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ORIGINAL PAPER

Urbanization, coal consumption and CO2 emissions nexus in China using bootstrap Fourier Granger causality test in quantiles

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Abstract
This short note aims at revisiting the causal links among urbanization, coal consumption and CO_2 emissions in China using a newly developed Bootstrap Fourier Granger Causality in Quantile test over the period of 1969–2019. The quantile causality approach evaluates causal relationships in a more detailed and flexible way than the conditional mean causality analysis. While the causality definition of Granger (Econometrica 37:424–438, 1969) cannot provide information about a tail causal relation or nonlinear causalities, the Causality in Quantiles test allows us to determine whether extremely low or high changes matter for the urbanization-coal consumption- CO2 emission nexus. Granger causality test based on our proposed model indicates one-way Granger causality running from urbanization to both CO2 emissions (within 0.2 quantile) and coal consumption (within 0.4, 0.6 and 0.8 quantiles) in China. These empirical results have important policy implications for the government conducting urbanization and energy policies in China.

Keywords Urbanization · Coal consumption · CO_2 emissions · Fourier expansion · Granger causality · Bootstrapping procedure · Quantile regression · China

JEL Classification C22 · Q44 · Q53 · R11

1 Introduction

The nexus between urbanization, coal consumption, and CO_2 emissions has attracted the attention of many studies in the literature, especially for developing countries where rates of urbanization change drastically. However, there is no consensus reached in the literature on the direction and size of the impact, as well as

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Table 1 Summary of Previous Literature

Year	Authors	Title	Methodology	Content and Results
2011	Lu and Huang	The impact of urbanization on Co2 emissions for energy in China,	VECM	This paper analyzes the impact of urbanization on CO_2 emissions for energy in China. The sample covers the period from 1980 to 2009. Granger test based VECM show that urbanization Granger causes carbon emissions for energy in China. The relationship of urbanization and CO_2 emissions for energy can be found in a long-run period but no such relationship in a short term.
2014	Wang et al.	Urbanization, energy consumption, and carbon dioxide emissions in China: a panel data analysis of China's provinces	Panel data model	This study investigated the relationship between urbanization, energy consumption, and CO_2 emissions over the period 1995–2011, using a panel data model, based on the data for 30 Chinese provinces. Results indicated that per capita CO_2 emissions in China were characterized by conspicuous regional imbalances during the period studied; in fact, per capita CO_2 emissions decrease gradually from the eastern coastal region to the central region, and then to the western region. Urbanization, energy consumption, and CO_2 emissions were found to present a long run bi-directional positive relationship, the significance of which was discovered to vary between provinces as a result of the scale of their respective economies.
2020	Anwar et al.	Impact of urbanization and economic growth on CO_2 emission: a case of far East Asian countries	Panel data-fixed effect model	This study examines the major determinants of CO_2 emissions in Far East countries in the period of 1980 to 2017. The study finds that urbanization, economic growth and trade openness significantly determine CO_2 emission in the selected countries.

Table 1 (continued)

Year	Authors	Title	Methodology	Content and Results
2016	Wang et al.	Exploring the relationship between urbanization, energy consumption, and CO2 emissions in different provinces of China	the STIRPAT model	This paper investigates the impact of urbanization on energy consumption and CO2 emissions with consideration of provincial differences. Results show: (1) Urbanization increases energy consumption and CO2 emissions in China, but it is not the most outstanding contributor to the increases. (2) Significant differences exist between provinces in terms of the impact of urbanization on energy consumption and CO2 emissions. The distribution of urbanization strongly and relatively strongly affects energy consumption in regions with high-urbanization areas but also those with low-urbanization areas. Meanwhile, urbanization strongly and relatively strongly affects the regional CO2 emissions in northern China, where the major coal production areas, characterized by an energy-guzzling heavy industry base, are located. (3) Some evidence supports the arguments of urban environmental transition theory. Cities at a post-industrial stage (such as Beijing and Shanghai) experience a large effect from urbanization because of higher energy consumption in private residential and public service sectors, while in western and central China, the impact of urbanization can be associated with industrial development, which is characterized by low energy efficiency, high energy consumption and high emissions. In eastern China, the coexistence of light industrial structures and rapid urbanization has led to a smaller impact from urbanization on energy consumption and CO2 emissions than in the other two regions

