The Relationship Between Health Expenditure, CO2 Emissions And Economic Growth In The BRICS Countries—Based On The Fourier ARDL Model

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The Relationship between Health Expenditure, CO2 Emissions and Economic Growth in the BRICS Countries—Based on the Fourier ARDL Model

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Abstract

In the process of urbanization in developing countries, transportation infrastructure will be built and population migration will also occur. Although these actions can promote economic growth, they can also affect CO2 emissions. CO2 emissions will affect the health of residents, thereby changing health expenditures. The interaction of these three aspects is also a hot topic among scholars. The BRICS countries are emerging countries with the highest carbon dioxide emissions in the world. Discovering problems from empirical research is the focus of our research. This paper finds that, in the long-term, with CO2 emissions as the dependent variable and health expenditure and economic growth as the independent variables, there is a cointegration relationship between Brazil and China. In the short-term, there is a causal relationship between India’s CO2 emissions and health spending; other countries only show a one-way relationship between carbon dioxide emissions, medical spending, or economic growth. Our recommendations to the BRICS countries are as follows: (1) The BRICS countries should transform their economic development methods and use low-polluting alternative energy sources; (2) Brazil and India should pay attention to the indirect effects of economic growth and align economic growth policies with health expenditure policies. (3) South Africa should pay more attention to the sustainability of the impact of economic growth policies on health expenditures.

Keywords: health expenditures, CO2 emissions, economic growth, BRICS Countries, Fourier ARDL

JEL Classification: C22, E23, I18, O13,

1. Introduction

In 2020, COVID-19 epidemic swept the world suddenly, accompanied by large-scale shutdowns around the world, leading to the interruption of domestic and foreign trade, reduced investment, and low consumption. The global economy is in a deep quagmire. Although governments have adopted large-scale fiscal stimulus policies, the actual effect is still highly uncertain. During the epidemic, how the global economy finds new growth drivers is particularly important. There is no doubt that in

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terms of economic growth potential, the BRICS, as a representative of developing
countries, deserve more attention than developed countries. According to estimates
from the IMF’s World Economic Outlook Report in October 2020, from 2021 to 2022,
among the BRIC countries, China’s forecast economic growth rates will be 8.1% and
5.6% respectively; India will be 11.5% and 6.8%; Russia will be 3.0%, 3.9%; South
Africa is 2.8%, 1.4%; Brazil is 3.6%, 2.6%. In the same period, the forecast growth
rate of advanced economies is only 4.3% and 3.1%.

However, restricted by their own endowments, the economic development model
of the BRIC countries is characterized by high pollution and high energy consumption,
such as large-scale investment in traditional energy sources and excessive
development of mineral resources. The direct consequence of this model is that it has
brought about an increase in carbon emissions and increased environmental pollution,
thereby restricting economic growth. According to the “BP Statistical Yearbook of
World Energy (2020)”, among the five BRIC countries, among the five BRICS
countries, China currently has the highest carbon emissions in the world. The total
carbon emissions in 2020 will account for 28.8% of the total global emissions; India
is 7.3%. Third in the world; the carbon emissions of Russia, Brazil, and South Africa
are 4.5%, 1.3%, and 1.4% respectively; in 2020, the total carbon emissions of the
BRICS countries accounted for 43.3% of the total global carbon emissions (see Figure
1).

In addition, with the increase in life expectancy, the impact of medical and health
expenditure on economic growth cannot be ignored. According to statistics from the
World Health Organization, in 2018, the average life expectancy in China, Brazil, and
Russia was 76.4, 76.8, and 72.7 years, respectively; the average life expectancy in
India and South Africa was 68.8 and 63.6 years. The average age of the population of

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1 Data Source from International Monetary Fund, World Economic Outlook, website address:
https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/CHN/BRA/IND/RUS/ZAF/ADVEC?
year=2021

2 Data source from British Petroleum (bp) website address:
https://www.bp.com/content/dam/bp/businesssites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-co2-emissions.pdf
the BRICS countries is 71.2 years old (see Figure 2).

Based on previous studies, this paper uses the Fourier Bootstrap ARDL model to explore the relationship between CO2 emissions, health expenditures and economic growth in the BRICS countries. The Fourier Bootstrap ARDL model considers both long-term and short-term effects. It can test whether the three variables have a cointegration relationship in the long-term and whether there is Granger causality in the short-term.

![Figure 2 The average life expectancy of the BRICS countries in 2018](image)

2. Literature review

The theory of factors affecting economic growth has been discussed by scholars from a long time ago. Generally speaking, the economic growth refers to the continuous increase of material products and services produced by a country or region. It means the expansion of economic scale and production capacity, which can reflect the growth of a country or region’s economic strength. Economic growth also means the expansion and improvement of many factors that determine productivity. The growth of productivity mainly depends on a country’s natural resource endowment, the accumulation of material capital and the improvement of quality, the accumulation of human capital, the improvement of the institutional environment, and the improvement of technological level. The mode of economic growth can be attributed to two types of expanded reproduction, namely, connotative expanded reproduction and extensional expanded reproduction. The expansion of reproduction is mainly through increasing the input of production factors to achieve the expansion of production scale and economic growth. The expansion of the connotation of reproduction is mainly to use technological progress and scientific management to improve the quality and efficiency of production factors, and to realize the expansion of production scale and the improvement of production level.

