Environmental Science and Pollution Research (2022) 29:10908–10927
https://doi.org/10.1007/s11356-021-17900-w

REVIEW ARTICLE

The relationship between health expenditure, CO_2 emissions, and economic growth in the BRICS countries—based on the Fourier ARDL model

Fangjhy Li[1] · **Tsangyao Chang**[2] · **Mei-Chih Wang**[3] · **Jun Zhou**[4]

Received: 30 June 2021 / Accepted: 29 November 2021 / Published online: 9 January 2022

Abstract
In this paper, we use (Yilanci et al. 2020) Fourier autoregressive distributed lag (ARDL) model to study the correlation between health expenditures, CO_2 emissions, and GDP fluctuations in BRICS countries from 2000 to 2019. The Fourier ARDL model has the function of bootstrap repeated simulation calculations, so that small samples can also achieve the advantages of finer inspection results. In this paper, we find that in the long term, Brazil and China are countries that both have cointegration relationships in health expenditure, CO_2 emissions, and economic growth. With CO_2 emissions as the dependent variable and health expenditure and economic growth as independent variables, in the short term, there is a negative causal relationship between India's CO_2 emissions and health expenditure; other countries only show the relationship between CO_2 emissions, health expenditure, or economic growth one-way relationship. This paper also has some policy suggestions on health expenditures and CO_2 emissions in the BRICS countries at the end.

Keywords Health expenditures · CO_2 emissions · Economic growth · BRICS countries · Fourier ARDL

JEL Classification C22 · E23 · I18 · O13

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 recession. 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 terms of economic growth potential, the BRICS, as representatives of developing countries, deserve more attention than developed countries. According to estimates from the International Monetary Fund's October 2020 World Economic Outlook Report, from 2021 to 2022, among the BRICS countries, China's economic growth is forecast to be 8.1 and 5.6%, respectively; India will be 11.5% and 6.8%, respectively; Russia will be 3.0% and 3.9%, respectively; South Africa will be 2.8% and 1.4%, respectively; and Brazil will be 3.6% and 2.6%, respectively. In the same period, the forecast growth rates of advanced economies are only 4.3% and 3.1%.[1]

However, restricted by their own endowments, the economic development model of the BRICS countries is characterized by high pollution and high energy consumption,

Responsible Editor: Ilhan Ozturk

✉ Mei-Chih Wang
wangsona@gmail.com

1 Department of Investment, School of Business, Wuchang University of Technology, Wuhan, Hubei, People's Republic of China

2 Department of Finance, College of Finance, Feng Chia University, Taichung, Taiwan, Republic of China

3 Center for Chinese Social and Management Studies, Tunghai University, Taichung, Taiwan, Republic of China

4 Department of Economics, the Center for Economic Research, Shandong University, Jinan, Shandong, People's Republic of China

[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.

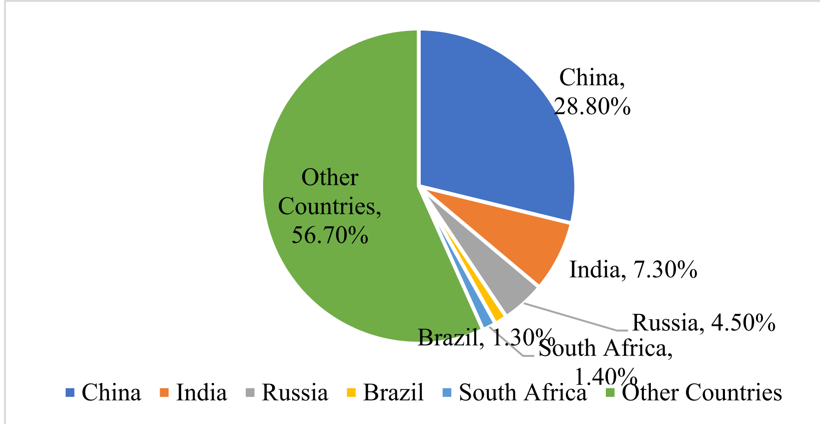

Fig. 1 Distribution of global CO_2 emissions in 2020

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 BRICS countries, China currently has the highest carbon emissions in the world. The total carbon emissions of China in 2020 accounted for 28.8% of the total global emissions; India accounted for 7.3% and is the third highest 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 Fig. 1).[2]

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 the BRICS countries is 71.2 years old (see Fig. 2).[3]

Due to the needs of economic development, the total amount of carbon dioxide emissions is still increasing day by day, posing many threats to the health of the residents of the BRICS countries. Considering the inevitability of the current economic development of the BRICS countries and the necessity of fossil energy demand, the CO_2 emissions of the BRICS countries may remain high, which will have a series of negative effects on the environment and climate. At the same time, it will also have a considerable impact on medical and health expenditure.

However, from some existing research results, due to a series of complex factors such as economic development level, population aging, medical and health supply resources, and years of education, it is still controversial whether CO_2 emissions will promote population aging and the impact of medical expenditure. The greenhouse effect caused by CO_2 emissions and other greenhouse gases will also cause certain changes in the climate, which in turn will have a negative impact on human health. Compared with the 1880s, the Earth's surface temperature has risen by an average of 1.5 °C.[4] Scientists believe that the rise in the surface temperature is of earth due to the increase of CO_2 and endothermic

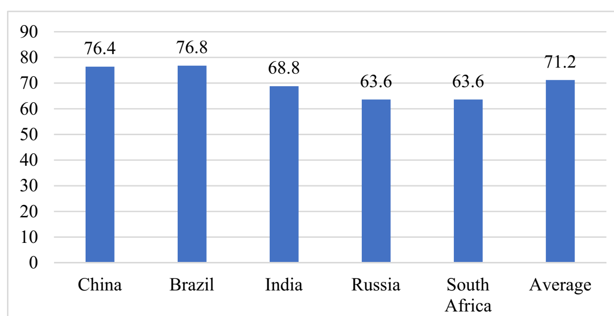

Fig. 2 The average life expectancy of the BRICS countries in 2018

[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.

[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.

[4] The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. See: Reports, Global Warming of 1.5 °C, October, 2018. https://www.ipcc.ch/sr15/

gases such as methane, nitrous oxide and fluorinated gases. Scientists generally believe that if certain measures are not taken to control the emission of endothermic gases such as CO_2, the content of CO_2 in the air will reach 0.1% by the beginning of the twenty-second century, twice as much as before the industrial revolution. Therefore, corresponding measures should be taken to control CO_2 emission, reduce its direct and indirect effects, and avoid certain damage to human health (such as household air pollution causes non-communicable diseases including stroke, ischemic heart disease, chronic obstructive pulmonary disease, and lung cancer[5]).

Based on previous studies, this paper uses the Fourier autoregressive distributed lag (ARDL) model to explore the relationship between CO_2 emissions, health expenditures and economic growth in the BRICS countries. The Fourier 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. Fourier ARDL model (Yilanci et al., 2020) in addition to retaining the advantages of McNown et al. (2018) bootstrap ARDL model with small sample verification, it can be more subtle with number of decimal (smooth break) representation instead of integer number (sharp break).

The topic of this paper is relatively novel. There are many academic literatures in the field of medical and health expenditure, and a lot of analysis on the influencing factors of health (medical and health) expenditure has also been done. However, there are relatively few empirical studies on the impact of CO_2 emissions (air pollution) on healthcare expenditures, especially for the BRICS countries. This paper mainly uses the health expenditure data from 2000 to 2018 in the World Bank database. The Fourier ARDL model, because its Fourier bootstrap ARDL model is suitable for small samples, can solve the problem of insufficient validity of the test results, and it is also the main contribution to the empirical results in the model method used in this paper. The shortcoming of this paper is that only health expenditure is used as an indicator of medical and healthcare. In future study, other indicators related to health and medical care should be added as variables and in this way can the empirical results of carbon dioxide emissions, health expenditures, and economic growth be explained more reasonably.

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.

The core purpose of the theory of economic growth is to find the most fundamental and important factor that determines economic growth. The earliest economic growth models are well-known economic growth models in development economics proposed by Harrod (1939) and Domar (1947), respectively. Based on Keynesian theory, appeared shortly after the great crisis of 1929–1931, but it was not the "orthodox" theory of economic growth theory, because the model concluded that "economic growth is unstable." The economic growth theory of Harrod-Domar model is the long-term and dynamic result of Keynes's short-term static analysis. The model assumes that the whole society produces only one product, which can be used for both consumption and production; there are only two factors of production: labor and capital, the ratio of the two is fixed; the return to scale is unchanged, that is, the unit product cost does not change with changes in production scale; there is no technological advancement. Harrod-Domar model economic growth theory attributes the fundamental factor that determines economic growth to savings, because if a country's economic growth mainly depends on capital accumulation, then capital accumulation will experience diminishing returns, and eventually growth will stagnate and capital accumulation will exist. At an optimal level, if a society's savings rate is too high, it will lead to the phenomenon of "economic dynamic failure" and reduce people's long-term happiness. Hahn and

[5] World Health Organization (WHO), Newsroom, Household air pollution and health, 2021, Sep. 22. See: https:// www.who.int/news-room/fact-sheets/detail/household-air-pollution- and-health.