Table 1 (continued)

Year	Authors	Title	Methodology	Content and Results
2018	Li and Xu	Factors affecting CO2 emissions in China's agriculture sector: a quantile regression	Quantile Regression	This paper divides China's 30 provinces into six quantile grades, and uses the quantile regression method to investigate the driving forces of CO2 emissions under high, medium, and low emission levels. The results show that the effects of economic growth on CO2 emissions in the upper 90th and 75th–90th quantile provinces are higher than in the 50th–75th, 25th–50th, 10th–25th and lower 10th quantile provinces due to the differences in fixed–asset investment and gricultural processing. The impact of energy efficiency in the upper 90th, 75th–90th, and 50th–75th quantile provinces are stronger than those in the 25th–50th, 10th–25th, and lower 10th quantile provinces because of the huge difference in R&D funding and R&D personnel investments. The effect of urbanization in the higher 90th quantile provinces is higher than in the other quantile provinces, owing to the differences in the level of agricultural mechanization and human capital accumulation. Similarly, financial capacity has the largest impact on CO2 emissions in the upper 90th quantile provinces in all quantile provinces. However, the impact of industrialization in the upper 90th quantile provinces is lower than in other quantile provinces. Thus, the heterogeneous effects of the driving forces should be taken into consideration when discussing CO2 emissions reduction in China's agriculture sector.

Table 1 (continued)

Year	Authors	Title	Methodology	Content and Results
2019	Ali et al.	Impact of urbanization on CO2 emissions in emerging economy: evidence from Pakistan	ARDL	Results showed that there was cointegration among the variables. Urbanization was found enhancing carbon emissions both in the long run and short run. Unidirectional short run causality existed from urbanization to carbon emissions. This study provided policy implications. Vehicular emissions can be reduced in urban areas by promoting public urban transportation system. Government interventions are required for adaptation of green technology by urban industrial and residential sectors and campaign should be launched to educate and train people regarding mitigation and adaptation with respect to environmental degradation
2018	Wang et al.	Urbanization, economic growth, energy consumption, and CO2 emissions: Empirical evidence from countries with different income levels	Panel unit root tests and the Pedroni cointegration test	The author(s) empirically explore the link between urbanization, economic development, energy consumption, and CO2 emissions, specifically taking into account the different income levels of the countries studied. A series of panel data models and a balanced dataset for a panel of 170 countries were utilized in the study, which took the period of 1980–2011 into consideration. The result of panel cointegration tests suggested that a cointegration relationship existed between variables in all the countries studied, and that a statistically significant positive relationship existed between the variables employed in the long run. The results of a Granger causality test based on the Vector Error-Correction Model (VECM) provided evidence of varied Granger causality relationships between the variables across the income-based subpanels. Their results cast a new light on the importance of a country's development stage and income level for government policy decisions relating to the reduction of CO2 emissions.

Table 1 (continued)

Year	Authors	Title	Methodology	Content and Results
2020	Udi et al.	New insight into the causal linkage between economic expansion, FDI, coal consumption, pollutant emissions and urbanization in South Africa	ARDL	This study examines the relationship between foreign direct investment inflows and economic growth in a carbon function, by incorporating the role of urbanization, and coal consumption as additional variables to avoid omitted variable bias. Results confirmed the existence of a long-run equilibrium relationship between the outlined series within the period under investigation, with a high speed of convergence. The ARDL equilibrium relationship shows that coal consumption is the largest emitter of carbon dioxide emissions in both short- (0.77%) and long-run (0.86%). Economic growth was found to escalate CO2 emission by approximately 0.27% (in the short-run) and 0.19% (in the long-run). The Granger causality test indicates a non-causal effect between FDI inflow and economic expansion in South Africa, which implies that FDI is not a driver of economic advancement. The empirical study shows a bidirectional causal effect between urbanization and foreign direct investment. This suggests that urban development stimulates foreign direct investment in South Africa. The findings reveal a one-way link from GDP to coal consumption, suggesting economic prosperity promotes coal consumption