Barro (2016) studied China’s economic growth rate from data on economic development in emerging countries. He believes that China is a successful case of integration of middle-income countries, but China cannot always deviate from the

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3 WHO, World Health Statistics - Monitoring Health for the Sustainable Development Goals (SDGs): https://apps.who.int/iris/bitstream/handle/10665/272596/9789241565585-eng.pdf
global historical experience. The per capita growth rate is likely to drop from about 8% to 3%-4% yearly. Saccone (2017) studied the main determinants of rapid economic growth in 38 emerging economies from 2000 to 2014. He found that the increase in investment growth rate and the increase in human capital are closely related to the decline in the age dependency ratio. Twinoburyo et al. (2018) believe that although monetary policy and economic growth are generally ambiguous, monetary policy is important for both short- and long-term growth. In this paper, we focus on the relationship between carbon dioxide emissions, health expenditures and economic growth in the BRICS countries.

2.1 CO2 Emissions and Economic Growth
Since the economic growth model of developing countries consumes a lot of energy, promoting economic growth will also bring about changes in CO2 emissions. Therefore, most scholars study the relationship between carbon dioxide emissions and economic growth in developing countries. Different scholars use different econometric models to study the relationship between energy consumption, carbon dioxide emissions, and economic growth and draw two different conclusions.

When the country uses traditional energy, some scholars have found that economic growth will increase CO2 emissions. Adebayo and Akinsola (2021) analyzed the time-series data from 1971 to 2018 and used the wavelet coherence method to study the relationship between energy consumption, carbon dioxide and economic growth in Thailand. The results showed that changes in economic growth led to changes in the frequency of carbon dioxide emissions. In addition, both short-term and long-term CO2 emissions are positively correlated with GDP growth. Kong (2021) used the asymmetric autoregressive distribution lag (ARDL) model and data from 1985 to 2019 to analyze the impact of China’s financial development, energy consumption, foreign direct investment, and economic growth on carbon dioxide emissions. The results show that actual GDP has a significant positive impact on CO2 emissions. Kongkuah et al. (2021) used Paris-Winsten regression to estimate a panel-corrected standard error model and studied the relationship between energy consumption, carbon dioxide emissions, and economic growth in the OECD and “Belt and Road” initiative countries. The study found that the Organization for Economic Cooperation while the economic growth rate is higher than that of the “Belt and Road” countries, CO2 emissions are also higher. Huong et al. (2021) used the Kaya identity and decomposition method to analyze the relationship between various factors that produced CO2 and economic growth in Vietnam from 1990 to 2016, and found that the increase in Vietnam’s industrialization level promoted economic growth at the cost of consuming a large amount of fossil fuels. Will lead to an increase in CO2 emissions. Öztürk and Suluk (2020) used the Generalized Moment Method (GMM) and panel data of G7 countries from 1991 to 2014 to study the relationship between CO2 emissions, energy consumption and economic growth, and found that there is an inverse relationship between CO2 emissions and economic growth causal relationship.

Chen and Lee (2020) found that when the country uses technological innovation and uses clean energy, economic growth will also reduce CO2 emissions. Yang et al.
(2021) using the autoregressive distribution lag (ARDL) method and data from 1995 to 2014, analyzed 24 economies in China’s Silk Road Economic Belt (SREB) and studied capital formation, renewable energy and carbon dioxide emissions, and the economy the relationship between growth. Their research found that the use of clean energy can significantly reduce carbon dioxide emissions and promote economic growth. Mongo et al. (2021) used 15 European countries autoregressive distribution lag model (ARDL) and 23 years of data to analyze the impact of per capita GDP, environmental innovation, renewable energy consumption and economic openness on carbon dioxide emissions, and found environmental innovation It will promote economic growth while reducing carbon dioxide emissions. Zangoei et al. (2021) used the seemingly uncorrelated regression (SUR) of 14 developing countries from 1986 to 2016 to study the relationship between foreign investment, alternative energy consumption, and economic growth. They found that alternative energy promoted the economy. While increasing, it will reduce CO2 emissions.

In the process of urbanization in developing countries, transportation infrastructure will be constructed and population migration will occur. While these behaviors promote economic growth, they will also affect CO2 emissions. Some scholars have carried out research based on this and found that in the process of urbanization, economic growth will increase CO2 emissions. Iheonu et al. (2021) used panel quantile regression analysis to study the impact of Sub-Saharan Africa (SSA) countries, economic growth, international trade and urbanization on CO2 emissions. Their study found that these regions are in the process of urbanization, GDP growth has promoted CO2 emissions. Hossein et al. (2021) studied the relationship between Iran’s taxation, private sector investment and other economic indicators related to economic growth, the process of urbanization, and CO2 emissions, using the Bayesian causal map (BCM) analysis method to analyze the relationship between 1980-2018 analysis of the data of the year found that in the process of urbanization in Iran, different economic indicators have different effects on CO2 emissions, but they will all lead to an increase in CO2 emissions. Adamu et al. (2020) used Dynamic Ordinary Least Squares (DOLS) and ARDL boundary test cointegration methods as robustness tests to analyze the relationship between Nigeria’s CO2 transport and economic growth, urbanization, and rural population from 1971 to 2018. The results of the study show that the process of rural population migration to cities, economic growth has also resulted in a substantial increase in CO2. Munir and Ameer (2021) used the STIRPAT model to analyze the relationship between urbanization, economic growth, technological progress, trade liberalization, and environmental pollution in emerging economies in Asia and Africa from 1975 to 2018. Their research found that economic growth has increased CO2 emissions. Zhang and Zhang (2021) used data from 2000 to 2018 and the panel vector autoregressive model estimated by GMM to analyze the relationship between China's transportation infrastructure, income inequality, carbon dioxide emissions and economic growth. Their study found that different infrastructures promote as the economy grows, it will increase CO2 emissions.

