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ORIGINAL PAPER

Cement production, environmental pollution, and economic growth: evidence from China and USA

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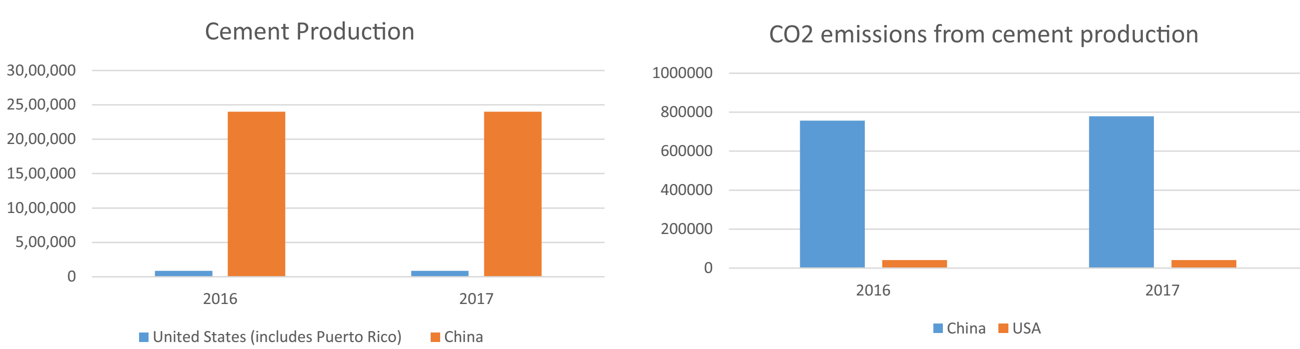
Abstract

The study focuses on the nonlinear Granger causality between cement production, economic growth and carbon dioxide emissions by Markov-switching vector autoregressive (MScVAR) and Markov-switching Granger causality approach for the period of 1960–2017 for China and the USA. The empirical findings from MSIA(2)-VAR(2) for the USA and MSIA(3)-VAR(3) for China suggest that cement production has an important impact on CO_2 emissions and economic growth. Markov-switching causality approach determines the evidence of unidirectional causality running from cement production to carbon dioxide emissions in all regimes for the USA and China. The cement production is an important source of environmental pollution. The USA and China have global responsibility for cement production determined as one of the central sources of carbon dioxide emissions. Moreover, MS-Granger causality results were compared with ones determined by traditional causality method. It was determined that to employ traditional method instead of MS-causality method can cause wrong policy applications if the tested series has nonlinearity.

Graphical abstract



Cement Production and CO2 emissions from Cement Production,
Sources: Andrew:2018 and USGS(2018)

Keywords MS-VAR · MS-Granger causality · Cement production · CO_2 emissions

Introduction

Anthropogenic CO_2 emissions emerge from three key sources: (1) land usage changes and deforestation (2) carbonate decomposition (Andrew 2018) (3) consumption of non-renewable energy. The most important source of emissions caused by the decomposition of carbonates is cement production.

Huge quantities of environmental pollutant, including SO_2, NO_X, CO and PM, are emitted from cement production (Lei et al. 2011). When the cement is produced, the high-temperature calcination of carbonate minerals causes clinker, and CO_2 is emitted into the atmosphere (Xi et al. 2016). The CO_2 emissions from cement production emerge in two aspects. Firstly, it is a rising chemical reaction

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during the production of the major component of cement. The cement is causing oxides (lime, CaO) and CO_2 in the effect of heat. These "process" emissions lead ~ 5% of total anthropogenic CO_2 emissions not including land-use alteration (Boden et al. 2017). Secondly, it is the combustion of non-renewable energy to produce the energy required to heat the raw materials over 1000 °C (IEA 2016).

The process of CO_2 emissions from the cement contains ~ 90% of universal CO_2 emissions from industrial procedures (Xi et al. 2016) and the total emissions of the cement industry form ~ 8% of global CO_2 emission (Le Quéré et al. 2016, 2017; Andrew 2018).

The USA and China are the world's top cement producers and CO_2 emitters. In particular, China's cement production rose dramatically from 2005 to 2010 (Long et al. 2015a, b). China was one of the largest cement producers in 2017. For China, estimations of the United States Geological Survey (USGS) indicate the 2.5 Bnt/yr capacity, while some foundations give cement production of China as nearly 3.5 Bnt/yr. In 2017, the USA has well-structured and large cement production in the capacity of 120.5 Mt/yr. The USGS indicates that the USA generated 82.9 Mt cement by utilizing 109 Mt/yr clinker capacity (Global Cement 2018). In China, the human-induced CO_2 emissions are ~ 30% of global emissions (Shan et al. 2018). The cement industry of China uses ~ 10% of total fossil fuel energy of the country (CCA 2010, 2011; NBS 2014), and this sector is the primary sources of emissions (Shan et al. 2018). In this condition, three-quarters of the increase in universal CO_2 emissions emerge from cement production and the burning of fossil fuels in the process of cement production between 2010 and 2012 in China (Liu et al. 2015). According to Wen et al. and Chen et al. (2015), cement sector in China is responsible for 7% of total fossil fuel usage and 15% of total CO_2 emissions. In the USA, this sector that has the most energy intensive in manufacturing industries consumes one-quarter of one percent of total energy. Share in energy consumed by the cement sector is ~ 10 times the share of goods and services (IEA 2013).

