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DOES CHINA EXHIBIT ANY EVIDENCE OF AN ENVIRONMENTAL KUZNETS CURVE? AN ARDL BOUNDS TESTING APPROACH

This paper is an attempt at empirically studying the link between environmental deterioration, economic growth and trade openness in China. The Environmental Kuznets Curve (EKC) is augmented as a theoretical framework for the study and an Autoregressive Distributed Lag bounds testing approach is applied to test whether China exhibits similar behaviour. With the objective of documenting the impact of economic growth and international trade on the emission of carbon dioxide in China, the traditional income-emissions model is applied with variables such as the GDP per capita, the squared value of the GDP per capita, and trade openness for annual data for the period 1971-2014. The findings of the study show that CO2 emissions in China are highly elastic in terms of their connection to the income levels, and that the income driven growth beyond a certain level makes society cleaner and less polluted. Furthermore, it is also found that, in the long run, the trade-driven growth causes more environmental degradation. The evidence available from this empirical exercise validates the EKC hypothesis for China in the long run. The results have significant policy implications. The policy makers in China should consider emphasising or continuing to promote those policy measures which will make it possible to reduce the emissions from trade induced economic growth.

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Population growth, inefficient technology, weak governance, a poorly developed health sector, low per capita income, and poverty are the common economic problems that affect the less developed countries. In this economic backdrop, the developing countries must design policies geared towards achieving rapid social and economic progress and higher growth (Popp, 2010). However, this leads to a concern regarding whether the environmental aspects are overlooked for the sake of economic growth (Bascom, 2016). Many of the economic gains accrued by the developed world since the industrial revolution of the 18th century in the form of increased wealth, income, standard of living, and improved health care facilities have come at the expense of environmental degradation. The pressure on the environment is the result of the overexploitation and depletion of resources and it leads to environmental constrains in the form of accumulation of CO2 and greenhouse gases in the atmosphere, pollution, and the destruction of eco-systems. Fossil fuels, raw materials, synthetics and chemicals such as pesticides, DDT, etc., which are considered high density pollutants, were used extensively for the purposes of industrial development (WCED, 1987).

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Thus, the lack of development on the one hand, and the process of economic growth on the other hand both have a negative impact on the environment.

According to data taken from World Development Indicators, the global carbon dioxide (CO2) emissions have increased from 4 metric tons per capita in 1970 to 5 metric tons per capita in 2014. During the same period, the global economy has also grown rapidly, as indicated by the rise in the GDP per capita (with 2010 as a constant) from USD 5,199 to USD 10,159. Khokhar (2017) estimated that global CO2 emissions increased by 60% in the period 1990-2013, which, when combating with other greenhouse gases, led to a rise of 0.8 degrees Celsius in the mean global temperature. According to the Intergovernmental Panel on Climate Change (2014), the burning of fossil fuels contributed to as many as 78% of the CO2 emissions in the total of greenhouse gases during the period 1970-2010.

A substantial number of research papers in the past decades have studied the link between CO2 emissions and the pace of environmental degradation (Chng, 2019). While some theories and studies linked the deterioration of the environment with the economic growth of a country, others did not show any evidence to support the existence of such a corelation. Regardless of the growing research on the topic, the inference that the economic activities which lead to economic growth contribute to environmental degradation through CO2 emissions remains an enigma, as each study applies a different strategy, a different methodology, and different sets of data while researching this topic (Chng, 2019).

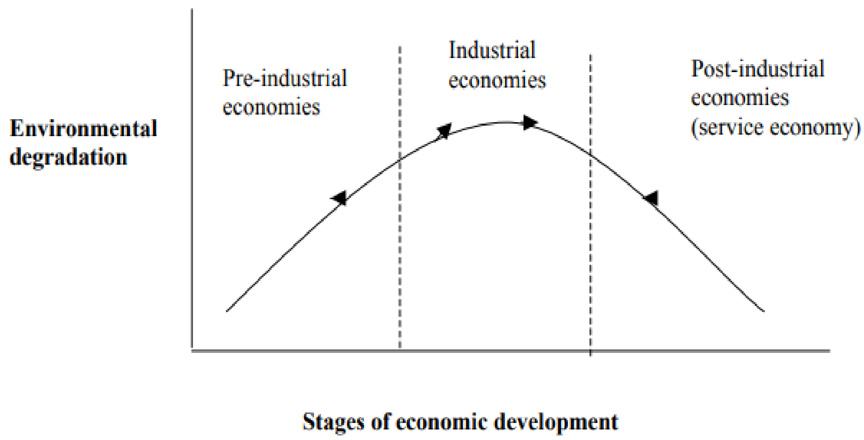
China's economy has been experiencing continuous rapid growth since the late 1970s and its total GDP ranked second in the world in 2018. According to World Bank reports, back in 1980, China was the seventh largest economy in the world, with a GDP of USD 305.35 billion, while the U.S. economy stood at USD 2.86 trillion. Since initiating its market reforms in 1978, the Asian giant has seen an economic growth averaging 10% annually (Investopedia, 2020). The U.S. economy increased to USD 20.58 trillion in 2018 in nominal terms, while China rose to USD 14.14 trillion (IMF, 2018). The GDP per capita in China increased from USD 118 in 1971 to USD 7,651 in 2014. It is noteworthy that, in parallel with this, China suffers from a high degree of environmental degradation. A study by Kan et al. (2012) found that in 17% of the cities in China the air quality is far below the national standards, while for the urban areas the number stands at 75% (Shao et al., 2006). Even more alarming is the fact is that the per capita CO2 emissions have increased by over 86% during the period between 1971 and 2014. Hence, the questions of what the income-emissions relationship in China is emerges. Therefore, the focus of the present paper is to detect whether the environmental degradation in China is augmented by its economic growth process and to verify whether the income-emissions relationship of China exhibits the behaviour outlined in the Environmental Kuznets Curve (EKC). In other words, the major objective of the study is to investigate whether in the early stages of economic growth the environmental pollution in China increased with the increase in income growth, and whether after reaching a certain level of growth, the pollution level declined as the income scaled up further.

