms at all levels of government, thereby weakening consumer and investor confidence. 2017 marked the beginning of a slow recovery in Brazilian economic activity. According to IEA Global Energy & CO_2 Status Report, 2018 [11], global CO_2 emissions hit a record high, and almost all countries have increasing trends. In terms of CO_2 emissions policies, Brazil is expected to reduce 600 million tons of CO_2 emissions in the atmosphere by 2028, which is equivalent to the sum of emissions from the country's two-year fuel mix. At the same time, the Ministry of Mines and Energy of Brazil encouraged the share of biofuels to increase from 20% to 28.6%. India's CO_2 emissions in 2018 reached 2.299 billion tons, up 4.8% from the previous year. China's CO_2 emissions were in the same period increased by 3.5%. India and the United States and China account for nearly 70% of global energy demand growth. The government of India is committed to generating 40% of its energy from renewable sources by 2030, based on the intensity of CO_2 emissions from economic development. At the end of 2018, the Ministry of Economic Development introduced a draft law "National regulation of greenhouse gases and amendments to certain legislative acts of the Russian Federation". The bill will lay the foundation for a national emissions trading system (ETS). The draft law includes provisions for economic instruments around three main pillars: stimulating activities to reduce greenhouse gas emissions; establishing a market mechanism to deal with greenhouse gas reduction credits, and paying greenhouse gas emissions fees that exceed established permits. The Chinese government has made a commitment to the following expected goals: by 2020, China plans to reduce carbon intensity by 40% to 45% from 2005 levels and 60% to 65% by 2030. The South African "Carbon Tax Act" is the first African country to implement a carbon tax. The South African Ministry of Finance said that climate change is one of the greatest challenges facing humanity, and the main goal of the carbon tax is to reduce greenhouse gas emissions in a sustainable, cost-effective and affordable way. The structure will include 34 GW of coal (45%); 1.9 GW (3%) of nuclear power; 4.7GW of hydropower (6%); 2.9GW of pumping water (4%); 7.9GW of solar photovoltaic (10%); 4GW wind (15%); 11.9GW natural gas (16%), and 0.6GW concentrated solar energy (1%) [11]. South Africa's current energy consumption depends on fossil fuels, so the carbon tax levy will inevitably affect the relevant industries and the economy. The BRICS countries have tried to reduce CO_2 emissions without affecting economic growth. Regarding the policy viewpoint, they are complying with the Paris Climate Agreement and are adopting the concept of "carbon neutrality" by implementing tree planting, forest restoration and avoiding CO_2 emissions, such as foresting, planting trees on the farm to obtain wood, making biodiesel or using for other commercial purposes. Renewable energy compensators typically include the use of wind, solar, and biomass fuels. While developing the economy, the BRICS countries are also committed to promoting the development of zero-carbon buildings, smart infrastructure, and using methods to reduce CO_2 emissions.

Papers on FDI trade and CO_2 emissions discussed in recent years have some conclusions on this topic: Kaya et al. discuss the long-term positive impact of Turkish FDI and trade liberalization on CO_2 emissions of bi-direction causality between CO_2 emissions and FDI [40]. The results of our research show that in the long-term, there is no country has a significant relationship between CO_2 emissions and trade and FDI. In the long-term economic development of BRICS countries, CO_2 emissions have not been causally related to trade and FDI. Ren et al. discussed the impact of China's trade openness, exports, imports, and per capita income on CO_2 emissions. Their results show that: (1) China's growing trade surplus is one of the important reasons for the rapid rise in CO_2 emissions. (2) A large amount of FDI has further exacerbated China's CO_2 emissions; in their opinion, in order to achieve environmentally sustainable economic development, China should strive to transform its trade growth model, adjust its foreign investment structure, improve energy efficiency, and develop low-carbon Economy [41]. Huang et al. studied the impact of China's FDI and foreign trade on the environment. They found that the impact of FDI on CO_2 emissions was negative and significant. The positive and indirect effects of FDI and foreign trade on CO_2 emissions outweigh the negative effects. It directly affects [42]. Haug et al. researched the impact of Turkish foreign trade and FDI on CO_2 emissions. They considered linear and nonlinear ARDL models. They found that in the long-term, reducing exports would reduce per capita CO_2 emissions. The increase in imports has increased per capita CO_2 emissions, while the reduction in imports has no long-term impact. The increase in exports leads to a decrease in the share of CO_2 emissions, while the increase in imports leads to an increase in the share of CO_2 emissions [43]. To et al. found that in the first stage of economic growth, FDI caused the environment to deteriorate, but declined in the next stage. In order to develop appropriate and good policies to attract FDI, decision-makers in the host country need to have a clear and accurate understanding of the best level of FDI in their country [44]. In our study, in the short-term, India and Russia's CO_2 emissions are inversely causal with FDI, which indicates that FDI in these two countries contributes to their CO_2 emissions. From another perspective, it should be that their countries have formulated stricter investment policies to encourage FDI by carbon-reducing cooperation. As for trade and FDI, our results show that some of the BRICS countries are consistent with other studies. In the long or short-term, trade and FDI have a positive causal relationship.

As the depth and breadth of energy cooperation between BRICS countries expand, cooperation between member countries in other regions will become closer. The mutually beneficial results of energy cooperation will continue to enhance the strategic mutual trust of member states, thereby further enhancing the willingness and ability of BRICS countries to cooperate in international affairs. If the BRICS can transcend specific differences, they can follow a path of mutually beneficial energy cooperation. Among the BRICS countries, China's economic scale and incremental contribution are the largest. The rapid growth of Chinese consumer demand has become an important factor driving the rapid growth of resource-rich countries such as Russia and Brazil. In this regard, China should have more initiative in promoting the BRICS cooperation mechanism. China should use the BRICS energy cooperation mechanism as a strength and platform to consolidate emerging economies, deepen cooperation potential, increase cooperation levels, and work with other member states to establish a stable, secure, fair, and transparent international new energy order.

6. Conclusions

The BRICS leaders held their 11th summit in Brazil on November 14, 2019 [45]. The theme of the meeting was "BRICS: Economic Growth, Creates an Innovative Future". The important issues are: working together to build a world of peace, stability, and prosperity. The BRICS countries implement the Paris Climate Agreement in accordance with their national conditions and the principles of the United Nations Framework Convention on Climate Change, and abide by the principle of common but differentiated responsibilities and their respective capabilities. Promote the multilateral system and increase the participation of emerging economies and developing countries in decision-making in international affairs. The BRICS countries committed to a balanced and comprehensive promotion of sustainable development from three areas: economy, society, and environment. The importance of implementing the 2030 Agenda for sustainable development, fully fulfilling official development assistance commitments, and providing developing countries with additional development resources. Committed to implementing the outcome of the Fourteenth Conference of the Parties to the "United Nations Convention to Combat Desertification", achieving the 2030 sustainable development goals, combating desertification, restoring degraded lands and soils, and striving to build a world with zero growth in land degradation [46].

The BRICS countries have different natural resource conditions and industrial structures, and their development models are different. They have certain complementarities and huge development space in economic and trade cooperation. Among the five member states, China is able to provide a large number of high-quality, low-cost industrial products. India can provide information software services and raw ore materials. Russia, Brazil, and South Africa have the capacity to provide abundant energy and mineral resources. By signing bilateral and multilateral trade agreements, the BRICS countries encourage international trade among member states, improve the level of economic and trade cooperation between the parties, and achieve the common rise of the BRICS countries. According to the United Nations (UN) climate statistics, the world's top five greenhouse gas emissions are the United States, China, Russia, India, and Japan, while Brazil is also ranked eighth. Due to the relatively low level of production technology in the BRICS countries, the energy structure is mainly based on coal. Economic growth still depends mainly on resource inputs [47]. In some developed countries, companies will avoid high pollution and high consumption to avoid strict supervision. The shift of the energy industry to developing countries has led to a rapid increase in CO_2 emissions in these countries. Developed and developing countries should implement the principle of common but differentiated responsibilities for carbon reduction. Developed countries should provide CO_2 emission reduction funds and technologies to developing countries. Russia is using a framework of CO_2 emissions through climate legislation. For example, CO_2 emissions trading permits systems and companies to reduce or capture tax credits for their CO_2 emissions. Russia is currently developing a policy plan that includes CO_2 pricing to achieve the goal of reducing greenhouse gases by 2020, which is to be 25% lower than the 1990 level by 2030 and 25–30% lower than the 1990 level. On the issue of CO_2 emissions, the BRICS countries met in 2017 with the leaders of the BRICS countries and reached an agreement to start a carbon neutrality project to offset the CO_2 emissions generated by themselves, through the form of afforestation, energy conservation, and emission reduction, or purchase of carbon credits in order to "zero-carbon" emissions were achieved in the end (Carbon neutrality refers to the total amount of greenhouse gas emissions directly or indirectly produced by enterprises, groups or individuals during the period of production and operation.) [48].

The Bootstrap ARDL simulation accommodates the bias of the narrow statistical environment used by McNown et al. [38]. In particular, the Bootstrap ARDL test allows for endogenous and feedback in the presence of variables. In addition, Pesaran et al. [37] provide a degenerate case #1 or #2 only in the key-value ARDL test framework to test one of two possibilities. Therefore, an empirical study using this method does not allow for two degenerate situations, and it can be concluded that there is cointegration when it does not exist. The BRICS countries are the most important emerging market countries in the world, accounting for 26% of the world's total area, and the population accounts for 42% of the world's total population [49]. After 2015, affected by the global economy, the differences in the economic development of these five countries have become larger [50]. We use the Bootstrap ARDL model to explore whether the three variables of CO_2 emissions, trade, and FDI in the five countries have a long-term cointegration relationship. We find that CO_2 emissions from Brazil and FDI have a cointegration relationship with trade with a lag of one period. In Russia and India, the CO_2 emissions and trade have a cointegration relationship with FDI that lags one-period of time. In the long-term, Brazilian FDI has a causal relationship with a trade that lags one-period of time. The trade between Russia and India has a long-term causal relationship with FDI that lags one-period of time. In the short-term causality test, the results presented in the empirical results described above are more complex. We use the Bootstrap ARDL model, and the largest limitation is on the variables. So far, this program from McNown et al. [38] can use only up to three variables. Therefore, it seems to be better than other models in explaining the causal relationship of variables. If variables can be added to the model, we can change the trade variable to two variables, i.e., import and export, which can explain only the impact of a country's imports and exports on CO_2 emissions, respectively. In addition, we use Bootstrap ARDL's method, which still has some related limitations. Additionally, the data (source, missing, uniformity, etc.) may contain other related limitations, which may cause analysis bias. Of course, this may also be the direction that this model can be improved in the future.

Author Contributions: All authors contributed to the development of the Bootstrap ARDL test on the relationship between trade, FDI, and CO_2 emissions manuscript. M.L. and X.L. conceived the study, analyzed the data, and wrote a manuscript. F.H. and F.L. provided suggestions for the simulation. F.H. also guided the research direction and proposed an analytical framework. K.-C.C. contributed to the revision process of the manuscript and the overall quality of the manuscript. All authors have revised and approved the final manuscript.

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