Table 1 (continued)

Year	Authors	Title	Methodology	Content and Results
2020	Xu and Lin	Investigating drivers of CO2 emission in China's heavy industry: a quantile regression analysis	Klein's criterion method and Quantile Model	Based on 2005–2017 panel data of China's 30 provinces, this paper uses a quantile regression model to investigate CO2 emissions in the heavy industry. Empirical results show that economic growth exerts a stronger influence on the heavy industry's CO2 emissions in the 25th–50th quantile provinces, due to the difference in the fixed asset investment and heavy industrial output. The impact of urbanization on CO2 emissions in the 10th–25th quantile provinces is lower than that in other quantile provinces because these provinces have the least number of college graduates. Energy efficiency has a smaller impact on CO2 emissions in the upper 90th quantile province, owing to the difference in R&D personnel investment and the number of patents granted. Similarly, environmental regulations have minimal impact on CO2 emissions in the upper 90th quantile province, since the growth rate of industrial pollution treatment investment in these provinces is the lowest. However, the impact of energy consumption structure on CO2 emissions in the 10th–25th and 25th–50th quantile provinces is the highest, because of the provincial differences in coal consumption
2020	Yang et al.	Driving forces of China's CO2 emissions from energy consumption based on Kaya-LMDI methods	Kaya-LMDI methods	This paper analyzes the driving forces of China's CO2 emissions from energy consumption based on Kaya-LMDI methods. Economic activity being the greatest driving force for CO2 emissions growth of China. Reducing the proportion of coal consumption mainly through vigorous development of natural gas currently. Electricity trading can serve as a valid temporary means for reducing CO2 emissions

Table 1 (continued)

Year	Authors	Title	Methodology	Content and Results
2020	Farhan and Balsalobre-Lorente	Comparing the role of coal to other energy resources in the environmental kuznets curve of three large economies	OLS, FMOLS DOLS, and CCR econometric regression	This article examines the dynamic relationship between coal, gas and oil consumption, economic growth and carbon dioxide (CO_2) emissions in the three largest economies namely China, the United States and India, over the period of 1965–2017. The authors employ recent econometric techniques based on the inclusion of structural break(s) in unit root, apply OLS, FMOLS DOLS, and CCR econometric regression to validate the EKC hypothesis for three selected countries. They find that the United States and India exhibit a U-inverted EKC between CO_2 emissions and economic growth. On the other side, China exhibits U-shaped EKC when we include as energy proxy coal and oil consumption. When they explore the connection between carbon emissions and economic growth considering gas consumption, they find a U-inverted EKC. These dissimilar behaviors confirm that the energy pattern of these countries exert a decisive impact over sustainable economic growth, enhancing previous literature that connects fossil sources, economic growth, and environmental degradation process. Their estimation results open up new insights for policy makers to control the level of coal consumption, to sustain economic growth and to mitigate CO_2 emissions
2017	Fan et al.	The impact of urbanization on residential energy consumption in China: an aggregated and disaggregated analysis	Divisia decomposition method	China as the largest developing country still has tremendous potential for urbanization in the future, and this paper thus explores the effect of urbanization on the changes of residential energy consumption during 1996–2012 for China both from aggregated and disaggregated perspectives, using the Divisia decomposition method. The findings on aggregated energy show that the urbanization contributes 15.4% to the increase of residential energy consumption during 1996–2012 but with a diminishing trend over time. Meanwhile, from the disaggregated perspective, the urbanization process contributes to an improvement of residential energy consumption structure. tonnes of oil consumption

Table 1 (continued)