Matthews (1964) used Harrod's (1939) economic growth theory model as a starting point to investigate the literature that contributed to economic growth theory in the 25 years from 1939 to 1963. After extensive research on economic growth theoretical models, they believe that the motivation of economic growth subjects needs to be analyzed in a substantive and deterministic way; at the same time, they consider the concept of the entire world as an underdeveloped economy, even in advanced sectors. The evolution of the country may not be properly understood separately from the underdeveloped sector.

Among the economic growth models, the Solow-Swan (1956) model can be said to be the basis of the modern economic growth theoretical model, and it has built the research framework of the modern growth theory. Economic growth theory is to study the long-term development behavior of economic growth. Another concept of long-term economic development is stability. Solow (1956) believed that if there are some phenomena in economic growth, such as (1) per capita real output grows at a consistent rate; (2) real capital stock grows at a roughly constant rate, and at this rate exceed the growth rate of labor input; (3) the growth rate of actual output and the growth rate of capital stock are roughly the same; (4) the effective demand changes sharply, occasionally causing strong changes, and the profit rate of capital shows level trends and other phenomena indicate that the economy is roughly on the path of economic growth. Solow (1970) also believed that the modern economic growth theory was used to analyze the characteristics of a stable state and was used to investigate whether an economy that was not initially in a stable state could enter a stable state under a specific law of motion. The Ramsey-Cass-Koopmans model integrated the optimal choices of consumers into the model to achieve the endogenous savings rate and the endogenous growth model with externalities or human capital, through the comparison of the Solow-Swan model. The basic elements can be reinterpreted to extend the Solow-Swan model; the endogenous technological progress model discusses how to give Solow the rate of technological progress in the Solow hope model a reasonable economic explanation; the lifetime population and labor supply model, discuss this is how to give a reasonable economic explanation for the population growth rate in the Solow-Swan model. Economists generally refer to the study of the Solow-Swan model and its followers as exogenous growth economics. Cass (1965) and Koopmans (1965) introduced the theme of Ramsey (1928) to internalize the savings rate after the separable utility framework, so as to prevent the inefficiency of dynamic accumulation that may occur in the original Solow-Swan model and maintain the conclusion of conditional convergence in the Solow-Swan model.

Arrow (1962) described how companies have learned how to produce more efficiently in the process of continuous investment. Romer (1986) followed the concept of Arrow (1962) to construct the first endogenous growth model. Uzawa (1964) constructed a two-sector endogenous growth model, which is roughly divided into two categories: technological progress with increasing product quantity and technological progress with product quality improvement. Lucas (1988) explained the reasons for technological progress from the perspective of human capital, thinking that the rate of change of human capital represents the rate of technological progress. Human capital promotes technological progress to increase the rate of return of capital and accelerate economic growth. Becker et al. (1990), Rosenzweig (1990), and Ehrlich and Lui (1991) discussed the impact of labor supply capacity and capital investment on economic growth. Aghion and Howitt (1992) proposed a set of endogenous technological innovation models based on R&D. They emphasized three common propositions: first, technological innovation is the core and source of economic growth; second, technological innovation is endogenous, and is the result of R&D efforts that stem from entrepreneurs' profit maximization; third, innovation. The product is inherently different from other economic products; once it is created, it can be copied continuously without cost. The proposal of this model provides a reasonable explanation for the two empirical facts of global economic growth—the continuous positive and non-decreasing growth of long-term per capita income in many countries and the difference in transnational per capita income. Braun (1993) divides the research work of population growth rate or labor supply endogenous into two aspects: population migration and endogenous selection of fertility, and endogenous selection of fertility follow the research work of Becker and Barro (1989).

Rao and Cooray (2008) studied three East Asian countries (Singapore, Malaysia, and Thailand) with high growth rates. The data period were from 1970 to 2004 and found that the economic growth effect of the medium and short-term investment rate was much higher than the long-term effect. 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 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.

CO_2 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 carbon dioxide 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 come to two different conclusions: positive correlation and negative correlation.

When the country uses traditional energy, some scholars have found that economic growth will increase CO_2 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, CO_2 emissions, 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 CO_2 emissions are positively correlated with GDP growth. Kong (2021) used the asymmetric 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 CO_2 emissions. Kongkuah et al. (2021a) 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, CO_2 emissions is also higher. Regmi and Rehman (2021) used the ARDL method time series data with cointegration test from 1971 to 2019 to reveal the impact of CO_2 emissions on Nepal's energy use, energy consumption, fossil fuels, population growth, and economic progress impact. In the long-term analysis, fossil fuel energy consumption and energy utilization will also have an impact on CO_2 emissions. The short-term analysis results showed that there is a production relationship between fossil fuel energy consumption, energy utilization, and CO_2 emissions. Granger causality test results verify the one-way connection between variables. Huong et al. (2021) used the Kaya identity and decomposition method to analyze the relationship between various factors that produced CO_2 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 CO_2 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 CO_2 emissions, energy consumption and economic growth, and found that there is an inverse relationship between CO_2 emissions and economic growth causal relationship. Ahmad et al. (2020a) used the GMM method to study the dynamic interaction between sustainable investment, air pollution, and sustainable development in the panel data model of 27 provinces and cities in China from 1996 to 2017. At the national, provincial and municipal levels of the Chinese economy, sustainable development and air pollution are absolutely interdependent. Li et al. (2021) used the STIRPAT model to conduct an empirical test on panel data from 30 provinces in China from 2011 to 2017 to explore the impact of energy structure and digital economy on carbon dioxide emissions. The results show that the increase in the energy structure of non-resource-based provinces dominated by coal has a greater impact on the carbon dioxide emissions of resource-based provinces. The coal-based energy structure has a significant driving effect on carbon dioxide emissions. Mongo et al. (2021) used 15 European countries ARDL model 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 the results show that in the short term, environmental innovation investment tends to increase carbon dioxide emissions due to the induced rebound effect. However, in the long term, investing in green technologies tends to reduce carbon dioxide emissions.

Chen and Lee (2020) found that when the country uses technological innovation and uses clean energy, economic growth will also reduce CO_2 emissions. Ahmad et al. (2020b) use the data of 28 provinces in China from 1998 to 2016 to explore the heterogeneous influence of FDI and income on the development level of China's carbon dioxide emissions. Among them, they found that using fossil fuels is cheaper than using renewable energy. Provinces aiming to achieve rapid economic growth continue to use fossil fuels, which hinders clean production. Yang et al. (2021a), using the 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 CO_2 emissions, and the relationship between economic growth. Their research found that the use of clean energy can significantly reduce carbon dioxide emissions and promote economic growth. Işik et al. (2020) used panel bootstrap cointegration to examine the impact of the increase in renewable energy consumption and international tourism income in G7 countries from 1995 to 2015 on CO_2 emissions. The results show that the increase in renewable energy consumption affects France, Italy, and the UK. And the US carbon dioxide emissions have a negative impact. Alvarado et al. (2020) explored whether economic development and human capital would reduce the consumption of non-renewable energy. They studied the 1980–2015 data of 27 OECD member countries and found that economic development did not reduce the energy consumption of fossil sources. Alvarado et al. (2021) used quantile regression to analyze the ecological footprint and environmental degradation in Latin America. The study found that the impact of natural resource rents and economic complexity on the distribution of the entire ecological footprint is heterogeneous. They also found that the use of quantile regression methods is suitable for the analysis of environmental degradation in countries that are highly dependent on natural resource rents and income inequality. Ahmad et al. (2021a) studied the short-term and long-term heterogeneous links between urban concentration, non-renewable energy use intensity, environmental emission index, and economic development in 31 provinces and regions in China. The data period is from 2004 to 2017. They found that there is a one-way positive correlation between the intensity of non-renewable energy use and the environmental emission index, and there is a two-way positive correlation between the short-term and long-term urban concentration of cross-regional development levels and economic development. Karim et al. (2021) used quantile regression model and data from the period from 2013 to 2019, covering UK FTSE All-share non-financial firms, and the results showed that capital expenditure and internal governance disclosed carbon emissions in all quantiles all have positive effects. Lu et al. (2021) used Bayesian quantile regression and panel threshold regression as well as data from 30 provinces in China from 2007 to 2017 to test the linear and non-linear effects of environmental regulations on health expenditures. The empirical research results show that there is significant heterogeneity in the impact of environmental regulations on health expenditures. Environmental regulations for the median health expenditure are negatively correlated with health expenditure. 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 CO_2 emissions. Ahmad et al. (2020c) studied the heterogeneous causality between urbanization, power consumption intensity, water-based pollutant emissions, and GRP in 29 provinces in China from 1999 to 2018. They used the CCEMGA model to estimate and found that there is a unidirectional positive causal relationship between urbanization and the intensity of electricity consumption and the growth of water-based pollutant 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 CO_2 emissions. Some scholars have carried out research based on this and found that in the process of urbanization, economic growth will increase CO_2 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 CO_2 emissions. Their study found that these regions are in the process of urbanization, and GDP growth has promoted CO_2 emissions. Kongkuah et al. (2021b) tested the dynamic relationship between the EKC hypothesis and China's ecological economic variables, and the results showed that economic growth, energy consumption, and trade significantly increased carbon dioxide emissions. In the long term, urbanization has significantly reduced the pollution caused by carbon dioxide 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 CO_2 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 CO_2 emissions, but they will all lead to an increase in CO_2 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 CO_2 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 CO_2. Munir and Ameer (2021) used the "Stochastic Influence by Regression on Population, Affluence, and Technology" (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 CO_2 emissions. Ahmad et al. (2021b) used the modified "Stochastic Influence by Regression on Population, Affluence, and Technology" (STIRPAT) econometrical method to study the relationship between the inward foreign direct investment (IFDI) and overall carbon emissions in 27 provinces in China and the data period is from 1999 to 2017. As a result of the research, the link between IFDI and overall carbon emissions is an inverted "U" shape. 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 economic growth, but increase CO_2 emissions.