The cement production is one of the important factors affecting environmental pollution, though the relationship has not been analyzed sufficiently in the environmental economics literature. The study aims to analyze the causality based on regime switching in the relationship between economic growth, cement production and CO_2 emissions. To that end, the Markov-switching vector autoregressive (MScVAR) and MScGranger causality methodologies are evaluated for datasets available corresponding to 1960–2017 for the USA and China. The selected countries are the main cement producers in the world. The USA and China have different levels of economic development. The USA, known as the world's biggest economy, has 24% of the world's GDP in 2016. China is an emerging country and its economy is growing at ~ 7% and this rate has almost three times higher than the rate of the USA. China's GDP is ~ 61.7% of the size of the USA GDP, according to IMF estimates in 2017, and China is the second-largest economy all over the world in nominal terms.

In many papers, the real GDP and per capita GDP are used as a measure of economic growth, which is shown to possess a nonlinear structure, i.e., asymmetry between expansionary and recessionary regimes in addition to regimes of accelerated growth and economic crises. The size and magnitude of GDP growth rates are subject to nonlinear adjustments during the phases of the business cycles (Bildirici 2012, 2013a, b). Linear time series do not take into regime changes and regime-dependent asymmetry into consideration. If the stages of the business cycles and/or fluctuations in economic growth are not taken into consideration, policy recommendations determined by the models will be erroneous. While the majority of the literature utilizes controlling the impact of crises with dummy variables, this approach prevents us from getting accurate results. The main difficulty in employing dummy variables is that the breaking points must be identified a priori in addition to assuming linear and constant slope parameters. Major gains of MScVAR method are to examine the model without employing the dummy variables, to explore various regimes of the economy instead of considering the economy in the same level through the analysis period and to determine different coefficients and Granger causalities for each regime of the economy. Moreover, the MScGC analysis presents flexibility in terms of investigating the nonlinear causal relationship between the variables without supposing a stable and linear relationship. In the context of this paper, in particular, the cement production itself is strongly influenced by many irregular events, such as the effect of the construction sector, economic growth and people's psychological expectations. Within this scope, the major reason of employing MScVAR method is to investigate the relationship among cement production, environmental pollution and economic growth in addition to provide important insights regarding the evolution of this relation in different regimes of the economy such as the crisis and expansion regimes. Each regime of the economy needs regime-specific policies, and instead of common and linear policy recommendations, modeling the characteristics of each distinct regime becomes a priority.

This paper aims at not only making contributions to the theoretical but also to the empirical application aspects. Theoretically, it analyzes simultaneously the causal relation between economic growth, cement production and environmental pollution in different regimes of the economy. From an application aspect, the proposed model allows different policy recommendations for different stages of the economy since different regimes of the economy require different policy recommendations.

This paper is configured as follows: The second section gives the literature review. The causal link between cement production and environmental damage in China and the USA is covered in Sect. 3. Section 4 introduces the data and econometric methodology. Section 5 covers the empirical results. And lastly, the policy discussion and conclusions are presented.

Literature review

The literature that addresses the relationships between economic development and environmental pollution focuses on the impact of pollutants, such as carbon dioxide (CO_2), sulfur dioxide emissions and various suspended particles. Accordingly, the possible intensification of pollution was analyzed as economic development strengthens. Grossman and Krueger (1991) provided an analysis evaluating the relation between GDP growth and emission and noted that pollution increases at low levels of per capita GDP and decreases at comparatively higher levels. Shafik (1994) and Shafik and Bandyopadhyay (1992) investigated the environmental Kuznets curve (EKC) and they found that an inverted U-shaped EKC cannot be rejected.

Stern et al. (1996) and Selden and Song (1994) showed that ecological pollutants could decline at higher development levels. Stern (2004) accented that this state could happen in the condition of both the decentralization of industry and the fall in urban population densities. Pettersson et al. (2013) discussed the convergence of carbon emissions and they accepted three convergence approaches: sigma, stochastic and beta. Anjum et al. (2014) suggested the approach covered both beta convergences in addition to findings suggesting EKC-type relations. Their model allowed the analysis of possible convergence, the contributions of economic growth to pollution and time impacts to the progress of pollution.

Keene and Deller (2015) tested an EKC analysis in the USA by making use of the particulate matter (PM 2.5). According to their results, the turning point that defined the existence of the inverted U-shaped EKC wanders between US$24,000 and US$25,500 depending on the estimator employed. Van Donkelaar (2010) found that the uppermost concentrations of PM 2.5 were in eastern China compared to other countries of the world. Chen et al. (2017) focused on the synergy between greenhouse gas (GHG) emissions and local air pollutants (LAPs). Long et al. (2015a, b) analyzed the relationship among CO_2 emissions, energy consumption and economic growth for the 1952–2012 period in China. Naminse and Zhuang (2018) found an inverted U-shaped curve and determined the presence of the EKC hypothesis in China. Luo et al. (2017) tested CO_2 emissions from agricultural economic growth in the period between 1997 and 2014 in 30 Chinese provinces. Long et al. (2018) explored the CO_2 emission intensity in agriculture sector for the 1997–2014 period.

Aside from the papers that test the environmental pollution at the domestic level, there are other papers analyzing the environmental pollution of specific industries. Sun et al. (2011) and Lin and Wang (2015) tested the effects on the environmental pollution of China's iron and steel industry.

For the cement industry, the number of papers evaluating the environmental impacts is rather limited and one conclusion regarding the sector is the increasing energy efficiency. Wang et al. (2013) determined the effects on GHG emission of China's cement sector and showed the central driving reasons of change in GHG releases in the cement sector were cement and clinker productions' activity effect. Teller et al. (2000) found that the CO_2 emission of China's cement sector is higher than CO_2 releases of many countries and the cement sector is one of the main CO_2-releasing manufacturing industry both in China-wide and worldwide. Hanke et al. (2004) analyzed the geographic locations of CO_2 emissions sources in the USA cement industry. Lin and Zhang (2016) tested the CO_2 emission of the cement industry during 1991–2010 in China. The results determined the labor productivity was the main factor in the rise of CO_2 emission in the cement industry in China.