Year	Authors	Title	Methodology	Content and Results
2020	Khan et al.	The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan	ARDL	This primary purpose of this study is to investigate the nexus between energy consumption, economic growth and CO2 emission in Pakistan by using annual time series data from 1965 to 2015. The estimated results of ARDL indicate that energy consumption and economic growth increase the CO2 emissions in Pakistan both in short run and long run
2019	Munir and Nimra	Energy consumption and environmental quality in South Asia: evidence from panel non-linear ARDL	Panel non-linear ARDL	The study uses annual panel data of three South Asian countries i.e. Bangladesh, India, and Pakistan from 1985 to 2017 and applies Panel non-linear ARDL methodology to examine the long-run and short-run relationship. Results show that an increase in gas, electricity, coal, and electricity consumption leads to an increase in the carbon dioxide emission, whereas decrease in electricity and coal consumption reduces the carbon dioxide emissions in the long run. Non-linear relationship exists between electricity consumption and CO2 emissions as well as between coal consumption and CO2 emissions in South Asian countries in the long run. Results of short run dynamics of individual countries show that non-linear relationship exists between oil consumption and CO2 emissions, electricity consumption and CO2 emissions, and coal consumption and CO2 emissions in Bangladesh and Pakistan. Research and development centers are required to control pollution through new technologies, while discourage to use higher electricity and coal consumption as a source of energy for a healthier environment

Table 1 (continued)

Year	Authors	Title	Methodology	Content and Results
2018	Sikdar and Mukhopadhyay	The nexus between carbon emissions, energy consumption, economic growth and changing economic structure in India: a multivariate cointegration approahch.	Multivariate Cointegration Approach	India, one of the fastest growing economies of the world is also one of the largest CO2 emitters in the world. Challenge before the country is to reduce this alarming emission levels without hindering its growth prospects. Against this backdrop, the present paper studies the dynamic causal relationships between India's CO2 emission, energy consumption, GDP growth and changing economic structure. The study uses cointegration and causality analysis - ARDL bound testing approach along with Johansen-Juselius maximum likelihood procedure to examine the existence of long run equilibrium relationship among the variables. Causal linkages between the variables are studied using Granger causality test in Vector Error Correction model framework. This study uses data on India for CO2 emissions, primary energy consumption, GDP per capita and structural variables like, agriculture and service value added, urbanization, production of capital and intermediate goods and employment. Primary energy consumption, per capita GDP and trade openness explain variations in CO2 emissions over long run. Elasticity of CO2 emission with respect to energy consumption is 2 percent in long run and 1.8 per cent in short run. CO2 emissions are less responsive to changes in per capita GDP (0.52) and trade openness (0.10). Both trade openness and GDP per capita growth lower emissions by producing and exporting more labor-intensive environment friendly goods. Causality analysis shows that trade openness Granger causes CO2 emission both in short run and in long run while CO2 emission Granger causes service value added and production of capital and intermediate goods in the short run. Output in these sectors in turn Granger cause employment in the long run. Given the nature of causality, there is no way that India can reduce energy consumption in service sector or in capital and intermediate goods sector

the significance in different stages of development. Table 1 summarize the previous studies. Urbanization is regarded as the other engine to deal with sluggish economic growth in China. As the second largest economy, China was an agricultural powerhouse in the past decades. The rural population takes the proportion of 88.82% of total population in the year of 1950. However, the proportion decreases to 36.16% in 2019 (National Bureau of Statistics of China, 2017–2019). In contrast, the urbanization rate represented by the ratio of urban population to total population peaks on 60.09% in 2019. There are significant achievements in encouraging the population to relocate to urban cities by government policy especially after the implementation of the 11th 5-Year Plan. In 1985, the coal consumption was 1966.55 million tons, but increase to 9017.98 million tons in next 30 years (see Wang et al. 2016; Lin and Xu 2018; and National Bureau of Statistics of China). Besides, developed countries always blame China and other developing countries for high pollutant emission (see Lu and Huang 2011; Wang et al. 2016; Chen et al. 2017; Lin and Xu, 2018; and Chen et al. 2019). To balance urbanization and pollution, the causality among coal consumption, CO_2 emission and urbanization should be figured out beforehand. For this, many scholars contribute their efforts to test whether there are some causal relations among urbanization, coal consumption, and CO_2 emissions.