In addition to the causality test, some scholars have also tested the symmetry relationship between CO_2 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 CO_2 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 (EACs) at the regional and national levels and the relationship between economic growth, carbon dioxide, and energy consumption. Their research found that there is an asymmetric relationship between economic growth and CO_2 emissions in different countries. Yang et al. (2021b) use the panel data of the Organization for Economic Cooperation and Development (OECD) from 1971 to 2016 to study the long-term impact of economic globalization and population aging on CO_2 emissions. The results show that economic globalization and population aging have reduced long-term carbon dioxide emissions. Xiangyu et al. (2021) used the quantile autoregressive lagged (QARDL) approach to study the nonlinear effects of US energy consumption, economic growth, and the number of tourists on CO_2 emissions. The results show that there is an asymmetry between short-term economic growth and CO_2. 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 CO_2 emissions.

CO_2 emissions and health expenditure

The amount of CO_2 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 CO_2 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 CO_2 emissions in Malaysia under the impact of COVID-19. Studies have found that the increase in health expenditures will increase CO_2 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 CO_2 emissions and public health expenditures in Anglophone Countries in West Africa from 1990 to 2013, and found that the increase in CO_2 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 CO_2 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. Travassos et al. (2020) discussed the impact of Brazilian diet on carbon, water and ecological footprint from the perspective of dietary environmental impact and sustainable diet. They used independent t test and ANOVA test, and the study found that the diet of Brazilian adults and the associated environmental impact are very large. In particular, beef consumption accounts for the largest share. Akbar et al. (2021) 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 CO_2 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 USA and public health expenditures. The study found that there is no obvious relationship between CO_2 emissions and public expenditures. Erdogan (2020) used a panel causality test to analyze the relationship between CO_2 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 CO_2 emissions. In other selected countries, this relationship has not yet been discovered.

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. Ahmad et al. (2021c) analyzed the dynamic and interactive causality among urban agglomerations, carbon emissions, and the economic performance of health expenditures in China's development gap. The study found that health expenditure growth and carbon emissions growth and GDP growth have a two-way positive causal relationship. The research results showed that the impact of development differences is different. If health expenditure adjusted by the quality of government expenditure increases by 100%, the economic growth rate will be 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 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 CO_2 emissions, health expenditure, and economic growth. Wang et al. (2019a) 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, CO_2 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. (2019b) used annual time series data from 1975 to 2017 and applied the autoregressive distributed lag (ARDL) cointegration model to study the medical expenditure and CO_2 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 USA and Germany. There is a causal relationship between GDP growth and CO_2 emissions in Canada, Germany, and the USA, 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 CO_2 emissions and health expenditure, and there is a two-way causal relationship between economic growth and health expenditure.

Coccia (2021) studied more than 160 countries that the per capita gross domestic product (GDP), health care expenditures and air pollution of each country are key factors related to COVID-19 mortality. Countries with higher health sector expenditures have lower COVID-19 mortality rates and fewer days of population exposure (PM2.5) to more than safe levels. Ahmad et al. (2021d) studied the data of 27 provinces in China from 1999 to 2018. The STIRPAT model is used to examine the heterogeneous dynamic relationship among healthcare expenditures, land urbanization, and carbon dioxide emissions at different development levels. The results show that there is a bilateral causal relationship between the growth of carbon dioxide emissions and the growth of health care expenditures, and the relatively more developed (underdeveloped) regions show a stronger (weak) influence. 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.

From our literature review, some scholars have recently studied the ARDL model (Adamu et al., 2020; Kong, 2021; Mongo et al., 2021; Yang et al., 2021a, b), and some scholars use the NARDL model (Ghazouani, 2021; Namahoro et al., 2021), and Xiangyu et al. (2021) use the QARDL model for empirical testing. The Fourier ARDL model, we used, is similar to the newly developed ARDL, but it uses bootstrap Monte Carlo simulation to make the results of the variable test more delicated. The Fourier ARDL model is based and derivated on Pesaran et al. (2001) ARDL bounds test model and McNown et al. (2018) bootstrap ARDL model.

Empirical data and methods

Data

We discussed the health expenditure, CO_2 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 CO_2 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 CO_2 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 10,000 times, so even a short database like variable of health expenditure can be showed significant results in time-series and we used E-views 10 to implement econometrical equations of Fourier ARDL.

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 brakes. 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 bounds test model:

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

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:

$H_0 : \alpha = \beta = 0 \text{or} H_0 : \alpha = 0$

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 in the World Bank database, only 19-year samples of 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 CO_2 affects health expenditures, and then the model can be expressed as:

$$HE_t = \alpha_0 + \alpha_1 GDP_t + \alpha_2 CO_{2_t} + \varepsilon_t \tag{2}$$

HE is health expenditure, *GDP* is gross domestic production, CO_2 is carbon dioxide emissions, and Eq. (2) is extended to the 3-variable ARDL situation. The transform model is following as:

$$\Delta HE_t = \beta_0 + \beta_1 HE_{t-1} + \beta_2 GDP_{t-1} + \beta_3 CO_{2_{t-1}} + \sum_{i=1}^{p-1} \varphi_i' \Delta HE_{t-i} + \sum_{i=1}^{p-1} \delta_i' \Delta GDP_{t-i} + \sum_{i=1}^{p-1} \varnothing_i' \Delta CO_{2_{t-i}} + e_t \tag{3}$$

$$H_{0A} : \beta_1 = \beta_2 = \beta_3 = 0 \tag{4}$$

$$H_{0B} : \beta_1 = 0 \tag{5}$$

$$H_{0C} : \beta_2 = \beta_3 = 0 \tag{6}$$

The above model, Eq. (3), can also incorporate dummy variables to capture the 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:

$$\mathrm{d(t)} = \sum_{k=1}^{n} \alpha_k (\sin\frac{2\pi kt}{T}) + \sum_{k=1}^{n} b_k \cos\left(\frac{2\pi kt}{T}\right) \tag{7}$$

$$\mathrm{d(t)} = \gamma_1 (\sin\frac{2\pi kt}{T}) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) \tag{8}$$

The Fourier ARDL model is estimated as follows:

$$\Delta HE_t = \beta_0 + \gamma_1 (\sin\frac{2\pi kt}{T}) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 HE_{t-1} + \beta_2 GDP_{t-1} + \beta_3 \mathrm{CO}_{2_{t-1}} + \sum_{i=1}^{p-1} \alpha_i' \Delta HE_{t-i} + \sum_{i=1}^{p-1} \delta_i' \Delta GDP_{t-i} + \sum_{i=1}^{p-1} \varnothing_i' \Delta \mathrm{CO}_{2_{t-i}} + e_t \tag{9}$$

$$H_{0A} : \beta_1 = \beta_2 = \beta_3 = 0 \tag{10}$$

$$H_{0B} : \beta_1 = 0 \tag{11}$$

$$H_{0C} : \beta_2 = \beta_3 = 0 \tag{12}$$

Following the research of Christopoulos and Leon-Ledesma (2011) and Omay (2015), we use all values of k in the interval of $k = [0.1, \ldots, \ldots, 5]$ to estimate Eq. (9), where 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 F^*, t_1^* and t_2^* 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).