In addition to the causality test, some scholars have also tested the symmetry
relationship between CO2 and economic growth and have reached different conclusions. Ghazouani (2021) used NARDL and ARDL bounds test and time-series data from 1972 to 2016 to study the impact of Tunisian crude oil prices, FDI inflows, and economic growth on CO2 emissions. Their study found that there is a two-way symmetric relationship between economic growth and carbon dioxide emissions. Namahoro et al. (2021) used panel data from 1980 to 2016, using nonlinear autoregressive distribution lag (NARDL) and causality tests to study the population growth of seven East African countries (EAC) at the regional and national levels the relationship between economic growth, carbon dioxide, and energy consumption. Their research found that there is an asymmetric relationship between economic growth and carbon dioxide emissions in different countries. Xiangyu et al. (2021) used the quantile autoregressive lagged (QARDL) approach to study the non-linear effects of US energy consumption, economic growth, and the number of tourists on CO2 emissions. The results show that there is an asymmetry between short-term economic growth and CO2. Cheikh et al. (2021) implemented a regime-switching model, that is, under the framework of nonlinear panel smooth transition regression (PSTR), they studied the relationship between energy consumption and economic growth in the Middle East and North African (MENA), and found that economic growth has significant effects asymmetry impact on CO2 emissions.

2.2 CO2 Emissions and Health Expenditure

The amount of CO2 emissions will affect the health of residents, which will change health expenditures. Some scholars have conducted research on this. Although they have used different methods, most of them have come to a similar conclusion that the increase in CO2 emissions will increase medical expenditures. Samah et al. (2020) used the dynamic panel data system GMM estimation model to study the relationship between health expenditures and CO2 emissions in Malaysia under the impact of COVID-19. Studies have found that the increase in health expenditures will increase CO2 emissions. Gündüz (2020) used the hidden cointegration approach to analyze the impact of the US carbon footprint on health expenditures. The study used time-series data from 1970 to 2016. The results showed that the long-term carbon footprint and health expenditures have a cointegration relationship. Moreover, an increase in the carbon footprint will increase the health expenditure budget. Oyelade et al. (2020) used Panel Quantile Regression to study the impact of CO2 emissions and public health expenditures in Anglophone Countries in West Africa from 1990 to 2013, and found that the increase in CO2 will increase public health expenditures. Taghizadeh-Hesary and Taghizadeh-Hesary (2020) used Panel Vector Error Correction Model (VECM) and Panel Generalized Moment Method (GMM) to analyze the data of ten Southeast Asian countries from 2000 to 2016, and studied the relationship between energy use and health expenditure. The study found that the increase in CO2 emissions brought about by the use of fossil fuels will cause an increase in per capita health expenditure, while the use of renewable energy will reduce per capita health expenditure. Akbar et al. (2020) used a panel VAR model to analyze the relationship between health expenditure, carbon dioxide emissions and the human development index (HDI) in 33 OECD countries from 2006 to 2016, and
found that there is a two-way causal relationship between health expenditure and carbon emissions, which shows that carbon dioxide emissions significantly increase health expenditures. Apergis et al. (2020) studied the long-term dynamic relationship between environmental pollution and health care expenditures in four global income groups. They used data from 178 countries from 1995 to 2017. The study found that for every 1% increase in CO2 emissions, health expenditures would increase by 2.5%.

However, some scholars have reached different conclusions. Eckelman et al. (2020) studied the relationship between greenhouse gas emissions from energy consumption in various states in the United States and public health expenditures. The study found that there is no obvious relationship between CO2 emissions and public expenditures. Erdogan (2020) used a panel causality test to analyze the relationship between CO2 emissions and medical expenses in the Brazil, Russia, India, China, South Africa, and Turkey (BRICS) countries from 2000 to 2016. The results show that only China there is a one-way positive causal relationship between health expenditures and CO2 emissions. In other selected countries, this relationship has not yet been discovered.

### 2.3 Health expenditure and economic growth

Some scholars have found that there is a direct effect between economic growth and health expenditure. Scholars have used different measurement methods to analyze different countries or regions and have reached a similar conclusion, that is, there is a positive correlation between economic growth and health expenditure. Modibbo and Saidu (2020) used data from 2000 to 2017 and the generalized method of moments to study the impact of health expenditure on economic growth in 45 African countries. The study shows that average health expenditure has a positive and significant impact on economic growth in Africa. Rizvi (2019) used the sample data from 20 developing countries in South Asia, East Asia and the Pacific region from 1995 to 2017, established the production function based on the standard neoclassical “slow growth model” in steady state, and studied the relationship between institutional quality, health expenditure and economic growth. The research found that if the health care expenditure adjusted by the quality of government expenditure increases by 100%, the economic growth rate will increase by 5%. Ibukun and Osinubi (2020) used static (aggregating OLS and fixed/random effects) and dynamic (GMM) estimation methods to study the relationship between health expenditure, environmental quality and economic growth in 47 African countries. The study found that economic growth has an effect on health expenditure has a positive and significant impact. Gok et al. (2018) studied the relationship between health expenditure efficiency and economic growth in the emerging economies of the Brazil, China, India, Russia and South Africa (BRICS) and Mexico, Indonesia, South Korea and Turkey (MIST) countries from 2008 to 2012 the study found that economic growth can significantly improve the efficiency of health expenditures. Atems (2019) used a dynamic panel data model to study the relationship between public health expenditure and economic growth in various states in the United States from 1963 to 2015. The study found that there was a positive correlation between public health expenditure and growth.