Hasanbeigi et al. (2012) tested an evaluation of China's cement firms following an international scale. Hasanbeigi et al. (2013a, b) explored the decrease in CO_2 emissions and produced policy suggestions regarding the emergence of energy efficiency in cement production. Ke et al. (2012) also concluded huge potential of carbon emission mitigation and energy consumption reduction though energy efficiency measures in China's cement industry. Xu et al. (2012) analyzed the energy consumption of the cement sector and the CO_2 emissions in China and they produced policy implications including cutting down old pollutant plants and encouraging energy efficiency.

Cement production and environmental pollution

Cement production is one of the most important sectors in the development process of a country. The twentieth century witnessed the emergence of big structures, hydroelectric dams, high bridges and highways. Skyscrapers, like the World Trade Center and the Empire State Building in New York City and the Sears Tower in Chicago, used huge amounts of cement, ceramic tiles, etc. In the last of the century, the building of skyscrapers grew in Asia. Another advance of the twentieth century was a rise in home ownership. For example, while less than one-half of the USA population owned their own homes in 1900, (Morse and

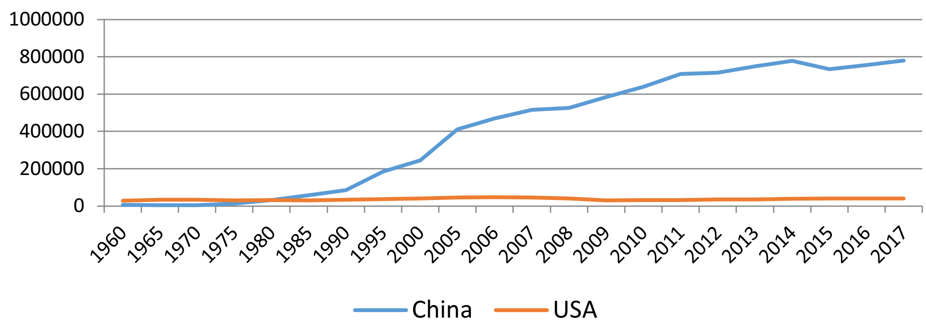

Fig. 1 The emissions from cement production. *Source*: Andrew (2018)

Glove 2000) approximately two-thirds owned their own residences in 2017.

This process accelerated the cement production. In China, the cement industry developed fast especially in recent 30 years in the effect of rapid economic growth and urbanization. Nowadays, China is the main cement producer resulting from rapid urbanization and industrialization which cause fast growth in the construction sector. In effect of this process, the production of cement that is used in the construction sector in all over the world increased through the twentieth century and continues to increase. For example, 76.2 billion tons of cement between 1930 and 2013 and 4.0 billion tons in 2013 alone were produced. Between 1990 and 2014, cement production rose from 209.7 million tons (Mt) to 2476 Mt (CEIC 2017; USGS 2017). Chinese cement production is 2.38 Bnt in 2017. The USA has a large cement production with 120.5 Mt/yr in 2017 (Global Cement 2018).

Figure 1 gives knowledge about the growth of emissions from cement production (Units: kilotonnes).

As the cement production rise, CO_2 emissions from cement production increase. So Baxter and Walton (1970) supplied the estimations for CO_2 emissions from cement production and fossil fuels for the period of 1860–1969. Keeling (1973) specified a systematic analysis of CO_2 emission from non-renewable energy (1860–1969) and cement production (1949–1969). A CaO content estimation for cement production was reported as 64.1% approximately which was found as 272 Mt in 1969. Remarkably, Marland and Rotty (1984) determined the CaO content at the rate of 63.8% in the period of 1950–1982 for the USA.

In the 2000's, in China, 13%–15% of CO_2 emission emerges from the cement production (Xu et al. 2012; Li and Li 2013). In China, the emissions of PM, NO_x, SO_2 are 15–27%, 8–12% and 3–4%, respectively (MEP 2014; Zhang et al. 2015a, b). The calcination is the main source of 50–60% of the CO_2 emission and the rest of the emission is caused by burning fossil fuels using for heating the raw materials in the kiln (NRMCA 2012).

Data and methodology

Data

The data of GDP, CO_2 emissions are given in their respective per capita levels. The cement production for China and the USA covers the 1960–2017 period, and the data are taken from USGS and CEIC for China. The CO_2 emissions per capita data are taken from the CDIAC and USGS. GDP per capita data are taken from the World Bank. The variables are subject to natural logarithms and differentiation which results in obtaining their respective growth rates. As a typical, the cement production data is subject to $\text{lcp}_t = \ln(\text{cp}_t)$ where ln(.) shows the natural logarithms. Similarly, other series are converted as $ly_t = \ln(\text{GDP}_t)$ and $\text{dlco}_{2t} = l\text{CO}_{2t} = ln(\text{CO}_{2t})$.