Empirical results and policy recommendations

Empirical results

When we are studying the correlation between health expenditures, carbon dioxide emissions and economic growth in the BRICS countries, because the results of empirical data of Russia show nonstationary of $I(2)$, if we use the data and these will get so-called spurious regression, so we did not use data of Russian in the whole paper. Table 1 is a descriptive statistical analysis of the three variables of health expenditures, CO_2 emissions,

Table 1 Description of statistics

Economies	Brazil			China			India			South Africa		
Variables	CO_2	Health	GDP	CO_2	Health	GDP	CO_2	Health	GDP	CO_2	Health	GDP
Mean	2.5801	2.7568	3.8384	3.8274	2.1462	3.5093	3.8274	2.1462	3.5093	2.6109	2.5757	3.7173
Maxi	2.7029	3.0109	4.1220	3.9655	2.6443	3.9425	3.9655	2.6442	3.9424	2.6521	2.7762	3.9034
Mini	2.4803	2.3911	3.4516	3.5266	1.6269	2.9820	3.5266	1.6268	2.9819	2.5284	2.2279	3.3983
Sd. Dev	0.0782	0.2330	0.2360	0.1542	0.3673	0.3452	0.1542	0.3672	0.3452	0.0410	0.1640	0.1502
Skew	0.2183	− 0.4722	− 0.4437	− 0.8647	− 0.0391	− 0.2036	− 0.8647	− 0.0390	− 0.2035	− 0.9490	− 0.7664	− 1.0043
Kurt	1.5111	1.5997	1.6803	2.3111	1.4766	1.5194	2.3111	1.4765	1.5194	2.5437	2.5333	2.8912
J-B	1.8056	2.1395	1.8970	2.5992	1.7452	1.7684	2.5992	1.7452	1.7684	2.8579	1.9257	3.0348

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

Table 2 Unit root tests

Country		Level			First difference		
		ADF	PP	KPSS	ADF	PP	KPSS
Brazil	CO_2	− 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
China	CO_2	− 3.9374***	− 3.3594**	0.5165**	− 1.1463	− 1.3744	0.4743**
	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
India	CO_2	− 3.9374***	− 3.3594**	0.5165**	− 1.1463	− 1.3744	0.4743**
	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
South Africa	CO_2	− 1.9808	− 2.2580	0.4260*	− 3.5901**	− 3.5685**	0.3577*
	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

and economic growth in the BRICS countries after taking natural logarithm of the variables. All statistical data verification results are left-skewed with right long tail, only Brazil's carbon dioxide emissions are left-skewed with right long tails, and the dynamic test results are all low-spread peaks (< 3), while the kurtosis data of South Africa's GDP is It is 2.8912 which is closest to the standard kurtosis (= 3). 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. In order to determine the stability of the unit root test results, we use the three commonly used ADF, PP, and KPSS by scholars in academic and the unit root test to ensure the reliability of our empirical test. The test results show that the three variables of the four countries meet the standard, except Russia, 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, CO_2 emissions and health expenditure should have a long-term cointegration relationship.

However, Table 3 is a test of the cointegration relationship between health expenditures and carbon dioxide emissions. The test results show that there is no long-term cointegration relationship between health expenditures and CO_2 emissions in the BRICS countries. From the perspective of the frequency of Fourier changes, in Brazil (1.5), China (2.5), India (2.5), and South Africa (3.6), the frequency of changes in CO_2 emissions to health expenditures is longer than that of health expenditures to carbon dioxide emissions.

The short-term causality test in Table 4 shows that the CO_2 emissions of Brazil, China, and India are causally related to health expenditures after a period of lag. Specifically, Brazil's CO_2 emissions have a negative causality relationship with health expenditures, while China's health

Table 3 Cointegration analysis (2 variables)

Country	Dependent variable| Independent variable	frequency	AIC	γ	F^*	F	t^*_{dep}	t_{dep}	t^*_{indep}	t_{indep}	Result
Brazil	CO_2 | Health	1.5	−6.31	19.62***	12.78	7.099	−4.635	−3.163	4.607	2.995	No cointegration
	Health | CO_2	1.4	−3.96	4.352**	3.393	0.733	−2.024	0.190	1.101	−0.261	No cointegration
China	CO_2 | Health	2.5	−6.10	0.465	3.315	1.567	−1.866	−0.484	1.098	0.484	No cointegration
	Health | CO_2	0.5	−5.16	33.33***	4.541	1.235	−2.348	−1.300	0.783	1.119	No cointegration
India	CO_2 | Health	2.5	−6.10	1.183	3.167	1.567	−1.915	−0.484	1.030	0.484	No cointegration
	Health | CO_2	2.5	−6.10	5.893**	3.002	1.567	−1.614	−0.484	1.095	0.484	No cointegration
South Africa	CO_2 | Health	3.4	−5.59	0.087	5.286	2.752	−2.850	−0.650	2.385	0.038	No cointegration
	Health | CO_2	2.6	−3.59	1.7791	7.063	6.547	−3.238	−3.263	2.072	2.682	No cointegration

***, **, 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		ΔCO_2 equation	ΔHealthequation
Brazil	$\Delta\ CO_{2t}, CO2_{t-1},$	n.a	4.173*** (0.002)(-)
	$\Delta\ Health_t, Health_{t-1}$	0.175 (0.864)(-)	n.a
China	$\Delta\ CO_{2t}, CO2_{t-1},$	n.a	0.885 (0.398)(+)
	$\Delta\ Health_t, Health_{t-1}$	16.890* (0.000)(-)	n.a
India	$\Delta\ CO_{2t}, CO2_{t-1},$	n.a	5.765*** (0.000)(-)
	$\Delta\ Health_t, Health_{t-1}$	8.873*** (0.000)(-)	n.a
South Africa	$\Delta\ CO_{2t}, CO2_{t-1},$	n.a	1.343 (0.210)(-)
	$\Delta\ Health_t, Health_{t-1}$	1.2405 (0.201)(+)	n.a
Country	**$Health_t \rightarrow CO_2$**		**$CO_2 \rightarrow Health_t$**
Brazil	x		v(−)
China	v(−)		x
India	v(−)		v(−)
South Africa	x		x

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

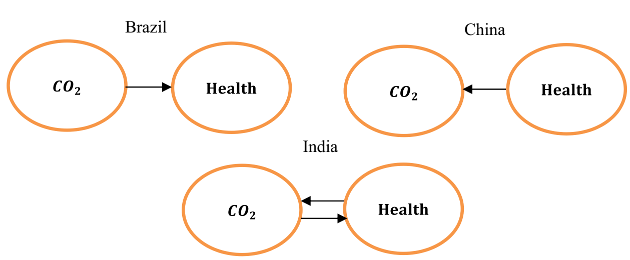

Fig. 3 Granger causality analysis based on Fourier ARDL model (2 variables)

expenditures also have a negative causality relationship with CO_2 emissions. Only India's CO_2 emissions and health expenditures have a two-way negative causality relationship. The CO_2 emission is a kind of environmental pollution. In the long term, this means that it has a significant negative impact on the health of Brazil and India. In China and India, health expenditure is negatively correlated with CO_2 emissions, which means that increasing health expenditure will help reduce environmental pollution (see Fig. 3).