Other scholars have found that there is not only an indirect effect, but also an
indirect effect or structural effect between health expenditure and economic growth. Yang (2019) used a panel threshold model and panel data from 21 developing countries from 2000 to 2016 to analyze the relationship between economic growth and national health expenditure under different levels of human capital. The results showed that the relationship between economic growth and health expenditure related to human capital. Specifically, when the level of human capital is low, economic growth and medical expenditure are significantly negatively correlated. When human capital is at a medium level, the impact of health expenditure on economic growth is positive, but not significant. When the level of human capital is high, the positive impact of health expenditure on the economy will be greatly enhanced. Somé et al. (2019) used 2000-2015 data from 48 African countries in the panel data regression framework to conduct an empirical study on the relationship between economic growth, the medical industry and health expenditures in Africa. Their study found that health expenditure has a direct and indirect significant impact on economic growth, but overall health expenditures always promote economic growth.

There is little research literature on the relationship between CO2 emissions, health expenditure, and economic growth. Wang et al. (2019) used data from 1995 to 2017, and the autoregressive distributed lag (ARDL) model to study the dynamic relationship between Pakistan’s carbon dioxide emissions, health expenditure and economic growth under the condition of gross fixed capital formation and per capita trade. The results show that there is a long-term causal relationship between health expenditure, carbon dioxide emissions and economic growth in Pakistan. There are two-way Granger causality between health expenditure and carbon dioxide emissions, health expenditure and economic growth. There is a short-term one-way causal relationship between carbon dioxide emissions and health-related expenditure. Wang et al. (2019) used annual time series data from 1975 to 2017 and applied the autoregressive distributed lag (ARDL) cointegration model to study the medical expenditure and CO2 emissions of 18 Organization for Economic Cooperation and Development (OECD) countries Whether there is a long-term relationship between quantity and per capita income per capita GDP. Their research found that when real per capita GDP is used as the dependent variable, the Netherlands has a cointegration relationship; when health expenditure is the dependent variable, New Zealand has a cointegration relationship; when carbon dioxide emissions are the dependent variable, the United States has a cointegration relationship. The main results indicate that there is a short-term relationship between these three variables. Specifically, there is a two-way causal relationship between GDP growth and medical expenditures in the United States and Germany. There is a causal relationship between GDP growth and CO2 emissions in Canada, Germany and the United States, and there is a causal relationship between carbon dioxide emissions and health expenditures in Norway and New Zealand causal relationship. Wang et al. (2020) used the Bootstrap ARDL to test the relationship between China’s health expenditure and carbon dioxide emissions in the context of economic growth. The results show that long-term carbon dioxide emissions and health expenditures have a very significant impact on China’s economic development. In addition, they also found that there is a two-way causal
relationship between China’s CO2 emissions and health expenditure, and there is a
two-way causal relationship between economic growth and health expenditure.
Atuahene et al. (2020) used a dynamic group to study the relationship between China
and India’s carbon dioxide emissions, economic growth, and health spending. The
study uses data from 1960 to 2019, and uses the generalized method of moments
(GMM) data model for estimation. Their research found that there is a significant
relationship between the three. During the study period, carbon dioxide emissions had
a significant positive impact on health expenditures in both countries, while economic
growth had a negative impact on health expenditures.

3. Empirical data and methods

3.1 Data

We discussed the health expenditure, CO2 emissions and economic growth of the
BRICS in this paper. The data of health expenditure and economic growth came from
the World Bank database; the data of CO2 emission came from public data provided
by British Petroleum (BP). However, because the time-series data of health
expenditure is very short, from 2000 to 2019, our other variables of CO2 emissions
and economic growth data have to be adjusted accordingly. We use the Fourier ARDL
method and similar Monte Carlo simulation methods to bootstrap variables 5,000
times, so even a short database like variable of health expenditure can be showed
significant results in time-series.

3.2 Model method

According to the papers of gallant (1981) and gallant and Souza (1991), they
pointed out that a small number of low frequency components of Fourier
approximation can capture an unknown number of progressive and sharp structural
brake. Yilanci et al. (2020) used Bootstrap with sharp brakes (using the Dummy
variable). ARDL is modified to Bootstrap ARDL with smooth break (using Fourier
function). Pesaran et al. (2001) and the subsequent ARDL model, we can write the
following ARDL bound test model:

\[
\Delta Y_t = c + \alpha Y_{t-1} + \beta X_{t-1} + \sum_{i=1}^{p-1} \theta \Delta Y_{t-i} + \sum_{i=1}^{p-1} \delta X_{t-i} + \sum_{j=1}^{q} \eta D_{t,j} + \epsilon_t
\]

(1)

The above equation does not require feedback from Y to X. This means that we
cannot allow two or more variables (weak) to be endogenous, and the researchers
ignored this assumption in the empirical significance of Pesaran et al. (2001) ARDL
bounds test. This does not exclude the cointegration relationship between regressions,
nor does it assume that there is no (short-term) Granger causality between the
dependent variable and the regression. It assumes that the regression variable is
weakly exogenous. In the long-term, these regression variables are not affected by the
dependent variable, but this does not exclude the cointegration relationship between
the regressions, nor does it assume that there is no (short-term) Granger causality
between the regression and the dependent variable. The researchers ignored this
assumption in the empirical implications of the ARDL Bounds test.