Knowledge of the causal relationship and the direction among urbanization, coal consumption and CO_2 emissions are of particular importance to policy makers from China to make an appropriate urbanization and energy strategy. This study revisits its urbanization, coal consumption and CO_2 emissions nexus in China using a novel Granger causality namely Bootstrap Fourier Granger Causality in Quantiles (BFGC-Q, hereafter). In fact, we extended the Nazlioglu et al. (2016)'s Fourier Toda-Yamamoto Granger causality test and rather than focusing on a single part of the conditional distribution, the causality is tested in all conditional quantiles. The BFGC-Q test has two main properties more than Toda-Yamamoto GC test. First, the smooth breaks in the deterministic parts (intercept/trend function) are controlled by Fourier expansions. Second, the GC is tested within each conditional quantiles and this property allows us to identify which part of distribution of dependent variables are predicted by covariates. Empirical results indicate ne-way Granger causality running from urbanization rates to both CO2 emissions (within quantile 0.2) and coal consumption (within quantiles 0.4, 0.6 and 0.8) in China. Our empirical results have important policy implications for the government conducting urbanization and effective energy polices in China. We hope the current research can fill the existing gap in the literature.

This study is organized as follows. Section 2 discusses the proposed new Bootstrap Fourier Granger Causality in Quantiles test. Section 3 describes the data used in our study. Section 4 presents the empirical results and some policy implications of these empirical finings. Section 5 offers the conclusions of this study.

2 Methodology

While the causality definition of Granger causality test (Granger 1969) cannot provide information about a tail causal relation or nonlinear causalities, the quantile causality approach evaluates causal relationships in a more detailed and flexible way. In this paper, we propose the Fourier Toda-Yamamoto Granger causality test of Nazlioglu et al. (2016) based on quantile autoregression approach, call Bootstrap Fourier Granger causality in quantiles (BFGC-Q), and apply it to examine the nexus among urbanization, CO2 emissions and coal consumption for China. Following Nazlioglu et al. (2016), to allow for the structural breaks in the deterministic parts of Granger causality equation, the Fourier expansion in the Eq. (1) is included instead of using dummy variables in the Granger causality equation[1]:

$$d(t) = \gamma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) \tag{1}$$

where $d(t)$ is the Fourier function to capture the smooth breaks, k represents the frequency of the Fourier function. γ is the coefficients' vector and measures the amplitude and displacement of the frequency component (sin(.) and cosine(.) terms), and t and T, are the linear trend and number of observations respectively. The sin(.) and cosine(.) terms are included to control for smooth breaks in the deterministic terms of GC equation.

To test the null hypothesis of non-Granger causality using BFGC-Q approach, we design a two steps procedure. In the first step, to control for smooth breaks of deterministic terms, the Fourier expansions $d(t)$ is included in the following Granger causality equation:

$$Y_t = \gamma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^{p+h} \theta_i Y_{t-i} + \sum_{j=1}^{m} \sum_{i=1}^{p+h} \vartheta_{j,i} X_{j,t-i} + \varepsilon_t \tag{2}$$

where Y and X are the dependent and independent variables, respectively, p is lag lengths, h is the maximum integration degree of the variables, and m is number of covariates. To estimate the Eq. (2), we should select the optimal value of k, say k^* and optimal value of lag(s), say p^*. To this end, we do a grid search and for each $i \in \{1, 2, \ldots, p\}$, we select $k = k^*$ as optimum frequency when the SSR is minimized and then select the optimal value of lags, p^*, using AIC criteria. We apply the standard restricted F test statistics to test the null hypothesis of $\gamma_1 = \gamma_2 = 0$.