Brazil established the Unified Health System (Sistema Único de Saúde, SUS) in 1988, and Brazil has made progress in achieving universal health coverage. Since then, Brazil has achieved access to healthcare services for almost everyone in implementing health plans and organizing the health system. However, the implementation of austerity fiscal policy in 2016 has led to geographical inequality, insufficient funds and poor cooperation between the private sector and the public sector, threatening its sustainability and fulfilling its ability to provide health care for all. In recent years, due to the weak recovery of the international economy, sluggish commodity prices, and structural problems in the domestic economy, the Brazilian economy has gradually fallen into recession. As far as Brazil's national finance is concerned, its manufacturing capacity is not strong, mainly

Table 5 Cointegration analysis (3 variables)

Country	*Dependent variable| Independent variable*	*frequency*	*AIC*	γ	F^*	F	t^*_{dep}	t_{dep}	t^*_{indep}	t_{indep}	*Result*
Brazil	CO_2 | Health, GDP	1.5	−6.20	7.81**	6.568	2.860	−3.384	−2.451	7.277	3.862	No cointegration
	Health | CO_2 GDP	1.9	−6.58	96.***	5.444	0.389	−1.633	−0.014	5.236	0.563	No cointegration
China	CO_2 | Health, GDP	0.4	−7.06	13.***	6.488	9.122	−3.521	−4.997	7.639	9.250	**Cointegration**
	Health | CO_2 GDP	0.5	−6.09	9.7***	7.635	6.583	−4.074	−4.149	9.883	7.467	No cointegration
India	CO_2 | Health, GDP	0.4	−7.06	0.1872	7.183	9.122	−3.467	−4.997	8.383	9.250	**Cointegration**
	Health |CO_2 GDP	0.5	−6.91	7.27**	8.053	6.583	−4.274	−4.149	10.656	7.467	No cointegration
South Africa	CO_2 | Health, GDP	2.8	−6.34	1.632	6.057	1.688	−3.267	−1.994	7.701	2.531	No cointegration
	Health | CO_2 GDP	1	−6.54	3.844*	12.03	4.943	−4.7092	−0.349	14.791	4.703	No cointegration

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

relying on bulk commodities. Especially after the COVID-19 epidemic, under the impact of the epidemic, the demand for bulk commodities has fallen, and the stagnation of logistics and shipping has caused poor transportation, which has led Brazil to rely on the channels for obtaining finance for commodity exports have weakened. If the efforts to fight the epidemic are not supported by the economy, there will be many difficulties. The implementation of a high-welfare social security policy has made Brazil's finances more overwhelmed, and at the same time inhibited the increase in social labor productivity. At present, Brazil has the largest social security system in the world, covering many aspects such as free medical care, free education, relief funds and pensions. Brazilians enjoy the treatment of developed countries. Brazil's pension is equivalent to 97% of Brazil's average salary after tax, which is much higher than the 69% of OECD countries. Brazil's debt level is getting higher and higher, and heavy debt is equivalent to a large overdraft of future wealth in advance. The economic recession of Brazil has also brought about a reduction in the quality of medical services and health expenditures. In terms of carbon dioxide emissions, Brazil is different from other BRICS countries. The main source of carbon emissions is deforestation. For the Brazilian government, developed countries should bear the greatest responsibility for carbon dioxide emissions and global warming, and have the obligation to contribute to the development initiatives to protect forests and improve the income of people in the Amazon region. The Brazilian government pledged to reduce illegal deforestation to zero by 2030.

Table 5 examines the long-term cointegration relationship between health expenditures, CO_2 emissions and economic growth in the BRICS countries. The test results show that only China and India, when CO_2 emissions are used as the dependent variable, health expenditures, and economic growth are regarded as independent variables. The Fourier frequency (smoothed) for Brazil and China are both 0.4 ($k = 0.4$). The Fourier ARDL model is an improvement of the McNown et al. (2018) Bootstrap ARDL test (sharp break), which can show the part of the breakpoint in a more subtle way (decimals replace integers). From a long-term perspective, the three variables of health expenditure, carbon dioxide emissions, and economic growth in Brazil and China have a cointegration relationship, which can well explain the economic development models that Brazil and China have adopted in recent years with high-polluting energy. In terms of the medical system, the Indian government has also seen an imbalance between the two major policy goals of economic development and social equity. Public policies are clearly tilted towards the upper classes of society, ignoring the interests and needs of the middle and lower classes of society. The Indian government strengthens the fairness of the medical security system, adheres to the principle of "government-led and market-participated" in the provision of medical services, and increases financial investment in medical and health care. In terms of carbon dioxide emissions, India is one of the five BRICS countries with carbon dioxide emissions and a major environmental pollution country. The Indian government's commitment is a necessary prerequisite for achieving air quality improvement. In

Table 6 The results of long-term estimation analysis based on Fourier ARDL model

Country		ΔCO_2 equation	ΔHealthequation
China	$\Delta\, CO_{2t}, CO2_{t-1},$	n.a	n.a
	$\Delta\, Health_t, Health_{t-1}$	3.133** (0.019)(+)	n.a
	$\Delta\, gdp_t, gdp_{t-1},$	3.830*** (0.002)(-)	n.a
India	$\Delta\, CO2_t, CO2_{t-1},$	n.a	n.a
	$\Delta\, Health_t, Health_{t-1}$	-0.865 (0.432)(-)	n.a
	$\Delta\, gdp_t, gdp_{t-1},$	0.0493 (0.932)(+)	n.a

***, ** 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		ΔCO_2 equation	Healthequation
Brazil	$\Delta\ CO_{2t,}CO2_{t-1,}$	n.a	44.779** (0.00) (-)
	$\Delta\ Health_t\ Health_{t-1}$	1.728 (0.309)(-)	n.a
	$\Delta\ gdp_{t,}gdp_{t-1,}$	2.613** (0.102)(+)	22.6184** (0.000)(+)
China	$\Delta\ CO_{2t,}CO2_{t-1,}$	n.a	0.501 (0.600)(+)
	$\Delta\ Health_t\ Health_{t-1}$	0.493 (0.432)(-)	n.a
	$\Delta\ gdp_{t,}gdp_{t-1,}$	1.133 (0.932)(+)	0.908 (0.309)(-)
India	$\Delta\ CO_{2t,}CO2_{t-1,}$	n.a	0.557 (0.203)(+)
	$\Delta\ Health_t\ Health_{t-1}$	3.650*** (0.008)(+)	n.a
	$\Delta\ gdp_{t,}gdp_{t-1,}$	3.069** (0.012)(-)	0.898 (0.507)(-)
South Africa	$\Delta\ CO_{2t,}CO2_{t-1,}$	n.a	-0.036 (0.965)(-)
	$\Delta\ Health_t\ Health_{t-1}$	0.076 (0.932)(-)	n.a
	$\Delta\ gdp_{t,}gdp_{t-1,}$	0.495 (0.691)(+)	1.997* (0.088)(+)

Country	$Health_t$ ➔ CO_2	GDP ➔ CO_2	CO_2 ➔ $Health_t$	GDP ➔ $Health_t$
Brazil	x	v(+)	v(−)	v(+)
China	x	x	x	x
India	v(+)	v(−)	x	x
South Africa	x	x	x	v(+)

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

2019, India released the National Clean Air Plan (NCAP), which plans to reduce pollution in 102 cities by 20–30% within 5 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 CO_2 emissions when their health expenditures and CO_2 emissions lag behind by one period. China to improve environmental governance and effectively control pollution sources, government departments should establish a scientific vehicle exhaust detection system, conduct real-time exhaust detection of locomotives on the road, and adopt scientific control measures.

Control atmospheric pollutants in the production process and rationally plan the industrial structure gradually eliminate high-pollution and high-consumption industries, and attach importance to industrial upgrading. The China government should play the role of industry supervision, strengthen supervision and management of high energy-consuming industries, and give priority guidance; implement policy incentives for key energy-saving enterprises, such as adopting tax reduction policies, encouraging enterprises to carry out technological innovation, reducing pollutant emissions, and improving pollution control level. Strengthen environmental legislation, establish a sound legal system, promote the modernization of the ecological environment governance system and governance capabilities, and improve the environmental governance laws, regulations and policy systems.

In recent years, due to the rapid development of the Internet in China and its application to the medical system, medical resources can use Internet information, which greatly improves the quality and effectiveness of medical care. China has fully established a unified national medical security information platform, continued to optimize the operation and maintenance system and safety management system, perfected the "Internet + medical health" medical insurance management services, improved the "Internet + medical health" medical insurance service fixed-point agreement management, and improved the "Internet + medical service prices and medical insurance payment policies", extending medical insurance management services to "Internet + medical health" medical behaviors, forming a relatively complete "Internet + medical health" medical insurance policy system, service system and evaluation system. In this COVID-19 epidemic, the medical system has also played a great role in the control of the Internet.

Table 7 conducts a lag period test and a short-term causality test between the health expenditures, CO_2 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 CO_2 emissions have a cointegration relationship; India's health expenditure and economic growth have a cointegration relationship with CO_2 emissions; South Africa's economic growth has a cointegration relationship with CO_2 emissions. The results of short-term

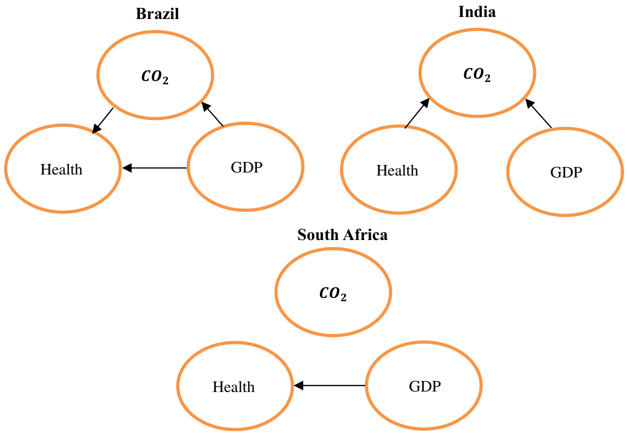

Fig. 4 Granger causality analysis based on Fourier ARDL model (3 variables)

causality show that Brazil's economic growth has a positive causality relationship with CO_2 emissions and health expenditures, and CO_2 emissions have a reverse causality relationship with health expenditures; India's economic growth has a positive causality relationship with CO_2 emissions, and CO_2 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 Fig. 4).

In the context of the large gap between public medical resources and people's health needs, the South African government encourages public–private cooperation, uses the power of private institutions to strengthen the construction of human resources in public hospitals, and at the same time promotes private sector participation in the provision of health services, so that more people can access medical and healthcare services to improve the efficiency and quality of service delivery. South Africa has an extreme and persistently high unemployment rate, which interacts with inadequate education, inadequate health, crimes, and racial inequality and other economic and social problems. Derivative problems damage investment and economic growth, thereby affecting employment. The dysfunction of the South African health system and the conflict between infectious and non-communicable diseases are racial and gender discrimination, the immigrant labor system, the destruction of family life, huge income inequality, and extreme violence. The health sector is facing a serious human resource crisis, which inevitably affects health and medical services. Despite the substantial increase in social subsidies, macroeconomic policies that promote growth rather than redistribution have led to the persistence of economic inequality between races. The public health system has been transformed into a comprehensive and comprehensive national service, but the failure of leadership and management and poor management have led to ineffective implementation of generally good policies. The key aspects of primary health care are not yet in place, and the health sector is facing a serious human resource crisis. The health system faces enormous challenges, many of which still exist.

Policy recommendations

The health expenditures of the BRICS countries have a great role in promoting the production of healthy capital. Since health expenditures can indirectly promote economic development by improving the health of residents and increasing the stock of healthy human capital, the governments of the BRICS countries should increase health expenditures. For example, the CO_2 emissions of Brazil have an impact on the increase in medical expenditure. If CO_2 emissions are not effectively reduced, increasing medical expenditure can improve people's health. This investment will play a role in the production of health capital. Economic growth has changed from relying on traditional growth drivers such as physical capital investment and demographic dividends to relying on emerging industries and innovation. The economic growth of Brazil and South Africa has significantly boosted health expenditure. Although Brazil has established a nationwide medical system, the Brazilian government has invested very little in the medical and health system over the years. This is directly related to the strict fiscal austerity policy introduced by the Brazilian government in 2016. Although the economy of the BRICS countries is developing rapidly, the cost of the extensive economic development model is huge, and such as India, problems serious environmental pollution and damage to the ecosystem have become increasingly prominent. If the BRICS countries want to formulate reasonable economic policies and coordinate health expenditures, economic growth, and environmental protection, they must coordinate the national health expenditures, economic growth, coal consumption, capital, labor, CO_2 emissions, and other indicators to make an accurate judgment and analysis in the direction.

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 CO_2 emissions, that is, economic growth and changes in CO_2 emissions are consistent, and economic growth in the short-term has led to an increase in CO_2 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. The government of Brazil should continue the development of biomass ethanol, power energy conservation, and encourage the use of renewable energy and biodiesel. These comprehensive projects will help reduce greenhouse gas and CO_2 emissions. The Brazilian government strictly legislates, enforces and punishes them to ensure the authority of environmental protection. Encourage the participation and collaboration of the government, enterprises and the public. Enhancing environmental protection is an important measure to implement the scientific development concept. Enhancing environmental protection is conducive to promoting economic restructuring and the transformation of growth patterns, and achieving faster and better development. The Chinese government should use CO_2 emission reduction to lead the improvement of various policies for power energy conservation and emission reduction, formulate plans and play a guiding and restrictive role, take multiple measures to promote the effective consumption of new energy power generation, and use low-carbon standards as a guide to strengthen power and related fields and power coordinate and coordinate all aspects of the system itself, accelerate the development of new electrification, promote the clean and low-carbon transformation of energy and power, and simultaneously promote the reform of the electricity market and the construction of the carbon market. The Indian government should increase power generation from non-fossil fuels and renewable energy sources such as wind, solar, and hydropower, continue afforestation to increase forest coverage, absorb CO_2, and reduce CO_2 emissions.

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 CO_2 emission and the increase of CO_2 emissions has reduced health expenditures. In terms of health expenditures, Brazil should improve its industrial structure and recover its industrial manufacturing capacity. Adjust the social security system, reduce the proportion of pension after-tax salary income, reduce the government's financial burden, balance the development of medical care, and reduce the poverty population. 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. India should apply scientific methods to carry out emission inventory compilation, data monitoring, air quality model establishment, pollutant source analysis and cost–benefit analysis, etc., to ensure that relevant policies and measures are effective. When formulating air quality improvement goals and plans, the impact of regional transmission on air quality should be fully considered. Establish a systematic air quality monitoring network combined with a strong monitoring mechanism to ensure the effective implementation of policies and measures. Only improving the deteriorating air quality is also an opportunity for India to adjust and optimize the energy and industrial structure, thereby developing the economy, and also conducive to technological innovation and stimulating its market development. Since the government alone cannot provide basic medical services for all citizens, it is recommended that the medical and health authorities of the Indian government encourage the development of private medical institutions, advocate public–private cooperation and community participation, and seek financial and technical assistance from international non-governmental organizations. Establish a community-based medical service organization to provide low-income people, especially the poor, with quality-guaranteed medical services with reasonable fees, and gradually realize the accessibility of medical services. China should take rationalizing government market relations as the core, improve the top-level design, and comprehensively promote the implementation of medical reform policies. Guided by the people sharing the prosperity of economic development, governments at all levels have gradually increased financial investment in health care. Promote the full introduction of social capital in the field of non-basic medical and health services, create a good environment for the development of private hospitals and promote the sustainable and healthy development of private hospitals; expand the space and connotation of medical services; promote the improvement of digital technology of medical services and improve service quality and efficiency.

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.

In general, the BRICS countries should pay more attention to the "green effect" of economic growth in their future development, increase their efforts in environmental governance, set phased and progressive carbon emission reduction targets, and achieve steady economic growth. Deepen the transition to clean energy and gradually reduce the dependence on fossil energy such as coal. Further optimize the energy structure so that clean energy can be used more safely and efficiently, increase the development of new energy, and promote the comprehensive green transformation of the energy structure of the BRICS countries. The BRICS countries should increase expenditures on the scale of environmental and health expenditures, guide enterprises to carry out technological innovations, and at the same time encourage enterprises to improve technical efficiency, and achieve the "U"-shaped goal of transcending environmental regulations and economic growth; in the structure of environmental and health expenditures The government should increase the proportion of environmental research, environmental health education and other projects, create an external environment conducive to economic growth, and give full play to the positive role of environmental public expenditures in building a good external technological innovation environment and enhancing social health human capital.

Conclusions

In this paper, we used the Fourier bootstrap ARDL model to study the cointegration relationship and short-term causality between health expenditures, CO_2 emissions, and economic growth in the BRICS countries. The research results show that, in the long term, Brazil and China have cointegration relationships between CO_2 emissions as the dependent variable and health expenditure and economic growth as the independent variables. In the short term, under the test of health expenditure and CO_2 emissions, in Brazil, CO_2 emissions have a one-way impact on health expenditure; i China, health expenditure has a one-way impact on CO_2 emissions; Iin India, there is a two-way causal relationship between CO_2 emissions and health expenditure. When economic growth is added as the control variable, in the long term, in China, health expenditure is positively correlated with CO_2 emissions, mainly because China's industrial development promotes the increase of CO_2 emissions and medical expenditure; at the same time, with the introduction of CO_2 emission policies in China, there are a negative correlation between economic growth and CO_2 emissions. When the control of economic growth is added, in the short term, Brazil's economic growth not only promotes the growth of health expenditure but also promotes the increase of CO_2 emissions. However, with weak economic growth and a sharp drop in federal government investment, Brazil's public medical care has deteriorated year by year, and private medical care has flourished. The severe polarization between the rich and the poor and the uneven distribution of medical resources have made Brazil. The average per capita expenditure on health has fallen instead of rising. India's health expenditure is positively correlated with CO_2 emissions, while economic growth is negatively correlated with CO_2 emissions; the CO_2 emissions formed by India's economic development mainly come from the increase in energy use in electricity, transportation, and industry. The Indian government should increase power generation from non-fossil fuels and renewable energy sources such as wind, solar, and hydropower, continue to plant trees and increase forest coverage to absorb CO_2. The economic growths of South Africa have promoted the growth of health expenditures. The impact of South Africa's economic growth on health expenditure is not sustainable enough, and the South African government should pay more attention to the impact of sustainable economic growth policies on health expenditure. The South African government needs to frequently invest in health expenditures to improve the efficiency of resource allocation.

Author contribution F. Li is responsible for organizing the progress of the paper, final revision and finalization; M.-C. Wang is responsible for data collection and analysis, part of the manuscript writing, and submission; T. Chang is responsible for guiding the topic selection, research methods, and comprehensive management of the structure and content of the article; J. Zhou is responsible for part of data collection, the article writing and structure the content of article.

Data availability If any researchers need the original data of this manuscript, the authors agree to provide relevant information.

Declarations

Ethical approval The authors all agree to ethical approval and understand its related rules and content.

Consent to participate The authors of this manuscript are all aware of the journal to which the manuscript was submitted, and all agree to continue to support the follow-up work.

Consent to publish This manuscript has not been submitted or published in other journals, and the authors agree to consent to publish.

Conflict of interest The authors declare no competing interests.

References

Adebayo TS, Akinsola GD (2021) Investigating the causal linkage among economic growth, energy consumption and CO_2 emissions in Thailand: An application of the wavelet coherence approach. IJRED 10(1):17–26

Adamu S, Danjuma M, Babaji M (2020) An analysis of the long run effects of economic growth, urbanization & population density on transport emissions in Nigeria: a bounds testing approach. Int J Intellect Discourse 3(2):146–162 https://www.researchgate.net/

publication/347278214_AN_ANALYSIS_OF_THE_LONG_RUN_EFFECTS_OF_ECONOMIC_GROWTH_URBANIZATION_AND_POPULATION_DENSITY_ON_TRANSPORT_EMISSIONS_IN_NIGERIA_A_BOUNDS_TESTING_APPROACH

Aghion P, Howitt P (1992) A Model of Growth Through Creative Destruction. Econometrica 60(2):323–351

Ahmad M, Chandio AA, Solangi YA, Shah SAA, Shahzad F, Rehman A, Jabeen G (2020a) Dynamic interactive links among sustainable energy investment, air pollution, and sustainable development in regional China. Environ Sci Pollut Res 28:1502–1518

Ahmad M, Jabeen G, Wu Y (2020b) Heterogeneity of pollution haven/halo hypothesis and environmental Kuznets curve hypothesis across development levels of Chinese provinces. J Clean Prod No. 124898

Ahmad M, Ahmed N, Jabeen M, Jabeen G, Qamar S, Chandio AA, Rehman A, Rauf A (2020c) Empirics on heterogeneous links among urbanization, the intensity of electric power consumption, water-based emissions, and economic progress in regional China. Environ Sci Pollut Res 27:38937–38950

Ahmad M, Işık C, Jabeen G, Ali T, Ozturk I, Atchike DW (2021a) Heterogeneous links among urban concentration, non-renewable energy use intensity, economic development, and environmental emissions across regional development levels. Sci Total Environ 765 No. 144527

Ahmad M, Jabeen G, Irfan M, Işık C, Rehman A (2021b) Do inward foreign direct investment and economic development improve local environmental quality: aggregation bias puzzle. Environ Sci Pollut Res 28(26):34676–34696

Ahmad M, Akram W, Shah IM, AA, Rehman A, Chandio AA, Jabeen G, (2021c) Estimating dynamic interactive linkages among urban agglomeration, economic performance, carbon emissions, and health expenditures across developmental disparities. Sustain Prod Consum 26:239–255

Ahmad M, Rehman A, Shah SAA, Solangi YA, Chandio AA, Jabeen G (2021d) Stylized heterogeneous dynamic links among healthcare expenditures, land urbanization, and CO_2 emissions across economic development levels. Sci Total Environ 753(1) No. 142228

Akbar M, Hussain A, Akbar A, Ullah I (2021) The dynamic association between healthcare spending, CO_2 emissions, and human development index in OECD countries: evidence from panel VAR model. Environ Dev Sustain 23:10470–10489

Alvarado R, Deng Q, Tillaguango B, Méndez P, Bravo D, Chamba J, Alvarado-Lopez M, Ahmad M (2020) Do economic development and human capital decrease non-renewable energy consumption? Evidence for OECD countries. Energy 215 No. 119147

Alvarado R, Tillaguango B, Dagar V, Ahmad M, Işık C, Méndez P, Toledo E (2021) Ecological footprint, economic complexity and natural resources rents in Latin America: empirical evidence using quantile regressions. J Clean Prod 318 No. 128585

Apergis N, Bhattacharya M, Hadhri W (2020) Health care expenditure and environmental pollution: a cross-country comparison across different income groups. Environ Sci Pollut Res 27(8):8142–8156

Arrow KJ (1962) The economy implication of learning by doing. Rev Econ Stud 29:155–173

Atems B (2019) Public health expenditures, taxation, and growth. Health Econ 28(9):1146–1150

Atuahene SA, Yusheng K, Bentum-Micah G (2020) Health expenditure, CO2 emissions, and economic growth: China vs. India. Preprint Submit Working Paper No. 2020090384

Barro RJ (2016) Economic growth and convergence, applied to China. China World Econ 24(5):5–19

Becker GS, Murphy KM, Tamura R (1990) Human capital, fertility, and economic growth. J Polit Econ 98(5):S12–S37

Becker R, Enders W, Lee J (2006) A stationarity test in the presence of an unknown number of smooth breaks. J Time Ser Anal 27(3):381–409

British Petroleum (bp) website (2021) https://www.bp.com/content/dam/bp/businesssites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-co2-emissions.pdf

Cass D (1965) Optimum Growth in an Aggregative Model of Capital Accumulation. Rev Econ Stud 32(3):233–240

Cheikh NB, Zaied YB, Chevallier J (2021) On the nonlinear relationship between energy use and CO_2 emissions within an EKC framework: Evidence from panel smooth transition regression in the MENA region. Res Int Bus Finance 55 No. 101331

Chen Y, Lee C-C (2020) Does technological innovation reduce CO_2 emissions? Cross-country evidence. J Clean Prod 263 No. 121550

Christopoulos DK, Leon-Ledesma MA (2011) International output convergence, breaks, and asymmetric adjustment. Stud Nonlinear Dyn Econ 15(3):1–33

Coccia M (2021) High health expenditures and low exposure of population to air pollution as critical factors that can reduce fatality rate in COVID-19 pandemic crisis: a global analysis. Environ Res 199 No. 111339

Domar ED (1947) Expansion and Employment. Am Econ Rev 37(1):34–55

Eckelman MJ, Huang K, Lagasse R, Senay E, Dubrow R, Sherman JD (2020) Health care pollution and public health damage in the United States: an update: study examines health care pollution and public health damage in the United States. Health Aff 39(12):2071–2079

Ehrlich I, Lui F (1991) Intergenerational Trade, Longevity, and Economic Growth. J Polit Econ 99(5):1029–1059

Erdogan S, Kirca M, Gedikli A (2020) Is there a relationship between CO_2 emissions and health expenditures? Evidence from BRICS-T countries. Bus Econ Res J 11(2):293–305

Gallant AR (1981) On the bias in flexible functional forms and an essentially unbiased form. J Econom 15(2):211–245

Gallant AR, Souza G (1991) On the asymptotic normality of Fourier flexible form estimates. J Econom 50(3):329–353

Ghazouani T (2021) Impact of FDI inflow, crude oil prices, and economic growth on CO2 emission in Tunisia: Symmetric and asymmetric analysis through ARDL and NARDL approach. Environ Econ 12(1):1–13

Gok MS, Ongel V, Altindag E (2018) Analysis the interplay between economic growth and health expenditures: the case of emerging economies. J Glob Strateg Manag 12(2):53–62

Gündüz M (2020) Healthcare expenditure and carbon footprint in the USA: evidence from hidden cointegration approach. Eur J Health Econ 21(4):801–811

Hahn FH, Matthews RC (1964) The theory of economic growth: a survey. Econ J 74(296):779–902

Harrod RF (1939) An Essay in Dynamic Theory. Econ J 49(193):14–33

Hossein EA, Mojtaba A, Arezoo B (2021) Relationship between urban growth, selected economic indicators and CO2 emissions in Iran. J Environ Water Eng 6(4):402–414

Huong TT, Shah IH, Park H-S (2021) Decarbonization of Vietnam's economy: decomposing the drivers for a low-carbon growth. Environ Sci Pollut Res 28(1):518–529

Ibukun CO, Osinubi TT (2020) Environmental quality, economic growth, and health expenditure: empirical evidence from a panel of African countries. Afr J Econ Rev 8(2):119–140

Iheonu C, Anyanwu O, Odo O, Nathaniel S (2021) Does economic growth, international trade and urbanization uphold environmental sustainability in sub-Saharan Africa? Insights from quantile and causality procedures. Environ Sci Pollut Res 28(3):28222–28233

International Monetary Fund, World Economic Outlook (2021) https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/CHN/BRA/IND/RUS/ZAF/ADVEC?year=2021

Işik C, Ahmad M, Pata UK, Ongan S, Radulescu M, Adedoyin FF, Bayraktaroğlu E, Aydın S, Ongan A (2020) An evaluation of the tourism-induced environmental Kuznets curve (T-EKC) hypothesis: evidence from G7 countries. Sustainability 12(21) No. 9150

Karim AE, Albitar K, Elmarzouky M (2021) A novel measure of corporate carbon emission disclosure, the effect of capital expenditures and corporate governance. J Environ Manage 290(15) No. 112581

Kong S (2021) Environmental cost of energy consumption and economic growth: can China shift some burden through financial development? An asymmetric analysis. Environ Sci Pollut Res 28(20):25255–25264

Kongkuah M, Yao H, Fongjong BB, Agyemang AO (2021a) The role of CO_2 emissions and economic growth in energy consumption: empirical evidence from Belt and Road and OECD countries. Environ Sci Pollut Res 28(18):22488–22509

Kongkuah M, Yao H, Yilanci V (2021b) The relationship between energy consumption, economic growth, and CO_2 emissions in China: the role of urbanisation and international trade. Environ Dev Sustain

Koopmans TC (1965) On the concept of optimal economic growth. The economic approach to development planning. Rand McNally, Chicago

Li Y, Yang X, Ran Q, Wu H, Irfan M, Ahmad M (2021) Energy structure, digital economy, and carbon emissions: evidence from China. Environ Sci Pollut Res 1–24

Lu W, Wu H, Geng S (2021) Heterogeneity and threshold effects of environmental regulation on health expenditure: Considering the mediating role of environmental pollution. J Environ Manag 297 No. 113276

Lucas RE (1988) On the mechanism of economic development. J Monet Econ 22:3–42

Ludlow J, Enders W (2000) Estimating non-linear ARMA models using Fourier coefficients. Int J Forecast 16(3):333–347

McNown R, Sam CY, Goh SK (2018) Bootstrapping the autoregressive distributed lag test for cointegration. Appl Econ 50(13):1509–1521

Modibbo HU, Saidu AM (2020) Health expenditure and economic growth nexus: a generalised method of moment approach for the case of selected Africa countries. Lapai J Econ 4(1):12–21

Mongo M, Fateh B, Ramdani B (2021) The effects of environmental innovations on CO2 emissions: empirical evidence from Europe. Environ Sci Policy 118:1–9

Munir K, Ameer A (2021) Assessing nonlinear impact of urbanization, economic growth, technology, and trade on environment: evidence from African and Asian emerging economies. Geo J 1–14.

Namahoro JP, Wu Q, Xiao H, Zhou N (2021) The impact of renewable energy, economic and population growth on CO_2 emissions in the East African region: evidence from common correlated effect means group and asymmetric analysis. Energies 14(2):312

Omay T (2015) Fractional frequency flexible Fourier form to approximate smooth breaks in unit root testing. Econ Lett 134:123–126

Oyelade AO, Tijani OD, Wakile MO, Kanimodo AL (2020) Environmental quality and its attendant effect on human health: new evidence from panel quantile regression for Anglophone countries in West Africa. Int Immunol 8(4):89–95

Öztürk S, Suluk S (2020) The relationship between CO_2 emission, energy and economic growth: an empirical analysis for the G7 countries. IPASJ Int J Manag 8(11):16–24

Perron P (1989) The great crash, the oil price shock, and the unit root hypothesis. Econometrica 57(6):1361–1401

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econ 16(3):289–326

Ramsey FP (1928) A Mathematical Theory of Saving. Econ J 38(152):543–559

Rao BB, Cooray A (2008) Growth literature and policies for the developing countries. MPRA paper No. 10951 https://mpra.ub.uni-muenchen.de/10951/

Regmi K, Rehman A (2021) Do carbon emissions impact Nepal's population growth, energy utilization, and economic progress? Evidence from long- and short-run analyses. Environ Sci Pollut Res 28(39):55465–55475

Rizvi SAF (2019) Health expenditures, institutional quality and economic growth. Empir Econ Rev 2(1):63–82

Romer P (1986) Increasing returns long-run growth. J Polit Econ 94(5):1002–1037

Rosenzweig M (1990) Population growth and human capital investments: theory and evidence. J Polit Econ 98(5):S38–S70

Samah IHA, Abd Rashid IM, Husain WAFW, Ibrahim S, Hamzah H, Amlus MH (2020) The impact of healthcare expenditure and healthcare sector growth on CO_2 emission using dynamic panel data system GMM estimation model during COVID 19 crisis. Int J Energy Econ Policy 10(6):235–241

Saccone D (2017) Economic growth in emerging economies: what, who and why. Appl Econ Lett 24(11):800–803

Solow RM (1956) A contribution to the theory of economic growth. Q J Econ 70(1):65–94

Solow RM (1970) Growth theory: an exposition. Clarendon Press, Oxford

Somé J, Pasali S, Kaboine M (2019) Exploring the impact of healthcare on economic growth in Africa. Appl Econ Financ 6(3):45–57

Swan TW (1956) Economic growth and capital accumulation. Econ Rec 32(2):334–361

Taghizadeh-Hesary F, Taghizadeh-Hesary F (2020) The impacts of air pollution on health and economy in Southeast Asia. Energies 13(7):1812

Travassos GF, Antônio da Cunha D, Coelho AB (2020) The environmental impact of Brazilian adults' diet. J Clean Prod 272 N0. 122622

Twinoburyo EN, Odhiambo NM (2018) Monetary policy and economic growth: a review of international literature. J Cent Bank Theory Pract 7(2):123–137

Uzawa H (1964) Optimal growth in a two-sector model of accumulation. Rev Econ Stud 31:1–24

Wang Z, Asghar MM, Zaidi SAH, Wang B (2019a) Dynamic linkages among CO_2 emissions, health expenditures, and economic growth: Empirical evidence from Pakistan. Environ Sci Pollut Res 26(15):15285–15299

Wang C-M, Hsueh H-P, Li F, Wu C-F (2019b) Bootstrap ARDL on health expenditure, CO2 emissions, and GDP growth relationship for 18 OECD countries. Front Public Health 7 No. 324

Wang C-M, Chang C-Y, Yuan C-C, Wang J, Feng Y (2020) Examining CO_2 emissions, health expenditure, and economic growth nexus for China: A co-integration approach. IOP Conference Series: Earth and Environmental Science 555(1) No. 012020 https://iopscience.iop.org/article/10.1088/1755–1315/555/1/012020/pdf

WHO, World Health Statistics - Monitoring Health for the Sustainable Development Goals (SDGs). https://www.apps.who.int/iris/bitstream/handle/10665/272596/9789241565585-eng.pdf

Xiangyu S, Jammazi R, Aloui C, Ahmad P, Sharif A (2021) On the nonlinear effects of energy consumption, economic growth, and tourism on carbon footprints in the USA. Environ Sci Pollut Res 28(16):20128–20139

Yang X (2019) Health expenditure, human capital, and economic growth: an empirical study of developing countries. Int J Health Econ Manag 20(2):163–176

Yang Z, Abbas Q, Hani I, Alharthi M, Taghizadeh-Hesary F, Aziz B, Muhammad M (2021a) Short- and long-run influence of energy

utilization and economic growth on carbon discharge in emerging SREB economies. Renew Energ 165(1):43–51
Yang X, Li N, Mu H, Zhang M, Pang J, Ahmad M (2021b) Study on the long-term and short-term effects of globalization and population aging on ecological footprint in OECD countries. Ecol Complex 47 No. 100946
Yilanci V, Bozoklu S, Gorus MS (2020) Are BRICS countries pollution havens? Evidence from a Bootstrap ARDL Bounds testing approach with a Fourier function. Sustain Cities Soc No. 102035
Zhang J, Zhang Y (2021) The relationship between China's income inequality and transport infrastructure, economic growth, and carbon emissions. Growth Change NO. 12472
Zangoei S, Salehnia N, Mashhadi MK (2021) A comparative study on the effect of alternative and fossil energy consumption on economic growth and foreign direct investment in selected countries using SUR approach. Environ Sci Pollut Res 28(16):19799–19809