According to the research of Pesaran et al. (2001), for the following hypotheses,
the cointegration test requires F-test or t-test:
McNown et al. (2018) suggested supplementing the existing $F$-test and $t$-test for cointegration proposed by Pesaran et al. (2001) by adding an additional $F_2$ test. McNown (2018) et al. improved the ARDL Bounds test of Pesaran et al. (2001) and used the Bootstrap ARDL method test to distinguish all three defined cointegration, non-cointegration, and degeneration cases. They set the degeneration cases as follows:

1. When the test result is significant in the $F$-test and $t$-test of the lagged independent variable, and the $t^2$ test of the lagged dependent variable is not significant, it is degeneration situation #1.

2. When the test result is significant in the $F$ test and $t$ test of the lagged dependent variable, but the lagged independent variable is not significant, it is degeneration case #2.

Pesaran et al. (2001) proposed a critical value for degeneration case #2, but there is no critical value for degeneration case #1. To exclude degeneration case #1, the order of integration of the dependent variable must be $I(1)$ but Perron (1989) thought the unit root test is un-reliable for its low degree of inspection.

The advantage of the Bootstrap ARDL test is that the endogenous problem has no effect on the size and power characteristics of the ARDL Bounds test frame. Using the asymptotic threshold of Monte Carlo simulation can help solve this problem. Another feature is that it can solve the sample on the time-series. The problem of insufficient health expenditures (2000-2018) can be obtained, and the Bootstrap ARDL test can solve this kind of problem efficiently. McNown et al. (2018) also proposed an extension of the ARDL test framework for alternative degeneration scenarios, with a threshold generated by the Bootstrap ARDL test.

Therefore, the recommended Bootstrap ARDL test can better understand the cointegration status of the time-series in the model. Yilanci et al. (2020) followed Becker et al. (2006) and Ludlow and Enders (2000) and allowed the use of single frequency. For example, we want to use GDP as a control variable to test whether CO2 affects health expenditures, and then the model can be expressed as:

$$HE_t = \alpha_0 + \alpha_1 GDP_t + \alpha_2 CO2_t + \varepsilon_t$$  \hspace{1cm} (2)

$HE$ is health expenditure, $GDP$ is gross domestic production, $CO2$ is carbon dioxide emissions, and equation (2) is extended to the 3-variable ARDL situation. The transform model is following as:

$$\Delta HE_t = \beta_0 + \beta_1 HE_{t-1} + \beta_2 GDP_{t-1} + \beta_3 CO2_{t-1} + \sum_{i=1}^{p-1} \phi_i' \Delta HE_{t-i} + e_t$$  \hspace{1cm} (3)

$$\sum_{i=1}^{p-1} \delta_i' \Delta GDP_{t-i} + \sum_{i=1}^{p-1} \phi_i' \Delta CO2_{t-i} + e_t$$

The above model, Equation (3), can also incorporate dummy variables to capture structural break $D_t$. We can think of this model as a Bootstrap ARDL with obvious structural breaks. Since Gallant (1981) and Gallant and Souza (1991) showed that a
small amount of low-frequency components of the Fourier approximation can capture
an unknown number of progressive and sharp breaks, we use the following Fourier
function to replace the dummy method variables:

\[ d(t) = \sum_{k=1}^{n} \alpha_k \sin \left( \frac{2\pi k t}{T_n} \right) + \sum_{k=1}^{n} \beta_k \cos \left( \frac{2\pi k t}{T_n} \right) \]  

(7)

\[ d(t) = \gamma_1 \sin \left( \frac{2\pi k t}{T_0} \right) + \gamma_2 \cos \left( \frac{2\pi k t}{T_0} \right) \]  

(8)

The Fourier ARDL model is estimated as follows:

\[ \Delta HE_t = \beta_0 + \gamma_1 \sin \left( \frac{2\pi k t}{T} \right) + \gamma_2 \cos \left( \frac{2\pi k t}{T} \right) + \beta_3 HE_{t-1} + \beta_4 GDP_{t-1} + \beta_4 CO2_{t-1} + \sum_{i=1}^{p-1} \alpha'_i \Delta HE_{t-i} + \sum_{i=1}^{p-1} \delta'_i \Delta GDP_{t-i} + \sum_{i=1}^{p-1} \theta'_i \Delta CO2_{t-i} + \epsilon_t \]  

(9)

Following the research of Christopoulos & Leon-Ledesma (2011) and Omay (2015), we use all values of \( k \) in the interval of \( k = [0.1, ..., 5] \) to estimate equation (9), which The increment is 0.1 and the \( k \) that produces the smallest residual sum of squares is selected. Christopoulos and Leon Ledesma (2011) proposed that fractional frequencies represent permanent breakpoints, while integer frequencies represent temporary breakpoints. Therefore, we use Bootstrap ARDL to estimate the critical values of \( F1^*, F2^* \) and \( t^* \) and Fourier frequency (smooth) to transfer the breakpoints. A detailed description of the Bootstrap ARDL can be found in the paper by McNown et al. (2018).