By choosing the k^* and p^*, we estimate the Eq. (2) by quantile regression rather than OLS estimator:

$$\begin{aligned} Q_{Y_t}(\tau|\mathrm{Z}) = \gamma_0(\tau) + \gamma_1(\tau) \sin\left(\frac{2\pi k^* t}{T}\right) + \gamma_2(\tau) \cos\left(\frac{2\pi k^* t}{T}\right) \\ + \sum_{i=1}^{p^*+h} \theta_i(\tau) Y_{t-i} + \sum_{i=1}^{p^*+h} \vartheta_{j,i}(\tau) X_{j,t-i} + \varepsilon_t \end{aligned} \tag{3}$$

where Z is a matrix of all covariates in the regression model (3). Estimating the regression model (3) by quantile regression approach allows for testing the null

[1] Gallant (1981) and Gallant and Souza (1991) show that a small number of low-frequency components of a Fourier approximation can capture an unknown number of breaks of both gradual and sharp structural breaks.

Table 2 Descriptive Statistics

	CO2 emission	Coal consumption	Urbanization rate
Mean	4080.841	870.2016	33.62721
Median	2970.647	657.2780	28.77509
Maximum	9636.100	1964.372	60.60000
Minimum	748.9334	165.9200	17.13181
Std. dev.	3041.322	640.1929	14.12383
Skewness	0.724057	0.676577	0.479027
Kurtosis	1.937327	1.858888	1.869096
Jarque–Bera	6.721470*	6.527419*	4.576689*

Table 3 Unit Root Test Results

	ADF	PP Level	KPSS	ADF First	PP Difference	KPSS
CO2 emission	−0.4815	−1.2729	0.9280***	−4.032***	−4.0320***	0.1393
Coal consumption	−1.3787	−1.2437	0.9210***	−3.977***	−4.1041***	0.1399
Urbanization rate	−0.8327	0.6452	0.9284***	−2.992**	−3.7260***	0.1994

Notes: ***, ** and * indicate significance at the 1, 5 and 10% levels, separately

Table 4 Fourier Test

Country	Frequency(k*)	Lags(p*)	F_test.	CV 10%.	CV 5%.	CV 1%.
China	2.2	4	10.932	7.295	9.725	11.844

Notes: ***, ** and * indicate significance at the 1, 5 and 10% levels, separately. The optimal Frequency (k*) and optimal lag lengths (p*) were selected based on Akaike Information Criteria (AIC)

hypothesis of Granger non-causality from X to Y (X$\nrightarrow \ominus$Y) at different qunatiles $\tau \in (0, 1)$ as follows:

$$H_0 : \hat{\vartheta}_{j,1}(\tau) = \hat{\vartheta}_{j,2}(\tau) = \ldots = \hat{\vartheta}_{j,p^*}(\tau) = 0, \quad \forall \tau \in (0, 1) \tag{4}$$

The null hypothesis of Granger non-causality in the restriction (4) is tested by following Wald test:

$$\text{Wald} = \left[\text{T}\left(\left(\hat{\vartheta}_j(\tau) \right)' \left(\hat{\Omega}(\tau) \right)^{-1} \left(\hat{\vartheta}_j(\tau) \right) \right) \right] / \tau(1 - \tau) \tag{5}$$

where $\hat{\vartheta}_j(\tau)$ is the vector of estimated coefficients of τ th quantile, $\hat{\Omega}(\tau)$ is the consistence estimator of variance–covariance matrix of the $\hat{\vartheta}_j(\tau)$. As noted by Hatemi and Uddin (2012), due to the existence of autoregressive conditional heteroskedasticity (ARCH) effects in data, they do not usually follow a normal distribution and hence there is the possibility that the distribution of the Wald statistic substantially deviates from its asymptotic distribution. We thus use the bootstrapping simulation technique based on Hatemi and Uddin (2012) approach for 10,000 iterations to

Table 5 Quantile Granger Causality Test among Urbanization, CO2 Emissions and Coal Consumption