Markov-switching VAR models

In the study, the MScVAR and MScGC models discussed by Krolzig (1998), Fallahi (2011) and Bildirici (2012, 2013a, b) are to be investigated for the analysis of the causal nexus between the analyzed series. The above-mentioned methodology assumes the variables to be estimated with MSIA(.)-VAR(.) or MSIAH(.)-VAR(.) models to achieve state-dependent causality. The MSIAH(.)-VAR(.) model is stated as

$$y_t = \mu^{(s_t)} + \sum_{i=0}^{i} A_i^{(s_t)} \mathbf{x_t} + u_t^{(s_t)} \quad (1)$$

where $u_t / s_t \sim N(0, \delta^2(s_t))$ and A_i (.) represents the coefficients of the lagged variables in differentiated regimes. The conditional variance $\delta^2(s_t)$ of the residuals is regime dependent. $\mu(s_t)$ describes the dependence of the conditional mean μ of the K-dimensional time series vector on the regime variable s_t. For a two-variate case, the variables are defined in matrix form, $\mathbf{x_t} = [\mathbf{x}_t']' = (y_{t-1}, \ldots, y_{t-p}, x_{t-1}, \ldots, x_{t-p})'$ for $t = 1, 2, \ldots, n$. For the purposes of the study, the variable set includes the GDP growth rates, the cement production growth rates and CO_2 emission growth rates, denoted as ly_t, lcp_t, lCO_{2t}. As a result, $\mathbf{x_t} = \left[\mathbf{x}_t'\right]' = \left(ly_{t-1}, \dots, ly_{t-p}, lcp_{t-1}, \dots, lcp_{t-p}, lCO_{2t-1}, \dots, lCO_{2t-p}\right)$ where the optimum lag length p is selected by depending on an information criterion, such as SIC, AIC or the FPE final prediction error criterion to control for autocorrelation. Assume that P_j is the order of the VAR model, i.e., the number of included lags in regime j. The matrix of transition probabilities $P = \{p_{ij}\}$, where $i, j = 1,\dots, s$ is determined by and the state variable s_t denotes the regime prevailing at time t. The residuals are assumed to follow independent and identical distribution in each regime determined by s_t, therefore, $u_t \sim \text{i.i.d.}\, N\left(0, \delta^2\left(s_t\right)\right)$ if $|\phi| < 1$. It should be noted that, s_t is a discrete variable taking values of 1 or 2 in a two-regime model. In an MScVAR model, s_t is governed by a Markov chain,

$$P_\gamma\left[s_t|\{s_{t-1}\}_{i=1}^{\infty}, \{y_{t-1}\}_{i=1}^{\infty}\right] = P_\gamma\left[s_t|s_{t-1};\rho\right], \tag{2}$$

where p includes the probability parameters, i.e., the state in period t depends only on the state in period $t-1$. Conversely, the conditional probability distribution of y_t is independent of s_{t-1}, that is, $P(y_t|Y_{t-1}, s_{t-1}) = P_r(y_t|Y_{t-1})$.

The Markov chain is ergodic and irreducible, and an absorbing state does not exist, i.e., $\bar{\xi}_p \in (0,\ 1)$ for all $m = 1, \dots, M$ and $\bar{\xi}_p$ is an ergodic or unconditional probability of regime q. The transition matrix is defined as

$$P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \tag{3}$$

p_{ij} that has unconditional distribution is represented as

$$Pr\left(s_t = j|s_{t-1} = i, s_{t-2} = k, \dots, s_0 = h\right) = Pr\left(s_t = j|s_{t-1} = i\right) = p_{ij} \tag{4}$$

and

$$Pr\left(s_t = 1\right) = \frac{1 - p_{22}}{2 - p_{11} - p_{22}}, \quad Pr\left(s_t = 2\right) = \frac{1 - p_{11}}{2 - p_{11} - p_{22}} \tag{5}$$

Following (Hamilton 1990), the EM algorithm is accepted in many empirical analyses. The EM algorithm is designed to estimate the parameters of a model $Pr\left(s_t = j\right)$ represents the restructured (filtered) probability that $s_t = j$ given the information set y_t. Following (Hamilton 1990), ε_{tlt} denotes the vector of forecast probabilities. Optimal forecast probabilities are obtained using

$$\varepsilon_{t|t} = \frac{\varepsilon_{t|t-1}\varphi_t}{1'\left(\varepsilon_{t|t-1}\varphi_t\right)'} \tag{6}$$

$\varepsilon_{t+1|t} = P'\varepsilon_{t|t}$ and φ_t are the vector of conditional densities, 1 is a unit column vector with element-by-element multiplication. The estimation is conducted with,

$$E_t(y_{t+1}) = \sum_{j=1}^{s}\sum_{i=1}^{s} Pr_t(S_t = j)P_{ij}\,(w_0^{(j)} + \sum_{l=1}^{p(j)} \beta_l^{(j)} y_{t-l+1}) \tag{7}$$

MScVAR nonlinear Granger causality

Bildirici (2012, 2013a, b) and Fallahi (2011) utilize the MS-GC for MSIA(H)(.)-VAR(.) models. Dependent upon the coefficients of the lagged values of dly_t $dlcp_t$ and $dlCO_{2t}$ in the equations, one can determine the presence of causalities. The model is given as,

$$\begin{bmatrix} ly_t \\ lCO_{2t} \\ lcp_t \end{bmatrix} = \begin{bmatrix} \mu_{1(st)} \\ \mu_{2(st)} \\ \mu_{3(st)} \end{bmatrix} + \sum_{k=1}^{p} \begin{bmatrix} \phi_{11}^{(j)}st & \phi_{12}^{(j)}st & \phi_{13}^{(j)}st \\ \phi_{21}^{(j)}st & \phi_{22}^{(j)}st & \phi_{23}^{(j)}st \\ \phi_{31}^{(j)}st & \phi_{32}^{(j)}st & \phi_{33}^{(j)}st \end{bmatrix} \begin{bmatrix} ly_{t-j} \\ lCO_{2t-j} \\ lcp_{t-j} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,st} \\ \varepsilon_{2,st} \\ \varepsilon_{3,st} \end{bmatrix} \tag{8}$$

In the dly_t vector, $dlCO_{2t}$ and/or $dlcp_t$ is/are Granger-cause of dly_t in each jth regime if the parameter set or sets of $\phi_{12}^{(j)}$ and $\phi_{21}^{(j)}$, and $\phi_{13}^{(j)}$ and $\phi_{31}^{(j)}$ are statistically different than zero. Accordingly, Granger causalities are detected by testing $H_0 : \phi_{12}^{(k)} = 0$ and $H_0 : \phi_{21}^{(k)} = 0$, $H_0 : \phi_{23}^{(k)} = 0$ and $H_0 : \phi_{32}^{(k)} = 0$, and $H_0 : \phi_{13}^{(k)} = 0$ and $H_0 : \phi_{31}^{(k)} = 0$ for the vector of dly_t (Bildirici and Gökmenoglu 2017).

The empirical results

The study focused on the following steps in the empirical section.

1. NG Perron test is conducted to determine if the variables are stationarity.
2. In the second step, the Johansen cointegration test was evaluated to obtain causality based on the MScVAR models. If the Johansen test fails to produce a cointegrated vector, the innovations of the series are used for MScCausality. Within this approach, the direction of causality is determined as an accuracy model.
3. After testing for the appropriate architecture of the MScVAR model with LL an LR tests, the dating obtained from the MScVAR model is evaluated if the crisis years are captured accurately. In addition to the LL and LR tests, if the dating produced by the model coincides with the crisis dates determined by ECRI, the model will be selected.
4. And lastly, the direction of causality determined by MS-Granger Causality will be compared with the ones determined by traditional causality method.

Table 1 Unit root results

	Mza	MZt	MSB	MPT	Mza	MZt	MSB	MPT
	China				USA			
ly_t	− 1.995	− 1.228	1.962	8.005	− 4.521	− 1.418	0.3137	5.587
dly_t	− 10.881	− 7.324	0.032	1.293	− 30.46	− 3.789	0.1243	1.156
lCO_{2t}	− 2.752	− 1.562	0.995	5.185	− 3.213	− 1.236	0.38461	7.590
$dlCO_{2t}$	− 9.871	− 4.719	0.197	1.674	− 33.92	− 4.088	0.12049	0.814
*l*cp	− 2.551	− 1.9961	0.285	7.172	− 2.152	− 1.036	0.4156	6.152
*Dl*cp	− 11.85	− 3.298	0.172	0.118	− 28.45	− 3.891	0.1156	0.895
Asymptotic critical values								
5%		− 8.10000		− 1.98000		0.23300		3.17000
1%		− 13.8000		− 2.58000		0.17400		1.78000

Table 2 Johansen cointegration test

	China	USA
$r=0$	30.1427	29.23
$r\leq1$	13.619	12.11
$r\leq2$	3.01	2.91

Table 3 Recession and crises dates

China		USA	
Model dating	ECRI	Model dating	ECRI
		1960:1–1961:1	1960:04–1961:02
		1970:1–1970:1	1969:12–1970:11
		1974:–1975:1	1973:11–1976:03
		1980:1–1982:1	1980:01–1980:07 1980:07–1982:11
1988:1–1990	1988:08–1989:12	1990:1–1991:1	1990:07–1991:03
		2001:1–2001:1	2001:03–2001:11
		2007:1–2009:1	2007:12–2009:06
Coincidence ratios: 1/1 = 100%		Coincidence ratios: 6/7 = 86%	

Unit root test results

Firstly, the unit root tests for the integration order of the variables were applied. The results by NG tests were exhibited in Table 1. The results indicated the ly_t, lcp_t and lCO_{2t} variables follow $I(1)$ processes.

Johansen cointegration test results

At the second stage, Johansen's procedure was employed to find the existence of cointegration among ly_t, lcp_t and lCO_{2t}.

The results determined by the Johansen test were exhibited in Table 2 where the null hypothesis of no cointegration was not rejected for the variable under analysis. Since no cointegration relation exists among the variables, the first-differenced or innovation variables, dly_t, dlcpt, and $dlCO_{2t}$, will be investigated with MS-Granger causality.

MS-VAR results

To determine the number of regimes, the tests based on information criteria (AIC/HQ) were employed. It was estimated MSIA(2)-VAR(2) model for the USA and MSIA(3)-VAR(3) for China with 2 and 3 regimes and 2 and 3 lags models, respectively. While regime 1 describes the recession stage, regime 2 depicts the moderate growth and regime 3 characterizes high-growth stages. According to the results, the total time in the growth periods accepted as regime 2 and 3 is longer than the total period of regime 1. It is noted that the transition probability matrix is ergodic and could not be irreducible. In the state of two regimes, the classification rule suggests transmission of the observation as

$$\text{Prob}\left(s_t = 2|s_{t-1} = 2\right) \text{ and } \text{Prob}\left(s_t = 1|s_{t-1} = 1\right) > 0.5 \text{ and } \text{Prob}\left(s_t = 2|s_{t-1} = 1\right) \text{ and } \text{Prob}\left(s_t = 1|s_{t-1} = 2\right) < 0.5.$$

The business cycle characteristics

Table 3 displays the business cycle dates found by the MSc-VAR model and those given by Economic Cycle Research Institute (ECRI). And it exhibits coincidence ratios that suggested by Altuğ and Bildirici (2012) to assess the achievement of the model dating by matching it with ECRI dating.

Table 4 MSIA(2)-VAR(2) model estimation results for the USA

Variables	Regime 1			Regime 2		
	$dl\text{cp}_t$	$dl\text{CO}_t$	$dlyp_t$	$dl\text{cp}_t$	$dl\text{CO}_t$	$dlyp_t$
c	−0.25 (−2.21)	−0.22 (−0.42)	−1.81 (−1.31)	0.22 (2.1)	−0.52 (−0.31)	0.212 (0.12)
$dl\text{cp}_{t-1}$	1.31 (3.2)	0.59 (1.88)	0.356 (2.33)	−0.13 (−0.44)	0.548 (2.23)	0.32 (2.2)
$dl\text{cp}_{t-2}$	0.11 (0.85)	−0.83 (−1.94)	−0.82 (−0.35)	0.33 (2.51)	0.84 (2.24)	−0.22 (−0.66)
$dl\text{CO}_{2t-1}$	0.41 (0.44)	0.52 (2.11)	0.75 (1.92)	0.55 (1.11)	0.234 (2.2)	0.025 (2.221)
$dl\text{CO}_{2t-2}$	0.32 (1.05)	0.323 (1.98)	0.522 (2.18)	0.116 (1.24)	0.51 (2.25)	0.158 (1.29)
dly_{t-1}	0.884 (2.88)	0.11 (1.93)	−0.35 (1.88)	0.385 (2.66)	0.41 (1.75)	0.118 (2.25)
dly_{t-2}	−0.55 (−2.44)	−0.17 (−0.3)	0.42 (1.1)	−0.013 (−2.04)	0.167 (2.25)	0.11 (1.83)
se	0.00125	0.056	0.13	0.0015	0.056	0.13
		Prob.		Trans. prob.		
Reg. 1		0.25		P_{11}		0.65
Reg. 2		0.73		P_{22}		0.82

Log likelihood: 583.24; linear system: 509.04; AIC criterion: 5. 9; linear system: 5.6; LR linearity test: 143.23

[†]For the standard deviation (se) terms, t values are not reported: by testing exclusion of se terms under the null yielded Chi(6) = 470.37[0.00] suggesting acceptance of MSIA(2)-VAR(2) model

For the coincidence ratios, it is permitted maximum inconsistency of two (three) quarters between ECRI dating for China and the USA, and the coincidence ratios were determined as 100% for China and 86% for the USA. The crisis dating results of the model track fairly well the crisis dates given by the ECRI. The results exhibit significant levels of asymmetries.

MScVAR estimation and MScGranger causality results[1]

The MS-VAR model has two regimes, both of which are defined with three vectors, where the included variables are dly_t, dlCO_{2t} and dlcp_t, respectively. Furthermore, it should be noted that the variables dly_t, dlCO_{2t} and dlcp_t are innovations of economic growth, cement production and CO_2 emissions.

To determine regime numbers for the USA, firstly, a linear VAR model was tested against a MScVAR with 2 regimes, and the H_0 hypothesis, which hypothesizes linearity, was rejected by using the LR test statistics. H_0 hypothesis implies that there are 2 regimes that were not rejected, and MScVAR model with 2 regimes was accepted as the optimal model because LR statistic was greater than the 5% critical value of χ^2. To determine regime numbers in China, firstly, a linear VAR model was tested against a MScVAR with 2 regimes, and the H_0 hypothesis, which hypothesizes linearity, was rejected by using the LR test statistics. Secondly, a MScVAR model with 2 regimes was tested against a MScVAR model with 3 regimes; H_0 hypothesis implied that there are 2 regimes that were not accepted and MScVAR model with 3 regimes was accepted as the optimal model because LR statistic was greater than the 5% critical value of χ^2. Therefore, the number of regimes was determined as 3. The results of the MSIA(2)-VAR(2) model for the USA were exhibited in Table 4. The computed regime probabilities are $\text{Prob}(s_t=2|s_{t-1}=2)=0.82$ and $\text{Prob}(s_t=1|s_{t-1}=1)=0.65$. The growth stage of the economy in regime 2 is persistent. The computed probability that the crisis regime is followed by growth period was determined as 0.33. By considering the conditions depicted above, the existence of asymmetry cannot be rejected.

In China, the results of the MSIA(3)-VAR(3) model are given in Table 5. The computed regime probabilities are $\text{Prob}(s_t=1|s_{t-1}=1)=0.62$, $\text{Prob}(s_t=2|s_{t-1}=2)=0.81$ and $\text{Prob}(s_t=3|s_{t-1}=3)=0.55$. The growth stage of the economy in regime 2 is persistent. The existence of asymmetry cannot be rejected. Ergodic probabilities reveal that dominant regime is the second regime and $p_{11}=0.20$, $p_{22}=0.52$ and $p_{33}=0.267$ report an important asymmetry.

The dependent variable of the first vector is dlcpt, the innovations of cement production. It should be noted, since China and the USA are cement producers, and additionally, if considered the size of the economies of the USA and China, the GDP on cement production is expected to have important effects. In regime 1, the overall effect of GDP innovations on innovations of cement production is positive in lag (−1), but negative in lag (2) for both countries. The dependent variable of the second vectors in all regimes is dlCO_{2t}, that is, innovations of carbon dioxide emissions. In the second vector, the majority of the parameters are statistically significant

[1] The MScVAR and MScGC analyses are realized in Oxmetrics package 3.

Table 5 MSIA(3)-VAR(3) model estimation results for China

Variables	Regime 1			Regime 2			Regime 3		
	$dl\mathrm{cp}_t$	$dl\mathrm{CO}_t$	$dlyp_t$	$dl\mathrm{cp}_t$	$dl\mathrm{CO}_{2t}$	$dlyp_t$	$dl\mathrm{cp}_t$	$dl\mathrm{CO}_{2t}$	$dlyp_t$
c	0.11 (1.6)	0.18 (2.5)	1.4 (1.8)	0.22 (2.2)	1.2 (1.9)	0.11 (1.7)	1.3 (2.1)	0.1 (1.72)	1.1 (1.8)
$dl\mathrm{cp}_{t-1}$	0.17 (2.6)	−0.17 (1.17)	0.51 (3.6)	0.33 (3.5)	0.32 (2.8)	0.19 (1.2)	0.65 (5.5)	1.46 (5.1)	0.98 (0.9)
$dl\mathrm{cp}_{t-2}$	0.36 (1.9)	0.98 (2.99)	−2.5 (5.81)	0.191 (2.13)	0.256 (1.8)	0.17 (2.3)	−0.41 (2.2)	0.85 (2.1)	0.32 (2.5)
$dl\mathrm{cp}_{t-3}$	−0.7 (−0.5)	0.62 (3.8)	1.1 (3.4)	−0.09 (1.14)	0.13 (1.7)	−0.13 (2.06)	0.88 (1.01)	0.343 (0.4)	−0.42 (1.87)
$dl\mathrm{CO}_{2t-1}$	−0.17 (0.9)	0.1 (0.88)	−0.52 (−3.2)	−0.33 (0.7)	0.78 (5.9)	0.178 (2.5)	−0.87 (1.1)	1.16 (2.5)	0.22 (2.6)
$dl\mathrm{CO}_{2t-2}$	0.2 (1.3)	0.96 (3.57)	0.66 (4.3)	0.63 (0.8)	−0.19 (3.18)	−0.13 (1.8)	0.58 (1.32)	0.14 (2.5)	0.11 (2.2)
$dl\mathrm{CO}_{2t-3}$	−0.07 (0.1)	0.89 (1.3)	0.66 (2.2)	−0.27 (0.6)	−0.28 (5.6)	0.016 (0.4)	0.27 (1.1)	0.29 (2.2)	0.22 (1.9)
dly_{t-1}	0.92 (4.8)	−0.78 (−2.6)	1.5 (5.3)	+0.43 (2.9)	0.21 (3.83)	0.76 (6.9)	0.17 (2.9)	0.31 (0.1)	0.33 (3.1)
dly_{t-2}	−0.51 (1.5)	0.69 (1.5)	−0.22 (1.3)	−0.76 (−5.9)	−0.66 (2.87)	−0.41 (3.9)	0.41 (2.71)	0.878 (2.8)	−0.12 (2.5)
dly_{t-3}	0.57 (3.8)	−1.73 (2.8))	1.7 (3.5)	0.06 (0.79)	0.55 (2.99)	0.453 (7.2)	−0.03 (0.2)	0.44 (2.4)	−0.13 (1.4)
se	0.013	0.019	0.010	0.013	0.0191	0.23	0.013	0.019	0.010

	Prob.	Trans. Prob.	Reg. 1
Reg. 1	0.2	P_{11}	0.62
Reg. 2	0.52	P_{22}	0.81
Reg. 3	0.27	P_{33}	0.55

Log likelihood: 432.56; linear system: 289.229; AIC criterion: 12.47; linear system: 9.55; LR linearity test: 286.66; Chi(60) = [0.00]; Chi(66) = [0.00]; DAVIES = [0.00]. [†]For the standard deviation (se) terms, t values are not reported: by testing exclusion of se terms under the null yielded Chi(6) = 470.37[0.00] suggesting acceptance of MSIA(2)-VAR(2) model

at the conventional levels that in regime 1; the innovations of cement production and economic growth on *carbon dioxide emissions* cannot be rejected. In regime 1, once the parameter estimations and their statistical significances are evaluated, the overall effects of GDP growth and cement production innovations on *carbon dioxide emissions* innovations are statistically significant, leading to the conclusion that GDP growth and cement production have both positive and negative impacts on *carbon dioxide emissions*. For China, in lag (−2) and lag (−3) in regime 1, 2 and 3, the coefficients are positive and very high in lag (−2) with 0.98 and 0.849 values in both regime 1 and regime 3, respectively. For the USA, in lag (−1) in regimes 1 and 2, the coefficients are positive and close to 0.6, but the coefficients in lag (−2) in regime 1 and regime 2 exhibit differentiated values and signs of coefficients with −0.83 and +0.84.

In all regimes, the cement industry has important effects on CO_2 emissions.

Following Bildirici (2012, 2013) and Fallahi (2011), the estimation results of the MS-VAR model were used to obtain MS-Granger causality. As pointed out by Bildirici (2012, 2013a, b) and Fallahi (2011), the estimation results of the MScVAR model can be extended to MScVAR-based nonlinear Granger causality. The results were reported in Table 7.

Traditional and MScCausality results

In this section, the potential similarities and differences of causality results determined by two different methods are compared because the determination of the direction of causality offers important visions about the policy recommendations. The traditional causality results are exhibited in Table 6. For China and the USA, the cement production is not the Granger-cause of CO_2 emissions and CO_2 emissions are not the Granger-cause of cement production. For China, the results determined that there is the evidence of unidirectional causal nexus from cement production to economic growth and from economic growth to carbon dioxide emissions. For the USA, the evidence of non-causality between cement production and economic growth, and between carbon dioxide emissions and economic growth was found.

The results of MScCausality are given in Table 7. The results determined by traditional causality and MScGC tests are drastically distinguished from each other.

Table 6 Linear Granger causality results for the USA

	$dl\mathrm{cp} \to dl\mathrm{CO}$ $dl\mathrm{CO}_2 \to dl\mathrm{cp}$	$dl\mathrm{cp} \to dly$ $dly \to dl\mathrm{cp}$	$dly \to dl\mathrm{CO}_2$ $dl\mathrm{CO}_2 \to dly$
China			
	0.45	3.62	2.89
	0.275	0.52	0.42
Direction of causality	$dl\mathrm{cp} \neq dl\mathrm{CO}_2$	$dl\mathrm{cp} \to dly$	$dly \to dl\mathrm{CO}_2$
USA			
	0.898	1.25	0.27
	0.36	0.52	1.02
Direction of causality	$dl\mathrm{cp} \neq dl\mathrm{CO}_2$	$dl\mathrm{cp} \neq dly$	$lydl \neq dlCO_2$

Table 7 MScGranger causality results for China and the USA

	USA		China		
	First regime	Second regime	First regime	Second regime	Third regime
Direction of causality	$dlcp \leftrightarrow dly$	$dlcp \leftrightarrow dly$	$dlcp \leftrightarrow dly$	$dlcp \leftrightarrow dly$	$dlcp \leftrightarrow dly$
Direction of causality	$dlcp \rightarrow dlCO_2$	$dlcp \rightarrow dlCO_2$	$dlcp \rightarrow dlCO_2$	$dlcp \rightarrow dlCO_2$	$dlcp \rightarrow dlCO$
Direction of causality	$dly \leftrightarrow dlCO_2$	$dly \leftrightarrow dlCO_2$	$dly \leftrightarrow dlCO_2$	$dly \leftrightarrow dlCO_2$	$dly \leftrightarrow dlCO$

For China and the USA, the MScGC results found the evidence of one-way causal link from cement production to carbon dioxide emissions in all regimes. In all regimes, there is the evidence of two-way causal nexus between cement production and the economic growth for both China and the USA. And in all regimes in China and USA, there is the evidence of two-way causal nexus between carbon dioxide emissions and economic growth. As similar to the results of this paper, Lu (2017) determined bidirectional Granger causality between environmental pollution and economic growth for 16 Asian countries from 1990 to 2012. As similar to the result of the paper Teller et al. (2000), Lin and Zhang (2016) identified the importance on CO_2 emission of the cement industry in China.

Discussion of empirical results and policy recommendations

Employed methods determined two different results. According to these empirical results, employing traditional method instead of MS-causality method can cause wrong policy applications when the tested series and relations have nonlinearity.

In MScVAR results, in both China and the USA, the evidence of a one-way causal relation from cement production to CO_2 emissions was found and the evidence of a two-way causal relation between cement production and economic growth was noted. Two-way causal nexus postulates that cement production has a significant role in economic growth, decline of cement production can cause slowing economic growth. On the other hand, it can be said that in China and the USA, the cement sector is a main emitter of environmental pollution.

These results determined it will not be possible to reduce CO_2 emissions without reducing cement production because the cement production is the source of CO_2 emissions. But the cement sector can be accepted as the main player in the economic growth. If the environmental effects of cement industry are taken into account, identifying and measuring of the pollutants are as important as to create the effective environmental solutions.

Since a possible slowdown in cement production could be coupled with slowed economic growth, to achieve an improvement in terms of emissions resulting from cement production, it is possible to implement new production techniques and the energy efficiency must be improved by developing technology possessing the above-mentioned concerns (Ishak and Hashim 2015). Furthermore, fossil fuels could be replaced with alternative fuels (Rahman et al. 2015; McLellan et al. 2012). As a substitute to cement, dust from agricultural wastes that found in pozzolanic materials could be used (Aprianti et al. 2015).

The investments in new kiln technologies could decline the carbon dioxide emissions (Hasanbeigi et al. 2013a). Moreover, China's and the USA's cement sector must adopt new dry rotary kilns and they must abandon outdated kilns such as vertical wet kilns and shaft kilns. And new substitutes for the raw material are necessary.

Damages may be decreased by the addition of some materials and substances such as ash from coal furnaces, volcanic materials; blast furnace slag and limestone from steel and iron plants; kiln and pebble dust (Long et al. 2017). And it can be provided to recover by usage of wastes. Moreover, it can be decreased the cement production cost by technology of waste materials (Lamas et al. 2013; Long et al. 2017).

Conclusions

This paper is the first one examining the relation between economic growth, cement production and carbon dioxide emissions for China and the USA by employing MScVAR and MScGC methods. The main findings can be summarized as follows. The evidence of a two-way causal relation between cement production and economic growth was noted. Two-way causal nexus postulates that cement production has an important role in real per capita GDP. The unidirectional causality from cement production to CO_2 emissions was found in all regimes in China and the USA. These results determined the impossibility of reducing CO_2 emissions without decreasing cement production. The results determined by MScGC approaches were compared with the results determined by traditional causality approach. Traditional causality results found non-causality between cement production and CO_2 emissions. According to the implications of these results, cement production would not significantly affect carbon dioxide emissions. The cement production is not a significant factor on CO_2 emissions. If the governments track this suggestion, the determined strategies and policies could reverse the adverse effects on the environment.

Since MScVAR and MScGC approaches capture the phases of business cycles, the results determined with these approaches are superior to the ones determined with the traditional Granger causality test. According to the MScGC results, positive causal effects of economic growth and cement production on CO_2 emissions could not be excluded in all regimes. According to the results determined by MS-Granger causality, the cement production is not the only a source for global CO_2 emissions, but also is the most important one. The cement sector and economic growth have an important impact on the environmental pollution. The USA and China with global responsibility for cement production are determined as one of the central sources of global CO_2 emissions.

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