4. Empirical results and conclusions

4.1 Empirical results

Table 1 is a descriptive statistical analysis of the three variables of health expenditures, CO2 emissions and economic growth in the BRICS countries after logarithm. The analysis results show that the data distribution is relatively stationary and there are fewer outliers, which meets the requirements of empirical analysis. Table 2 shows the results of the unit root test for the stationary of the three variable time-series data. The unit root test is divided into the level item \( I(0) \) test and the first-order difference item \( I(1) \) test. The three variables only satisfy \( I(0) \) or \( I(1) \) test can use the Fourier Bootstrap ARDL for cointegration test. The test results show that the three variables of the five countries meet the standard, so the time-series data is stationary. In addition, after the unit root test is completed, the Akaike Information Criteria (AIC) needs to be determined. In this paper, we use the AIC criteria to select and judge the smallest AIC as the best lag period. It is generally believed that while the BRICS countries consume a large amount of high-polluting energy to promote economic growth, it will affect the health of residents and thus affect health expenditure. Therefore, CO2 emissions and health expenditure should have a long-term cointegration relationship. However, the test results in Table 3 show that there is no long-term cointegration relationship between health expenditures and CO2 emissions in BRICS countries. The short-term causality test in Table 4 shows that the CO2 emissions of Brazil, China, and India are causally related to health expenditures after a period of lag. Specifically, Brazil’s CO2 emissions have a negative causality
relationship with health expenditures, while China’s health expenditures also have a negative causality relationship with CO2 emissions. Only India’s CO2 emissions and health expenditures have a two-way negative causality relationship (see Figure 3).

Table 5 examines the long-term cointegration relationship between health expenditures, CO2 emissions and economic growth in the BRICS countries. The test results show that only China and India, when CO2 emissions are used as the dependent variable, health expenditures and economic growth are regarded as independent variables. Both Brazil and China have integration smooth frequency of 0.4 ($k = 0.4$). This is the Fourier ARDL test power improved the McNown et al. (2018) Bootstrap ARDL test of sharp breaks. In terms of variables, only the three have a cointegration relationship, which can well explain the economic development model of China and India in adopting high-polluting energy sources in recent years. On this basis, Table 6 further examines the cointegration relationship between China and India when the independent variables lag by one period. The results show that China and India have a cointegration relationship with CO2 emissions when their health expenditures and CO2 emissions lag behind by one period. Table 7 conducts a lag period test and a short-term causality test between the health expenditures, CO2 emissions and economic growth of the BRICS countries. The lag period test shows that under the conditions of one lag period, Brazil’s economic growth and CO2 emissions have a cointegration relationship; India’s health expenditure and economic growth have a cointegration relationship with CO2 emissions; South Africa’s economic growth has a cointegration relationship with CO2 emissions. The results of short-term causality show that Brazil’s economic growth has a positive causality relationship with CO2 emissions and health expenditures, and CO2 emissions have a reverse causality relationship with health expenditures; India’s economic growth has a positive causality relationship with CO2 emissions, and CO2 emissions have a positive impact on health. Expenditure has a reverse causality; South Africa’s economic growth has a positive causality on expenditure, and there is no obvious causality in other countries (see Figure 4).

4.2 Conclusion

In this paper, we used the Fourier Bootstrap ARDL model to study the cointegration relationship and short-term causality between health expenditures, CO2 emissions, and economic growth in the BRICS countries. The research results show that, in the long-term, Brazil and China have a cointegration relationship between CO2 emissions as the dependent variable and health expenditure and economic growth as the independent variables. When economic growth has lagged for one period of time, there is also a cointegration relationship between economic growth and CO2 emissions in Brazil and South Africa. In the short-term, the economic growth of Brazil and India has promoted the increase of CO2 emissions, and CO2 emissions have reduced health expenditures; the economic growth of Brazil and South Africa have promoted the growth of health expenditures.

4.3 Policy recommendations

(1) The BRICS countries need to change their economic development models and use low-polluting alternative energy sources
Because China, India, South Africa, Brazil and other countries have a long-term cointegration relationship between economic growth and CO2 emissions, that is, economic growth and changes in CO2 emissions are consistent, and economic growth in the short-term has led to an increase in CO2 emissions. Therefore, in order to avoid environmental pollution and achieve sustainable economic development, the government should look for cleaner energy sources to promote economic growth.

(2) Brazil and India should pay attention to the indirect effects of economic growth and coordinate economic growth policies and health expenditure policies. Because the economic growth of Brazil and India directly promotes the increase of health expenditures on the one hand, economic growth has increased CO2 emission and the increase of CO2 emissions has reduced health expenditures. This may lead to insufficient government investment in the health industry and affect people’s health. Therefore, relevant government departments must consider the indirect effects of economic growth and maintain the coordination of economic growth policies and health expenditure policies.

(3) South Africa should pay more attention to the sustainability of the impact of economic growth policies on health expenditures. Although in the short-term, South Africa’s economic growth has a positive effect on health expenditures, in the long-term, there is no significant cointegration relationship either in the current period or in the lag period. This means that the impact of economic growth on health expenditures is not sustainable enough, which this may make the government need to invest frequently in health expenditures, thereby reducing the efficiency of resource allocation, so the South African government should pay more attention to the sustainability of health expenditures by economic growth policies.