Theoretical contradictions

In 1955, Simon Kuznets, a Russian-American development economist, examined the relation between economic growth in terms of income per capita with income inequality using data from three industrialised countries, namely the United Sates, the United Kingdom and Germany. Kuznets (1955) concluded that as the economy embarks on its development path, the income inequality would initially widen, and then gradually narrows down after the economy reaches a certain stage. This resulted in Kuznets developing a hypothesis which posits that income inequality has an 'inverted U' shape if compared against income growth. Years later, Grossman and Krueger (1991) for the first time established the existence of a relationship between economic growth and environmental degradation and found an inverted U-shaped curve identical to the Kuznets curve. The authors determined this curve through analysing the relationship between the GDP per capita and many pollutants, based on data collected from 42 countries. They named it the Environmental Kuznets Curve (EKC). The EKC hypothesis posits that, initially, the environment deteriorates as the economy takes off, and that the damage to the environment gets reduced with the economy growing beyond a certain level.

Figure 1

Environmental Kuznets Curve (EKC)



Source. Panayotou, 1993.

The EKC presumes that the quest for economic growth leads to a higher production and consumption of industrial goods in the economy and that this comes at a trade off with the quality of the environment. The increasing damage to the environment is attributed to various projects that lead to growth in the initial phase. But after reaching a certain level of economic progress, and in parallel with the entry of the economy into the service-oriented sectors, the priority of the people generally shifts towards environmental protection, and the environmental damage decreases alongside the economic growth. Panayotou (1993) illustrated the EKC hypothesis graphically, as depicted in Figure 1. Other researchers (e.g. Shafik and Bandyopadhyay, 1992; Selden and Song, 1994) also corroborated Ponayotou's findings that the relationship between economic growth and environmental quality is not fixed along a country's development path. Instead, when a country reaches a certain level of income, it is expected that the relationship between the two will shift from a positive to a negative one. These authors determined that when people reach a higher level of income they can afford and demand for more infrastructure that is more efficient and geared towards a more cleaner environment. Adding to this, Beckerman (1992) opines that, in the longer run, the inevitable path towards improving the quality of the environment is to increase the economic wealth of a country. Barlett (1994) argued that environmental damages could be controlled through stricter environmental regulations by the government, although such measures can lead to reduced economic growth, at least to some extent (as quoted in Panayotou et al., 1999).

The trends in environmental quality with respect to economic growth, as propositioned in the EKC have been put to question by some theories. The limits theory (Arrow et al. 1996) defines the economy-environment relationship in terms of environmental damage hitting a threshold beyond which production is so badly affected that the economy shrinks (Meadows et al., 2004). The New Toxics theory by Stern (2004) and Davidson (2000) disagrees with the EKC's hypothesis that there exists a turning point in the degradation of the environmental quality and argues that environmental damage continues to expand as economies grow. It has been argued that, with economic growth, the new pollutants that are used as a substitute for the existing pollutants increase. Stern (2004) also proposed a 'race to the bottom' model, which states that, initially, international competition leads to an increase in environmental damage, until the point when the developed countries start reducing their environmental impact and outsourcing their polluting activities to the poorer countries.

The relationship between the quality of the environment and economic growth, as demonstrated by the theories outlined above, is complex and multi-dimensional. There is an absence of conclusive evidence to determine the shape of the economy-environment relationship.

Empirical evidence

The very first evidence for the existence of an EKC type of relationship between environmental deterioration and economic development was explored by Grossman and Krueger (1991). This study investigated the impact of the trade agreement between the USA, Canada and Mexico under NAFTA on the environment. The researchers found that the level of pollution increases in the initial years of economic growth but that after reaching a certain level of per capita income people tend to be more environmentally oriented, and thereby the level of pollution decreases with a further rise in the income of the people. Grossman and Krueger (1991) also tested

EKCs for sulphur dioxide by using data from 42 countries, for dark matter by using data from 19 countries, and for suspended particles by using data from 29 countries for the years 1977, 1982 and 1988. The EKC in the case of the sulphur dioxide and the dark matter could not be explored, but evidence was found that confirms the existence of an EKC for suspended particles. Shafik and Bandyopadhyay (1992) discovered that emissions originally increased and then reduced as the per capita income continued to rise. They studied the patterns of transformation in the environment in 149 countries with different income levels for the period spanning from 1960 to 1990. This study was used by the World Bank as a foundation paper based on which the relationship between the environment and economic growth could be further investigated. An inverted U-shape relationship between the deterioration of the environment and the income growth was confirmed by Panayotou (1993) as well, in a study on the corelation between deforestation and rising income.

Selden and Song (1994) developed a study on cross-national panel data for 130 countries for the period between 1951 and 1986. All four pollutants that were investigated by the model, namely CO2 emissions, SO2, NO2 and suspended particle matter, were found to have an ‘inverted U’ relationship with respect to the GDP per capita. On the other hand, Moomaw and Unruch (1997) could not discover any evidence in support of the EKC hypothesis. According to their study, the per capita CO2 emissions and the per capita GDP in 16 developed OECD countries did not exhibit an ‘inverted U’ relationship. An analysis by Roca et al. (2001) on the relationship between economic growth and six pollutants in Spain did not support the EKC behaviour in the case of five out of the six pollutants, with the exception of SO2. Harbaugh et al. (2000) reached a similar conclusion. Friedl and Gelzner (2003) studied the case of Austria, examining the corelation between CO2 emissions and the GDP for the period 1960-1990, however, they did not find any supporting evidence for the EKC hypothesis.