Quantile.		Wald test.	CV 10%.	CV 5%.	CV 1%.
0.2	**urb- > co2**	**20.307*(−)**	**19.51815**	**24.35519**	**33.95763**
0.4	*urb- > co2*	14.524(−)	16.47661	19.47738	28.36938
0.6	*urb- > co2*	14.500(−)	16.11807	20.29703	28.80530
0.8	*urb- > co2*	11.709(−)	18.34637	22.19768	35.02754
0.2	*urb- > coal*	8.856(+)	12.91977	16.11109	25.17769
0.4	***urb- > coal***	**11.857*(+)**	**10.66136**	**13.21945**	**20.94988**
0.6	***urb- > coal***	**11.707*(+)**	**10.73598**	**13.31381**	**19.42826**
0.8	***urb- > coal***	**15.571**(+)**	**11.83754**	**15.50671**	**22.78791**
0.2	*Coal- > urb*	1.769071	13.99525	17.15605	22.75656
0.4	*Coal- > urb*	5.245431	12.91664	15.31553	21.32435
0.6	*Coal- > urb*	3.580045	13.42595	15.91215	21.61505
0.8	*Coal- > urb*	5.789532	13.32118	16.04395	23.16991
0.2	*Co2- > urb*	2.152669	11.95559	14.44752	20.47196
0.4	*Co2- > urb*	4.417209	10.33864	12.16026	16.63627
0.6	*Co2- > urb*	2.532755	10.75744	13.16156	18.77115
0.8	*Co2- > urb*	3.811039	10.33421	13.04328	18.59180
0.2	*Co2- > coal*	8.414537	78.38193	92.62099	136.4971
0.4	*Co2- > coal*	13.38794	67.07499	78.12333	106.6060
0.6	*Co2- > coal*	7.839909	66.97396	79.28708	108.1799
0.8	*Co2- > coal*	27.03600	70.92937	87.30942	125.4781
0.2	*Coal- > co2*	8.414537	78.32335	94.12945	129.8887
0.4	*Coal- > co2*	13.38794	69.80537	81.85724	111.5283
0.6	*Coal- > co2*	7.839909	68.11817	81.07477	112.2653
0.8	*Coal- > co2*	27.03600	70.73266	86.10617	130.0532

Bold values indicate significance

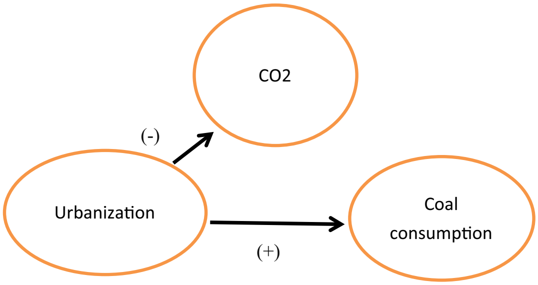
Notes: The frequency of the data is monthly. CV10%, CV 5%, and CV1% are the critical values of statistical significance, respectively. (*), (**), and (***) denote, rejection at the 10%, 5% and 1% levels, respectively. (−) and (+) mean negative and positive impacts, respectively

construct the 10%, 5%, and 1% critical values from the empirical distribution. We also computed the critical values of restricted F statistics (to test the null hypothesis of absence of sin(.) and cosine(.) terms in the Eq. (2)) using bootstrapping procedure.

3 Data

We apply annual data covering the period from 1969 to 2019 for China. The variables used in this study include the coal consumption, CO_2 emissions and the ratio of urban population to total population used to indicate urbanization. Both urban population and total population are retrieved from National Bureau of Statistics of China and both CO_2 emissions and coal consumption are retrieved from *BP Statistic Review of World Energy* (June, 2019). Table 1 reports the summary statistics for the

Fig. 1 Granger Causality Test Direction



data series. Jarque–Bera statistics indicate that CO_2 emissions, coal consumption, and urbanization are non-normally distributed. By looking at the data series plots that we find that all three variables are trending upwards although urbanization grew slower than both CO_2 emissions and coal consumption.

4 Empirical results and policy implications

In this study, we apply BFGC-Q approach to test the causal relationship among urbanization, coal consumption, and CO_2 emissions in China over 1969–2019. Firs we go for traditional unit root tests and then BFGC-Q test.

(1) Results from the Unit Root Test

We first apply several conventional unit root tests such as the ADF, PP, and KPSS and results are reported in Table 2. We find that CO_2 emissions, coal consumption, and urbanization are all non-stationary and becomes stationarity (I(0)) after taking the first differenced (Table 3).

(2) Granger non-Causality Test Results based on Bootstrap Fourier Quantile Model

To test the Granger causality, first we test the absence of Fourier expansion in the Eq. (2) using the conventional restricted F statistics. Before estimating our model, we set the maximum lag lengths ($p=6$) and Frequency (k = 4) respectively. The results from Table 4 indicate the value of F statistics equals 10.932 and greater than its bootstrap critical values at 5% (which equals 9.725). The results indicate the null hypothesis of absence of Fourier components i.e. $\gamma_1 = \gamma_2 = 0$ strongly reject at 5% level of significance. From this Table 4 that we also demonstrate the optimal Frequency (p*) and optimal lag lengths (q*) for Eq. (2) are 2.2 and 4, respectively, based on Akaike Information Criteria (AIC). Table 5 report the results of BFGC-Q test and we find a one-way Granger causality running from urbanization to both CO_2 emissions (within quantile 0.2) and coal consumption (within quantiles 0.4, 0.6, and 0.8). By looking at the sign of the coefficients of the independent variables that we find urbanization cause coal consumption going up but CO2 emissions going down. Apparently that when urbanization increases, people are provided with energy in a more centralised manner, in addition, people in urban areas tend to belong in higher income and education levels and hence be more conscious about their energy and environmental behaviours, causing thus CO_2 emissions to reduce (see Table 5 and Fig. 1). This means that when urbanization causes coal consumption to go up, coal consumption used in more efficient way in urban area, therefore CO_2 emissions further goes down. Since urbanization would effectively reduce the CO_2 emission, the Chinese government should encourage peasants relocate to urban cities to remove air pollution pressure from dependence of coal consumption in the past and then use coal consumption in more efficient way. The empirical results shed new light on the issues of climate change, the previous suggestions are mainly focused on improving coal utilization efficiency, exploit new energy including solar, nuclear and wind energy, another novel way is urbanization which is also able to reduce CO2 emissions in China.

5 Conclusions

China is coming under increasing pressure from its local population and the rest of the world to pay more attention to reducing their contribution to the emission of local air pollutants and greenhouse gases to mitigate the effects of pollution on health and climate change respectively. In this empirical note, we revisit the causal links among urbanization, coal consumption and CO_2 emissions nexus in China using a newly developed Bootstrap Fourier Quantile model over the period of 1969–2019. Empirical results indicate urbanization Granger causes both coal consumption and CO2 emissions in China. By looking at the sign of coefficients of the independent variable we find urbanization reduce CO_2 emissions but increase coal consumption. Apparently, cities can play an increasingly important role in helping China meet its future energy and CO_2 intensity reduction targets (Khanna et al. 2013 and 2016).

Our empirical results have important policy implications for Chinese government conducting both urban and efficient-energy polices to reduce CO_2 emissions. A research done by Liu (IEA 2019) suggests that enhancement of energy efficiency coupled with the acceleration of the process of urbanization could help in sustainable development. Figure 1 demonstrates the causal relationship among these three variables (i.e., urbanization, coal consumption and CO_2 emissions). This figure further confirms our empirical findings. Apparently our empirical results are not consistent with that of Wang et al. (2014) and Fan et al. (2017) found that urbanization increases energy consumption and CO_2 emissions in all 30 Chinese provinces but its specific impact varies depending on the province's geographical location and economic structure. Results are also not consistent with those of Jones (1989), Shen et al. (2005), Liu (2009), Peters et al. (2011), Jiang and Lin (2012), Zhang and Lin (2012), Khanna et al. (2013) and Zhou et al. (2015) fund urbanization increases both energy consumption and CO_2 emissions in China. On the other hand, our results are consistent with those of Fan et al. (2006), Wei et al. (2007), Zhu et al. (2012) and

Wang et al. (2014) found that urbanization affected different economies in opposite directions for nine Pacific Island countries and China, respectively.

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