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Table 1 Description of statistics

| Economies | Variables | E | India | | South Africa |
|-----------|-----------|---|-------|---|----------------|
|           | CO2       | 717 | 3.8274 | 2.1462 |
|           | Health    |     | 3.5923 | 2.6109 |
|           | GDP       |     | 3.8274 | 2.1462 |
| Mean      |           |     | 2.6109 | 2.5757 |
| Maxi      |           |     | 2.6521 | 2.7762 |
| Mini      |           |     | 2.9819 | 2.2279 |
| Sd.Dev    |           |     | 0.3452 | 0.1401 |
| Skew      |           |     | -0.2035 | -0.7664 |
| Kurt      |           |     | -0.9490 | -1.0043 |

Notes: ***, ** and * indicate the null hypothesis is rejected at the 1%, 5% and 10% levels.

Table 2 Unit root tests

| Country  | Dependent variable | Level ADF | Level PP | Level KPSS | First Difference ADF | First Difference PP | First Difference KPSS |
|----------|--------------------|-----------|----------|------------|-----------------------|---------------------|------------------------|
| Brazil   | CO2                | -0.8169   | -0.8169  | 0.5170**   | -3.6976**             | -3.6982             | 0.1229                 |
|          | Health             | -4.7396***| -0.8245  | 0.4747**   | -2.2098              | -2.5433             | 0.1622                 |
|          | GDP                | -3.7380** | -0.9982  | 0.4500*    | -2.6009              | -2.5650             | 0.1689                 |
|          | CO2                | -3.9374***| -3.3594**| 0.5165**   | -1.1463              | -1.3744             | 0.4743**               |
| China    | Health             | -1.2941   | -0.4197  | 0.5508**   | -2.3987              | -2.4306             | 0.1698                 |
|          | GDP                | -1.5235   | -1.1595  | 0.5481**   | -1.8313              | -1.8397             | 0.2554                 |
|          | CO2                | -3.9374***| -3.3594**| 0.5165**   | -1.1463              | -1.3744             | 0.4743**               |
| India    | Health             | -1.2941   | -0.4197  | 0.5508**   | -2.3987              | -2.4306             | 0.1698                 |
|          | GDP                | -1.5235   | -1.1595  | 0.5481**   | -1.8313              | -1.8397             | 0.2554                 |
|          | CO2                | -1.9808   | -2.2580  | 0.4260*    | -3.5901**            | -3.5685**           | 0.3577*                |
| South Africa | Health   | -1.2802   | -1.2590  | 0.4655**   | -2.9929*             | -2.9632*            | 0.1411                 |
|          | GDP                | -1.5844   | -1.5841  | 0.4012*    | -2.7001*             | -2.7507*            | 0.2583                 |

Table 3 Cointegration Analysis (2 Variables)

| Country  | Dependent variable | Independent variable | frequency | AIC | g | F | F^* | t^* | t | t^* | t^* | Result |
|----------|--------------------|----------------------|-----------|-----|---|---|-----|-----|---|-----|-----|--------|
| Brazil   | CO2 | Health | 1.5 | -6.31 | 19.62*** | 12.78 | 7.099 | -4.635 | -3.163 | 4.607 | 2.995 | No Cointegration |
|          | Health | CO2 | 1.4 | 3.96 | 4.352** | 3.393 | 0.733 | -2.024 | -0.190 | 1.101 | -0.261 | No Cointegration |
|          | Health | CO2 | 2.5 | 6.10 | 0.465 | 3.115 | 1.567 | -1.866 | -0.484 | 1.098 | 0.484 | No Cointegration |
| China    | CO2 | Health | 0.5 | 5.16 | 33.33*** | 4.541 | 1.235 | -2.348 | -1.300 | 0.783 | 1.119 | No Cointegration |
|          | Health | CO2 | 2.5 | 6.10 | 1.183 | 3.167 | 1.567 | -1.915 | -0.484 | 1.030 | 0.484 | No Cointegration |
|          | Health | CO2 | 2.5 | 6.10 | 5.893** | 3.002 | 1.567 | -1.614 | -0.484 | 1.095 | 0.484 | No Cointegration |
| India    | CO2 | Health | 3.4 | 1.59 | 0.087 | 5.286 | 2.752 | -2.850 | -0.650 | 2.385 | 0.038 | No Cointegration |
|          | Health | CO2 | 2.6 | 3.59 | 1.7791 | 7.063 | 6.547 | -3.238 | -3.263 | 2.072 | 2.682 | No Cointegration |
| South Africa | CO2 | Health | 3.4 | 1.59 | 0.087 | 5.286 | 2.752 | -2.850 | -0.650 | 2.385 | 0.038 | No Cointegration |

Notes: ***, ** and * indicate the null hypothesis is rejected at the 1%, 5% and 10% levels.
Table 4: Granger-Causality Analysis based on Fourier ARDL Model

| Country   | \(\Delta CO_2\) equation | \(\Delta Health\) equation |
|-----------|---------------------------|-----------------------------|
| Brazil    | \(\Delta CO_2, CO_2_{t-1}\) n.a. | 4.173*** (0.002) (-) |
|           | \(\Delta Health, Health_{t-1}\) 0.175 (0.864)(-) | n.a. |
| China     | \(\Delta CO_2, CO_2_{t-1}\) n.a. | 0.885(0.398)(+) |
|           | \(\Delta Health, Health_{t-1}\) 16.890 *(0.000)(-) | n.a. |
| India     | \(\Delta CO_2, CO_2_{t-1}\) n.a. | 5.765***(0.000)(-) |
|           | \(\Delta Health, Health_{t-1}\) 8.873*** (0.000)(-) | n.a. |
| South Africa | \(\Delta Health, Health_{t-1}\) 1.2405(0.201)(+) | n.a. |

Note: Values in bold refer to the case of cointegration and the causality test involved both lagged level and lagged differenced variables. Those values not in bold refer to the case of no-cointegration where the causality test involved only lagged differences.