Kahuthu (2006) studied the relationship between economic growth and the deterioration of the environment and the findings confirmed the existence of an environmental Kuznets curve. The study shows that when the domestic economy integrates with the global economy at an increasing rate in the initial stage, the environmental deterioration rises at rapid pace, but the quality of the environment improves once the economy reaches a certain level of global integration. A study by Tamazian and Rao (2010) found that economic development lowers environmental quality. However, it was found that the environmental deterioration decreases with the increase in the level of economic development, when financial and institutional variables are taken into consideration.

The EKC hypothesis was empirically studied by Narayan and Narayan (2010) using data from 43 developing countries and they found evidence to support the EKC hypothesis in the case of only 35% of the countries. These countries reported lower levels of emission in the long run as compared to the results in the short term. A pooled panel data analysis by Datta (2013) did not find evidence in support of the EKC hypothesis, but rather found an N-shaped pattern of the relationship for most of the countries included for study in the panel. This paper included two different models and both of them had environmental pressure as a dependent variable. However, the explanatory variables in the two models were different. The GDP is the explanatory variable in the first model, while the development balance index (DBI) is the explanatory variable in the second model. The relationship between economic growth, energy use and CO2 emissions in the context of Israel was analysed by Magazzino (2015) for the period 1971–2006. The causality test found that the real GDP drives the use of energy and the emission of CO2. Nevertheless, the forecast error variance decompositions could not support the hypothesis that the forecast errors in the CO2 emissions are connected to the GDP.

Shahbaz et al. (2015) found empirical evidence in support of the EKC hypothesis. They studied the case of Portugal using an autoregressive distributed lag (ARDL) bounds testing approach for the period from 1971 to 2008. The traditional income-emissions model was augmented for the purposes of the study. The emission indicators investigated in the model are energy consumption, urbanization, and trade openness. The results indicate that all the variables show the expected signs, with the exception of trade openness. Nicholas and Ozturk (2015) studied the income-emissions relationship in 14 Asian countries using data for the period from 1990 to 2011. The studied model includes CO2 emissions, GDP per capita, population density, land and industry as shares of the GDP and four indicators of the quality of institutions. The results show evidence to support the EKC hypothesis.

Zambrano-Monserrate et al. (2016) investigated the validity of the EKC hypothesis in the context of Brazil. By estimating an ARDL model, the nexus between CO2 emissions, economic growth, energy use and electricity production from hydro sources in Brazil was studied using annual data for the period from 1971 to 2011. The 'inverted U' relationship between CO2 emissions and economic growth was present in the long-term, thus confirming the existence of an EKC, whereas no evidence was found for an EKC in the short term. Alam et al. (2016) examined whether income, energy consumption and population growth have an impact on CO2 emissions in the short and long run using data from India, Indonesia, China, and Brazil. The results of the conducted ARDL bounds test show that Brazil, China and Indonesia provide evidence in support of the EKC hypothesis. This implies that the CO2 emissions will start decreasing as the income increases after it has reached a specific level. The Indian data show that CO2 emissions and income are in a positive relationship throughout the entire period of study, implying that an increase in income over time will not reduce CO2 emissions. Thus, in the case of India, no evidence was found to support the EKC hypothesis.

Azam and Khan (2016) tested the EKC hypothesis for Tanzania, Guatemala, China and the USA. These countries represent low income, lower middle income, upper middle income and high income countries, respectively. The study model consisted of CO2 emissions as a dependent variable and income, square of income, energy consumption, urbanization, and trade openness as regressors. The model was tested by using a Johansen co-integration estimation and the ordinary least squares method on the data for the period from 1975 to 2014. The results support the EKC hypothesis for the low and lower middle income countries (Tanzania and Guatemala). However, they did not validate the EKC hypothesis in the case of the upper middle income and high income countries (China and the USA). Through an ARDL bounds testing approach, Waluyo and Terawaki (2016) examined the nexus between economic development and deforestation in Indonesia. The results support the long-term 'inverted-U' relationship between the variables. This implies that, as the economy starts growing, the deforestation rate increases and subsequently declines after a threshold point. In contrast, Adu and Denkyirah (2017) arrived at the conclusion that economic growth negatively impacts CO2 in the short term, and that no significant decrease was observed for the pollutant indicator in the long run, which contradicts the EKC hypothesis.

Alvarado and Toledo (2017) also studied the link between economic growth and environmental deterioration by collecting data for Ecuador and they found that an inverse relationship exists between the real GDP and the vegetation cover. This implies that higher economic activities cause larger environmental degradation. The validity of the EKC was also studied by Mrabet and Alsamara (2017). This study developed two different models with different environment indicators as dependent variables. One of the models has CO2 as a dependent variable, while the other one has the ecological footprint (EF) as a dependent variable. The study used annual data for Qatar for the period from 1980 to 2011. The real gross domestic product (RGDP), the square value of the RGDP, energy use, financial development and trade openness are the regressors in both models. The results derived from the estimation of the ARDL model are divided when it comes to the EKC hypothesis. The inverted U-shaped hypothesis is not found valid in the case of CO2 emissions. But the same was found valid when the ecological footprint was the dependent variable.

Gambo (2018) found from a study on Malaysia that the negative impact of economic growth on the environment diminishes in the long run and thereby confirms the existence of an EKC. A study on G-7 countries by Raza and Shah (2018) reported mixed results on the impact of trade, economic growth, and renewable energy on environmental degradation. While economic growth and trade led to an increase in the CO2 emission in the long term, the renewable energy consumption reduced the CO2 emission in the long term. A study by Balcilar et al. (2019) on the EKC hypothesis for G-7 countries also provided mixed results. The EKC hypothesis was found to not be valid for most of the countries. For some of the countries the results showed either C-shaped or N-shaped curves. While for some of the other countries a neutral relation was found between economic growth and environmental quality. Gokmenoglu et al. (2019) validated the EKC hypothesis in relation to deforestation. A study on 12 East African countries by Sisay and Balázs (2019) found a bell-shaped curve and arrived at the conclusion that economic growth projects do not cause environmental degradation.

China-focussed studies also reflected mixed evidence for the EKC hypothesis. George (2003) found evidence in support of the EKC hypothesis, concluding that trade is a significant factor for pollution. Luo et al. (2014) examined whether economic development has an impact on air pollution. The study covered 31 capital cities of provinces in China using data for the period 2003-2012. The results were mixed. In some cases the relationship was quadratic, while in other cases it was negative. Yet, there were also some cases in which the 'inverted U' shape is observed as well.

Zheng et al. (2015) examined the environmental pollution in 111 Chinese prefectural-level cities which were classified into five different clusters. It was found that one of the clusters shows a relationship between pollution and economic growth, and that some of the countries in the cluster corroborate the EKC theory. Zhou et al. (2019) studied the income-emission relationship for seven watersheds and found evidence that supports the EKC hypothesis. These watersheds were found to have surpassed the 'turning point', and with their further development a reduction in emissions was observed.

Model Specification

In order to prove the existence of a link between the income and the emissions, the present study uses an EKC model that is presented in its general form in equation (1). It follows the assumption that the GDP per capita (GDP), the square value of the GDP per capita (GDP^2) and the trade openness (TO) are the expected determinants of carbon dioxide emissions (CO2) in China.

$$CO2 = f(GDP, \mathrm{GDP}^2, TO) \qquad (1)$$

The logarithmic linear specification provides more appropriate and efficient results as compared to a simple linear specification. Furthermore, the logarithmic form of the variables makes it possible to determine the direct coefficients of elasticity for their interpretation (Shahbaz et al., 2015). Therefore, the general linear specification of equation (1) is converted into the logarithmic linear model, which is presented in equation (2) below.

$$logCO2 = \beta1 + \beta2\, logGDP + \beta3\, log\mathrm{GDP}^2 + \beta4\, logTO + \mu \qquad (2)$$

Where, β2, β3 and β4 are the coefficients of elasticity that are to be estimated, while β1 and μ stand for the constant and the error term respectively.

This model has chosen carbon dioxide (CO2) as a proxy for measuring the environmental deterioration. CO2 has the largest share to the total greenhouse gases and hence represents a reflector of environmental pollution. The selection of CO2 as a measure of environmental pollution is also guided by some previous studies (e.g. Schmalnesee et al., 1998; Panayotou et al., 1999) as well. For the purpose of the study, the per capita CO2 emissions are collected and taken into consideration.

In the present study, economic growth is measured by two indicators, namely the GDP per capita and the square value of the GDP per capita, and they form the explanatory variables of the model. Past literature on the topic (Shabhbaz et al., 2015; Chang, 2019; Zambrano-Monserrate et al., 2016) has also considered them as the best available proxies for measuring economic growth in the short run and in the long run, respectively. The GDP per capita (GDP) is measured in USD at a constant rate which was measured for 2010. The study estimates that the GDP per capita has a positive impact on the level of CO_2 emissions. This is also reflected in the fact that, as the economy scales up the exploitation of the resources, environmental deterioration tends to take place at a faster pace. The squared value of the GDP per capita (GDP^2) represents the predicted economic growth of the country. The literature predicts that once the income (GDP^2) level reaches a specific higher level, further growth in income would reduce the levels of emission. This trend could be attributed to behavioural change and technological effects (Everett et al., 2010). Thus, a negative sign is predicted for the coefficient of the non-linear term of the GDP or the predicted GDP (i.e. GDP^2).

The review of the literature on the topic, which was presented above, identified trade openness as one of the potential agents of pollution. Josic et al. (2016) and Chang (2019) measured trade openness as the ratio of the sum of the value of the exports and imports to the GDP. The same estimation methodology has been used in the present study as well. Based on the literature, trade openness is predicted to have a differential impact on the levels of environmental pollution depending on the level of economic growth the country has managed to reach. In order to achieve a cleaner environment, the developed countries move their high pollution intensive industries to less developed economies and begin importing products and goods from such economies. Furthermore, the developed countries tend to have stringent polices on the import of products that contain pollutants. Hence, in the case of developed countries, the coefficient of trade openness is predicted to carry a negative value. At the same time, the developing countries are unable to find even poorer countries in which to relocate their production of pollution-intensive goods (Grossman and Kruger, 1995). Emerging markets rely more on trade as a means of generating further growth. Considering the case of China, much of its economic growth over the recent decades was driven primarily by promoting the export trade of manufactured goods. Hence, for emerging economies, including China, a positive coefficient of trade openness is predicted.

The present study uses annual data from World Development Indicators for the period from 1971 to 2014.

If the TO is excluded from the equation (2), one of the five potential outcomes outlined below can be expected (Stern, 2003; Dinda, 2004; Josic et al., 2016; and Chang, 2019).

- When $\beta 2 = \beta 3 = 0$, no relationship exists between the GDP per capita and the CO_2 emissions.
- When $\beta 2 > 0$ and $\beta 3 = 0$, the variables exhibit a linear relationship, indicating that a rise in the GDP per capita causes an increase in the CO_2 emissions.

• When β2 < 0 and β3 =0, a monotonic decreasing relationship exists between the variables. It suggests that an increase in the GDP per capita will lead to a decrease in the CO2 emissions.

• When β2 < 0 and β3 > 0, a 'U- shaped' relationship is predicted to exists between variables.

• When β2 > 0 and β3 < 0, an 'inverted U' shaped relationship exists between the variables, which validates the EKC hypothesis.

Table 1

Summary of the model estimation

Model: $logCO2 = \beta1 + \beta2\ logGDP + \beta3\ log\mathrm{GDP}^2 + \beta4\ logTO + \mu$		
Variable	Abbreviation	Expected Sign of the Coefficient
Dependent Variable Carbon dioxide emission per capita	CO2	
Independent Variables		
GDP per capita	GDP	+
Squared value of the GDP per capita	GDP^2	-
Trade openness	TO	+

Estimation methodology

The present study uses an Autoregressive Distributed Lag (ARDL) bounds testing approach (Pesaran and Shin, 1995) in order to investigate the EKC behaviour of China based on the data. This approach has been augmented in several past studies as well, because it has two major advantages in comparison with other existing techniques. One such advantage, according to Pesaran (1997) and Narayan (2005), is that the ARDL approach tests the relationship between the variables at different levels irrespective of whether the regressors are purely integrated at the level I(0), purely integrated after the first difference I(1), or a mixture of both; however, the variables should not be integrated after the second difference I(2). But in most of the cases, the time series data are stationary at least in I(1). In order to comply with the statistical requirement that no variable used in this study is in I(2), the study has performed a unit root test using an Augmented Dickey Fuller (ADF) approach. Furthermore, the estimates from the ARDL method are more efficient and less biased. Firstly, Narayan (2005) justifies this with the argument that the ARDL approach can be applied to studies that have small samples, such as the present study, which has a data sample covering 44 years. Peasaran and Shin (1999) also found consistency in the ARDL-based estimators of the long-run coefficients in small samples. Secondly, this approach evaluates the long-term and short-term components of the model simultaneously, removing the problems associated with omitted variables and autocorrelation. Thirdly, unlike Johansen's cointegration approach, the ARDL method distinguishes between dependent and independent variables. In accordance with equation (2), the unrestricted ARDL model has been estimated and presented in equation (3).

$$\Delta \text{ In } (CO2\,)t = \beta 1 + \beta 2 \text{ In}GDPt - 1 + \beta 3\, In\, GDP^2 t - 1 + \beta 4\, InTOt - 1 + \sum_{k=1}^{n} \beta 5k\, \Delta In\, (CO2)t - k + \sum_{k=0}^{n} \beta 6k\, \Delta In\, (GDP)t - k + \sum_{k=0}^{n} \beta 7k\, \Delta In\, (GDP)^2 t - k + \sum_{k=0}^{n} \beta 8k\, \Delta In\, (TO)t - k + \mu, \quad (3)$$

Where, β2, β3 and β4 indicate the dynamics in the long term; β5k, β6k, β7k and β8k represent the short term error correction dynamics; β1 is a constant; and μ is the error. The long term relationship between the variables is verified through the ARDL bounds test, where the null hypothesis is β2 = β3 = β4 = 0, implying that there is no cointegration; and that the alternative hypothesis representing the cointegration is β2 ≠ β3 ≠ β4 ≠ 0. A bounds test has been used to test the hypothesis. Under this method, the calculated F-statistics value is compared with the lower critical bound and the upper critical bound. This study uses the bounds criteria suggested by Narayan (2005), which is better suited for smaller samples of between 31 and 80. When the calculated F-statistics is smaller than the lower bound critical value, the null hypothesis cannot be rejected. If the calculated F-statistics is greater than the upper bound critical value, the hypothesis is rejected.

The selection of optimal lag length is guided by the (most accepted) Schwarz information criteria (SC).

After establishing the long-term cointegration, the short-term behaviour of the variables is examined by estimating a vector Error Correction Model (ECM), as presented in equation (4).

$$\Delta \text{ In } (CO2\,)t = \beta 1 + \sum_{k=1}^{n} \beta 2k\, \Delta In\, (CO2)t - k + \sum_{k=0}^{n} \beta 3k\, \Delta In\, (GDP)t - k + \sum_{k=0}^{n} \beta 4k\, \Delta In\, (GDP)^2 t - k + \sum_{k=0}^{n} \beta 5k\, \Delta In\, (TO)t - k + y * ECTt - 1 + \mu \quad (4)$$

Where, the coefficient (y) of the error correction term (ECT) estimates the speed at which the variables adjust to the long-term equilibrium level. In the present study, (y) is expected to be negative and statistically significant. The applicability of the model is checked through diagnostic tests like the Breusch-Godfrey serial correlation LM test, the cumulative sum (CUSUM) and the cumulative sum squared (CUSUMSQ).

Results and Discussion

As an early step before running the time series data through advanced techniques, a unit root test is applied to check the stationarity of the data sets. Ouattara (2004) states that if any variable is integrated at I(2), then the computation of the F-statistics for cointegration becomes inconclusive. Narayan's (2005) critical bounds, which are used in the present study, are based on the assumption that variables should be stationary at I(0) or I(1). To verify that none of the data series are integrated at I(2), a unit root test applying the Augmented Dickey Fuller (ADF) method has been performed. The unit root test results are presented in Table 2. The result shows that the data series are stationary either at level I(0) or at the first difference I(1), and that none of the series are integrated at the second difference I(2). Though the different data sets are not integrated in the same order, they are statistically fit to undergo an evaluation with the use of the ARDL model.

Table 2

Results of the ADF Unit Root Test

Variables	Order	t-statistic	Critical Value		P-value	Order of Integration	Level of Significance	Decision
CO2	I(0)	0.793154	1%	-2.621185	0.8804	I(1)	10%	Reject H0
			5%	-1.948886				
			10%	-1.611932				
	I(1)	-1.704822	1%	-2.621185	0.0833			
			5%	-1.948886				
			10%	-1.611932				
GDP	I(0)	2.470576	1%	-2.628961	0.9959	I(1)	1%	Reject H0
			5%	-1.950117				
			10%	-1.611339				
	I(1)	-7.317035	1%	-2.624057	0.0000			
			5%	-1.949319				
			10%	-1.611711				
GDP^2	I(0)	-4.417097	1%	-3.605593	0.0011	I(0)	1%	Reject H0
			5%	-2.936942				
			10%	-2.606857				
	I(1)	0.051377	1%	-3.596616	0.9579			
			5%	-2.933158				
			10%	-2.604867				
TO	I(0)	-1.288295	1%	-3.592462	0.6265	I(1)	1%	Reject H0
			5%	-2.931404				
			10%	-2.603944				
	I(1)	-4.806016	1%	-3.596616	0.0003			
			5%	-2.933158				
			10%	-2.604867				

Prior to running the ARDL bounds test for the long-term cointegration, an appropriate lag length is selected. The details of the tests and the results of the selected criteria are presented in Table 3. All the major criteria, including the Schwarz information criteria (SC), suggest a maximum lag order of 2. Furthermore, for annual data, as in the case of this study, Pesaran and Shin (1999) recommend choosing a maximum of 2 lags. Accordingly, the present study chose 2 as the maximum order of lags for the variables selected to be evaluated using the ARDL model for the period 1971-2014.

Table 3

Lag Length Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-989.6276	NA	1.32e+16	48.46964	48.63682	48.53051
1	-701.3321	506.2749	2.26e+10	35.18693	36.02282	35.49132
2	*-651.1053*	*78.40281**	*4.36e+09**	*33.51733**	*35.02193**	*34.06523**
3	-638.4302	17.31241	5.45e+09	33.67952	35.85283	34.47092

* indicates the lag order selected by the criterion; LR: the sequential modified LR test statistic (each test at 5% level); FPE: final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

Using equation (3), an ARDL bounds test for long-term cointegration among the variables in model (1) has been performed and the results are reported in Table 4. The bounds critical table values that are proposed by Narayan (2005) are also presented in Table 4.

Table 4

F-Statistics for testing the existence of long-term cointegration

Model: $CO2 = f(GDP, GDP^2, TO)$ **F-statistic: 4.070516**	Lag structure: ARDL (2,2,2,2,2) Probability: 0.0100		
Level of significance	Bound critical values – Narayan (2005) K=3; n=44		
	I(0)	I(1)	
1%	4.983	6.423	
5%	3.535	4.733	
10%	2.893	3.983	
R-squared	0.847130	Mean dependent variable	0.157212
Adjusted R-squared	0.781615	S.D. dependent variable	0.190524
S.E. of regression	0.089035	Akaike info criterion	-1.746792
Sum squared residue	0.221963	Schwarz criterion	-1.203464
Log likelihood	48.80924	Hannan-Quinn criterion	-1.548942
F-statistic	12.93020	Durbin-Watson statistic	1.827011
Probability (F-statistic)	0.000000		
Diagnostic Checks:			
Breusch-Godfrey Serial Correlation LM Test: Obs*R^2: 2.664559; Prob. Chi-Square(2): 0.2639 *Heteroskedasticity Test: Breusch-Pagan-Godfrey:* Obs*R^2: 8.066432; Prob. Chi-Square(12) - 0.7799 *CUSUM*: Stable; *CUSUMSQ*: Stable			

The calculated F-statistics (4.07) is higher than the upper bound critical value (3.98) at a 10% level of significance. Hence, the null hypothesis, which states that the model variables are not cointegrated, is not acceptable. In other words, the calculated F-statistics above the upper bound critical value indicates that the carbon emissions in China are cointegrated with income and trade in the country.

The stability of the result is verified through the application of several diagnostic tests. The model is tested for serial correlation through the Breusch-Godfrey Serial Correlation LM test and the Durbin-Watson test. These tests indicate that the prognostic model is free from serial correlation. The Breusch-Pagan-Godfrey test detects whether the model encounters any heteroskedasticity issues, however, the test result indicates that the prognostic model is indeed free from any heteroskedasticity issues. The CUSUM and CUSUMSQ tests reflect that the prognostic model is stable.

Table 5

Results of the long-term model

Dependent Variable: *ln CO2*				
Variables	Coefficient	Standard Error	t-Statistic	Probability
Constant	0.907492	0.060765	14.93446	0.0000***
ln GDP	0.001192	9.18E-05	12.97986	0.0000***
ln GDP^2	-6.01E-08	1.17E-08	-5.13278	0.0000***
ln TO	2.696706	0.316292	8.526009	0.0000***

R-squared	0.992253	Mean dependent variable	3.038663
Adjusted R-squared	0.991672	S.D. dependent variable	1.966727
S.E. of regression	0.179480	Akaike info criterion	-0.511003
Sum squared residue	1.288516	Schwarz criterion	-0.348804
Log likelihood	15.24206	Hannan-Quinn criterion	-0.450852
F-statistic	1707.763	Durbin-Watson statistic	0.397939
Probability (F-statistic)	0.000000		

*** 1% level of significance.

The results for the long-term estimates are reported in Table 5. The calculated coefficients for all the regressors in the model are consistent with the expected signs and are statistically significant at a 1% level. The coefficient term of the GDP is positive and it indicates that in the early stage of development with rapid industrialisation the CO2 emissions increase along with the rise in the GDP per capita. The coefficient term of the GDP^2 is negative and implies that with the higher income level of the people, the environmental damage tends to decrease. In other words, the link between the carbon emissions in China and the GDP per capita ceases to exist when the latter rises beyond a specific level. The negative sign of the coefficient of the GDP^2 denotes the delinking of the carbon emissions and the GDP per capita at a high level of per capita income in China. The evidence confirms that carbon emissions increase in the early stage of economic development and that they eventually decline beyond a given threshold of GDP per capita. As per the requirement (Stern, 2003; Dinda, 2004; Josic et al., 2016 and Chang, 2019), the EKC hypothesis is accepted under the condition of: $\beta2 > 0$ and $\beta3 < 0$. The result shows that the calculated $\beta2 > 0$ and $\beta3 < 0$, and hence the relationship between income and emissions appears to have an ‘inverted U’ shape. This provides evidence to validate the EKC hypothesis in the context of China. The results corroborate with some of the other China-focussed studies (e.g., George, 2003; Alam et al., 2016). But, at the same time, they also contradict with the findings of some other studies (e.g., Azam and Khan, 2016).

The result also shows that the relationship between trade openness and CO2 is positive and statistically significant. It means that the increasing open trade policy of China is causing a significant deterioration of the environment. The long-term elasticity of the CO2 emissions in the presence of trade openness is 2.69%. This implies that a 1% increase in the global trade of China would cause a 2.69% increase in the domestic CO2 emission levels.

The short-term dynamics between CO2 emissions and their regressors is tested and the results are reported in Table 6 and Table 7.

Table 6

Short-term dynamics and error correction model

Dependent Variable: ∆ *In CO2*					
Variables	Coefficient Code	Coefficient	Standard Error	t-Statistic	Probability
C	C1	0.042544	0.022696	1.874474	0.0703
∆ *In CO2(-1)*	C2	1.106249	0.198964	5.560058	0.0000
∆ *In CO2(-2)*	C3	0.005767	0.25259	0.022833	0.9819
∆ *In GDP(-1)*	C4	0.000184	0.000449	0.410906	0.6840
∆ *In GDP(-2)*	C5	-0.000213	0.000485	-0.438786	0.6639
∆ *In* GDP^2*(-1)*	C6	-7.72E-08	5.11E-08	-1.511954	0.1407
∆ *In* GDP^2*(-2)*	C7	6.18E-08	5.85E-08	1.056678	0.2988
∆ *In TO(-1)*	C8	-0.794069	0.688266	-1.153724	0.2574
∆ *In TO(-2)*	C9	-1.425576	0.550355	-2.590285	0.0145
ECT(-1)	C10	-0.312734	0.116541	-2.683468	0.0116

R-squared	0.803809	Mean dependent variable	0.157212
Adjusted R-squared	0.746851	S.D. dependent variable	0.190524
S.E. of regression	0.095860	Akaike info criterion	-1.643633
Sum squared residue	0.284864	Schwarz criterion	-1.225688
Log likelihood	43.69447	Hannan-Quinn criterion	-1.491440
F-statistic	14.11217	Durbin-Watson statistic	2.050612
Probability (F-statistic)	0.000000		

Diagnostic Checks:

Breusch-Godfrey Serial Correlation LM Test: Obs*R^2: 0.582487; Prob.Chi-Square(2): 0.7473

Heteroskedasticity Test: Breusch-Pagan-Godfrey: Obs*R^2: 7.336728; Prob. Chi-Square(9): 0.6021

CUSUM: Stable; *CUSUMSQ*: Stable

Table7

F-test result of the joint impact of the lagged terms of Each of the regressors on the CO2 emissions in the short term

Variables	Hypotheses	F-statistic	Probability
∆ In GDP(-1) + ∆ In GDP(-2)	C(4)=C(5)=0	0.109185	0.8969
∆ In GDP^2(-1) + ∆ In GDP^2(-2)	C(6)=C(7)=0	1.27603	0.2934
∆ In TO(-1) + ∆ In TO(-2)	C(8)=C(9)=0	3.76286	0.0344**

** 5% level of significance.

It appears that neither the initial economic growth (GDP) nor the predicted higher rate of economic growth (GDP^2) has any impact on carbon dioxide emissions. In the short term, the GDP per capita and the CO2 emissions are linked. On the other hand, trade openness is found to have a negative and significant impact on the carbon emissions. As outlined in Table 7, the joint impact of the lagged terms of trade openness on the CO2 emissions is statistically significant. Referring to Table 6, the policy of increased trade openness reduces the environmental pollution in China in the short term. Furthermore, it is also noteworthy that the joint impact of the lagged terms of the GDP and the GDP^2 is statistically insignificant. In the short term, China does not exhibit any EKC behaviour. This result is consistent with the findings of Zambrano-Monserrate (2016), and Saboori and Sulaiman (2013).

Referring to the result presented in Table 6, the lagged Error Correction Term (ECT) is negative and statistically significant at a 5% level. The properties of the ECT suggest that deviations from the mean in the CO2 emissions are corrected by 31.27% within a year. This indicates a moderate rate of convergence towards an equilibrium. The negative and significant ECT confirms the established long-term cointegration.

The reliability of the results is verified through a number of diagnostic tests (Table 6). Tests such as the Breusch-Godfrey Serial Correlation LM test and the Durbin-Watson test are conducted to check for the presence of any serial correlation issue. The model is thus proven to be free of any serial correlation problems. By using the Breusch-Pagan-Godfrey test, it has been confirmed that the model does not have any heteroskedasticity issues. The cumulative sum (CUSUM) test statistics and the cumulative sum of squares (CUSUMSQ) test statistics fall within the bounds, at a 5% level of significance (see Figure 2 and Figure 3). The CUSUM and CUSUMSQ statistics signify that the regression coefficient is stable and that the model has structural stability, respectively.

Figure 2

Plot of the cumulative sum of the recursive residuals

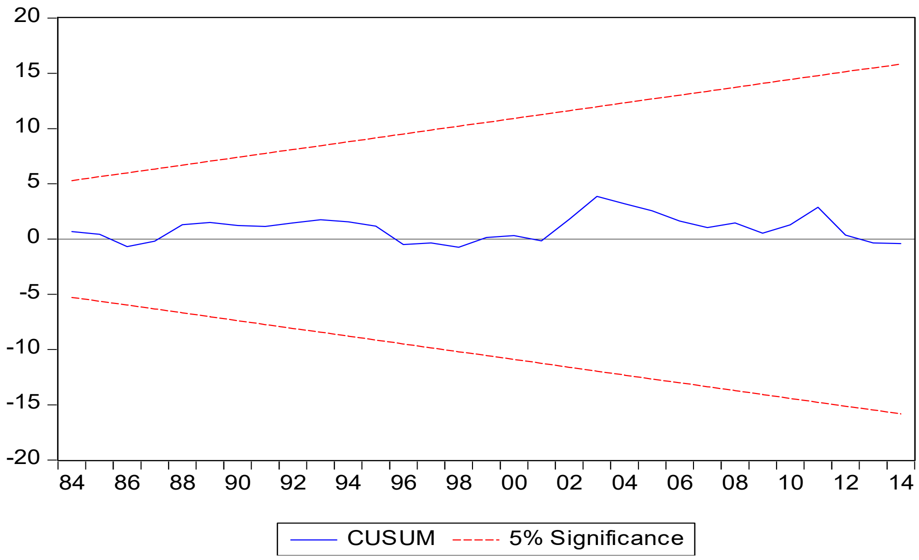
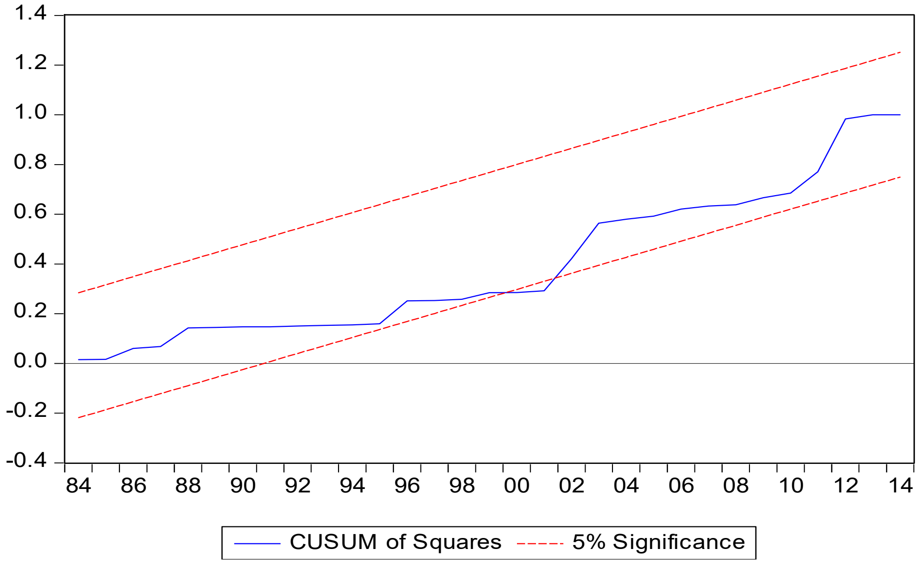


Figure 3

Plot of the cumulative sum of the squares of the recursive residuals



Conclusion and policy implications

In this paper, the EKC hypothesis has been tested for the economy of China based on the data for the period 1971-2014. The ARDL bounds test results identify the existence of a long-term relationship between CO_2 emissions, GDP per capita, and trade openness. The results suggest that in China the CO_2 emissions increase as the economy grows, but that they eventually start decreasing once the GDP per capita reaches a certain threshold level. It is evident that beyond that turning point, as the economy of China continues to develop, the level of environmental pollution has been declining. Everett et al. (2010) attribute the realisation of the EKC trend to the behavioural change and the technological progress that are taking place. During the early stages of growth, the economy is focused on higher levels of production and consumption, regardless of how they are achieved. But after a certain higher level of growth is reached, the need for consumption declines and greater consideration is given to the quality of life and of the environment. Furthermore, as the economy becomes economically more advanced, the technology evolves and the production process becomes more cleaner and more resource efficient. With the advent of the economic reforms in the late 1970s, China shifted its focus from agriculture to manufacturing. However, the constant and rapid exploitation of resources, the speedy urbanisation and the mounting infrastructure have resulted in substantial economic growth, deforestation and an increase in CO_2 emissions, which have in turn caused large-scale environmental deterioration. It is only in the recent years, after reaching a reasonably high level of growth, that China has started initiating sustainability practices. Emphasis has been placed on clean and green energy, as well as on designing environmentally friendly technologies for different production sectors. These efforts seem to be resulting in a gradual decrease in the CO2 emissions as the economy continues to grow.

It is also noteworthy that although in the short term the trade openness policy of China does not appear to be linked to the deterioration of the environment, in the long term, it was found that the CO2 emissions increase with the increased international trade. There is no evidence to support the Kuznets curve hypothesis or the “race to the bottom” hypothesis. This could be attributed to the fact that much of the growth in China over the last three decades has been achieved by increasing the export of manufactured goods and with hardly any outsourcing of the production of highly pollution intensive goods to other poorer countries. Eventually, this led to higher imports of pollution intensive products and a greater exploitation of resources in order to increase the exports. Two major findings could be taken from the present study. Firstly, that the CO2 emissions in China are highly elastic and sensitive to the income levels, and that the income-driven growth beyond a certain level makes society cleaner and less polluted. And secondly, that the trade driven growth causes more environmental deterioration in the long term.

The results based on China’s profile call for immediate policy actions to improve the environmental standards in the country. The policy makers of China should focus on or continue to promote those policy measures which will result in reduced emissions from international trade. The export-oriented industries in China need to implement a cleaner and greener production process. Enforcing strict policy guidelines for sustainability practices in the export sector, although it might affect its economic growth to a small extent in the short term, would result in environmental growth and sustainable development in the long run.

The environmental protection-oriented policy measures may also target the import process and imported products. The items with high pollution intensity that are imported into the country should be tracked down and their inflow could be discouraged by raising the import duties. China should also work towards increasing the share of cleaner energy as an alternative to the imported crude oil. The understanding of the EKC behaviour of China calls for rationalised resource allocation in terms of the budgets allotted to various projects. The budget should be allocated to those infrastructures and trade related projects which are environmentally friendly. Effective policy measures will help China continue to reduce its CO2 emissions as its income continues to grow, and to control the CO2 emissions that arise from trade.

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