Table 5: Cointegration Analysis (3 Variables)

| Country   | Health \(\rightarrow\) \(CO_2\) | \(CO_2\) \(\rightarrow\) Health |
|-----------|-------------------------------|-------------------------------|
| Brazil    | x                             | v(−)                          |
| China     | v(−)                          | x                             |
| India     | v(−)                          | v(−)                          |
| South Africa | x                             | x                             |

Figure 3: Granger-Causality Analysis based on Fourier ARDL Model (2 Variables)
### Table 6
The results of long-term estimation analysis based on Fourier ARDL Model

| Country    | Independent variable   | frequency | AIC  | $\gamma$ | $F^*$ | $F$  | $t^{	ext{dep}}$ | $t^{	ext{indep}}$ | $t^{	ext{wave}}$ | $t^{	ext{cycle}}$ | Result           |
|------------|------------------------|-----------|------|----------|-------|------|----------------|----------------|----------------|----------------|-----------------|
| Brazil     | $\text{CO}_2$ | Health, GDP | 1.5  | -6.20    | 7.81** | 6.568 | 2.360 | -3.384 | -2.451 | 7.277 | 3.862 | No Cointegration |
|            | Health | $\text{CO}_2$ GDP | 1.9  | -6.58    | 96.*** | 5.444 | 0.389 | -1.633 | -0.014 | 5.236 | 0.563 | No Cointegration |
| China      | Health | $\text{CO}_2$ GDP | 0.4  | -7.06    | 13.*** | 6.488 | 9.122 | -3.521 | -4.997 | 7.639 | 9.250 | **Cointegration** |
|            | Health | $\text{CO}_2$ GDP | 0.5  | -6.09    | 9.7*** | 7.635 | 6.583 | -4.074 | -4.149 | 9.883 | 7.467 | No Cointegration |
| India      | Health | $\text{CO}_2$ GDP | 0.4  | -7.06    | 0.1872 | 7.183 | 9.122 | -3.467 | -4.997 | 8.383 | 9.250 | **Cointegration** |
| South Africa | Health | $\text{CO}_2$ GDP | 2.8  | -6.34    | 1.632  | 6.057 | 1.688 | -3.267 | -1.994 | 7.701 | 2.531 | No Cointegration |
|            | Health | $\text{CO}_2$ GDP | 1    | -6.54    | 3.844*  | 12.03 | 4.943 | -4.709 | -0.349 | 14.791 | 4.703 | No Cointegration |

Notes: ***, ** and * indicate the null hypothesis is rejected at the 1%, 5% and 10% levels.

### Table 7
Granger-Causality Analysis based on Fourier ARDL Model (3 Variables)

| Country    | $\Delta \text{CO}_2$ equation | $\Delta \text{Health}$ equation |
|------------|--------------------------------|---------------------------------|
| Brazil     | $\Delta \text{CO}_2$ | $\text{CO}_{2t-1}$ | n.a. | n.a. | 44.779** | (0.00) | (-) |
|            | $\Delta \text{Health}$ | $\text{Health}_{t-1}$ | 1.728 (0.309) | (-) | n.a. | 22.6184** | (0.000) | (+) |
| China      | $\Delta \text{CO}_2$ | $\text{CO}_{2t-1}$ | 2.613** | (0.102) | (+) | 0.501 | (0.600) | (+) |
|            | $\Delta \text{Health}$ | $\text{Health}_{t-1}$ | 0.493 | (0.432) | (-) | n.a. | 0.908 | (0.309) | (-) |
| India      | $\Delta \text{CO}_2$ | $\text{CO}_{2t-1}$ | 1.133 | (0.932) | (+) | n.a. | 0.557 | (0.203) | (+) |
| South Africa | $\Delta \text{Health}$ | $\text{Health}_{t-1}$ | 3.650*** | (0.008) | (+) | n.a. | 0.898 | (0.507) | (-) |
|            | $\Delta \text{CO}_2$ | $\text{CO}_{2t-1}$ | 3.069** | (0.012) | (-) | n.a. | -0.036 | (0.965) | (-) |
|            | $\Delta \text{Health}$ | $\text{Health}_{t-1}$ | 0.076 | (0.932) | (+) | n.a. | 1.997 | (0.088) | (+) |

Note: Values in bold refer to the case of cointegration and the causality test involved both lagged level and lagged differenced variables. Those values not in bold refer to the case of no-cointegration where the causality test involved only lagged level.
| Country  | Health → CO₂ | GDP → CO₂ | CO₂ → Health | GDP → Health |
|----------|--------------|-----------|--------------|-------------|
| Brazil   | x            | v(+)      | v(−)         | v(+)        |
| China    | x            | x         | x            | x           |
| India    | v(+)         | v(−)      | x            | x           |
| South Africa | x     | x         | x            | v(+)        |

**Figure 4** Granger-Causality Analysis based on Fourier ARDL Model (3 Variables)
Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterialBRICSHealthExpenditure.docx