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Environment Kuznets curve for CO_2 emissions: A cointegration analysis for China

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ABSTRACT

This study examines the long-run relationship between carbon emissions and energy consumption, income and foreign trade in the case of China by employing time series data of 1975–2005. In particular the study aims at testing whether environmental Kuznets curve (EKC) relationship between CO_2 emissions and per capita real GDP holds in the long run or not. Auto regressive distributed lag (ARDL) methodology is employed for empirical analysis. A quadratic relationship between income and CO_2 emission has been found for the sample period, supporting EKC relationship. The results of Granger causality tests indicate one way causality runs through economic growth to CO_2 emissions. The results of this study also indicate that the carbon emissions are mainly determined by income and energy consumption in the long run. Trade has a positive but statistically insignificant impact on CO_2 emissions.

1. Introduction

The incredible economic growth of China, over the past three decades, is mainly attributed to its impressive industrial growth. However, industrial-based economic growth may inevitably lead to environmental degradation. China is rated as one of the largest contributor of carbon dioxide (CO_2) (IEA, 2008). Its annual growth rate of CO_2 emissions is around 11% during 2004–2009 (Auffhammer and Carson, 2008). China's 11th Five-Year Plan sets quantitative targets for the first time to reduce CO_2 emissions to 1.5 billion tons by 2010, one of the most significant carbon mitigation efforts in the world today (Lin et al., 2008).

Understanding the impact of economic growth on the environmental quality is becoming increasingly important as general environmental concerns are making their way into main public policy agenda. The relationship between environmental quality and economic growth has been empirically modeled through emissions–income relationship by many authors, and the outcome of most of these studies has been formulated by the so called environmental Kuznets curve (EKC) hypothesis. The EKC hypothesis proposes that there is an inverted U-shape relation between environmental degradation and income per capita, or a U-type relationship between environmental quality and income per capita. This has been taken to imply that economic growth will eventually undo the environmental impact of the early stages of economic development.[1] In this paper, for the first time, EKC relationship for CO_2 emissions for China, over a time period of 1971–2005, has been studied. Employment of time series data of a single country also allow to study the historic experiences, environmental policies, development of trade relations and other exogenous factors (Stern et al., 1996) through time.

The rest of the article is distributed into five main sections. Section 2 connects the study with the previous literature on EKC. In Section 3, an analytical framework has been developed based on the literature survey. The empirical model and data employed have been discussed in Section 4. The empirical results have been reported in Section 5, and finally in Section 6 conclusions have been drawn.

2. Literature review

The relationship between economic growth and environmental conditions has remained a debated issue over the last ten years. Several studies, on the subject, have argued that level of environmental degradation and economic growth follows an inverted U-shaped relationship. The growth–environmental pollution nexus has been tested by many after Grossman and Krueger (1995) and Selden and Song (1995) provided the empirical evidence that the economic growth will lead to a gradual degradation of environment in its initial stages and then, after a

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[1] However, despite its importance, there are very few studies that examine the relationship between CO_2 emissions and economic growth for the Chinese economy.

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certain level of growth, it leads to an improvement in the environmental conditions.[2] EKC hypothesis has also been tested for other indicators of environmental degradation, such as deforestation, carbon emissions and municipal waste. However, sulfur dioxide has been among the most commonly used environmental degradation indicators and EKC hypothesis has been shown to hold mostly for sulfur dioxide emissions in the literature.[3] However, an inverted U-shaped function for CO_2 emission has also been reported (DeBruyn et al., 1998; Heil and Selden, 2001; Holtz-Eakin and Selden, 1995; Moomaw and Unruh, 1997) by employing panel data. More recent studies have also reported results on EKC for CO_2, for different countries, by utilizing updated data and employing new techniques (Martinez-Zarzoso and Bengochea-Morancho, 2004; Vollebergh and Kemfert, 2005; Cole, 2005; Galeotti et al., 2006).

Energy consumption is another, along with economic growth, important determinant of CO_2 emissions. There are several studies emerged, in this regard, after the pioneer seminal study of Kraft and Kraft (1978). For example, Masih and Masih (1996), Yang (2000), Wolde-Rufael (2006), Narayan and Singh (2007), and Narayan et al. (2008) test the energy consumption and economic growth nexus with different techniques and different panel of countries. Therefore, it will be more fitting, if economic growth and energy consumption is taken simultaneously in a single multivariate model. Keeping this in view, the recent research is using these two nexus, growth–environment nexus and growth–energy nexus, into a single model. This approach enables the researchers to conduct the validity of both nexuses in the same framework. For example, Ang (2007), Soytas et al. (2007), and Halicioglu (2009) initiated this combined line of research.

Furthermore, most of the existing literature on this issue has employed pooled panel data of a group of countries to establish a link between economic growth and environmental degradation. However, a time series analysis for a single country may provide better framework to study the relationship. It would also allow examining the impact of environmental policies, development of trade relationship and other exogenous factors through time (Stern et al., 1996). Thus, the current study contributes to the discussion on the estimation of EKC for carbon dioxide emissions for a rapidly growing country China. The obvious rational for selecting China for our analysis is that it one of the most important transitional economies that maintained the highest growth rate, among others, over the last 20 years and the largest contributor in CO_2 emissions with the highest energy consumptions.

3. Econometric specification

This article follows closely the methodology of the recent studies (Ang, 2007; Soytas et al., 2007; Ang, 2008) that are using two nexus, (1) economic growth–environmental pollution nexus and (2) economic growth–energy consumption nexus, into a single multivariate framework. Furthermore, following Halicioglu (2009), our econometric model also includes the impact of foreign trade into the nexus to reduce the problems of omitted variable bias in the econometric estimation. Furthermore, Antweiler et al. (2001) and Cole and Elliott (2003) have argued that it is possible to decompose the environmental impact of trade liberalization into scale, technique and composition effects. On the one hand increase in the size of the economy (scale effect) is likely to increase pollution and on the other adoption of better production methods (technique effect) is expected to improve the environmental conditions through more competition among the competing firms and causing the most energy-inefficient firms to leave the industry (Ang, 2009). The direction of composition effect on environmental conditions, however, would depend on country's comparative advantage. So the net effect of more trade on environment is likely to be indeterminate. And therefore needs to be tested empirically.

A log linear quadratic equation is specified to test the long-run relationship among CO_2 emissions, energy consumption, economic growth and foreign trade in order to test the validity of the EKC hypothesis. The estimable econometric regression line is as follows:

$$c_t = \beta_0 + \beta_1 e_t + \beta_2 y_t + \beta_3 y_t^2 + \beta_4 tr_t + \varepsilon_t \tag{1}$$

where c_t is CO_2 emissions per capita, e_t is commercial energy use per capita, y_t is per capita real income, ${y_t}^2$ is square of per capita real income, tr_t is openness ratio which is used as a proxy for foreign trade, and ε_t is the regression error term. The lower case letters in Eq. (1) show that all variables are in their logarithmic form.

Generally, it is expected that the higher level of energy consumption should result in greater economic activity and stimulate CO_2 emissions; therefore, it is expected that $\beta_1>0$ in Eq. (1). Under the EKC hypothesis, the sign of β_2 is expected to be positive whereas a negative sign is expected for β_3. The expected sign of β_4 is mixed depending on stage of economic development a country. This may be negative in the case of developed countries, as it may reduce the production of pollution intensive goods and instead import these from other countries with less restrictive environmental protection laws. On the other hand, the sign of β_4 may be positive in the case of developing countries as they tend to have dirty industries with heavy share of pollutants (Grossman and Krueger, 1995; Halicioglu, 2009).

4. Estimation strategy

Problem of spurious regression may arise when time series data is employed in the level or non-stationary form. One of the solutions is to make the series stationary by differencing. However, differencing of the series would prevent long-run analysis. In order to circumvent this problem, a number of techniques can be employed to test for the existence of the long-run equilibrium relationship – cointegration – among the time series variables. In this paper a relatively new technique has been employed that has been introduced by Pesaran and Pesaran (1997), Pesaran and Smith (1998), Pesaran and Shin (1999), and Pesaran et al. (2001). This methodology is referred as autoregressive distributed lag model (ARDL), and it is based on the general-to-specific modeling technique. The ARDL has several advantages to the other techniques of cointegration.

One of the main advantages of this technique is that it can be applied irrespective of whether the variable is I(0), I(1) or fractionally cointegrated (Pesaran and Pesaran, 1997). The other advantage is that the model takes sufficient number of lags to capture the data generating process in a dynamic framework of general-to-specific modeling framework. Furthermore, the error correction model (ECM) can be derived from ARDL through a

[2] For example, Shafik (1994), Heil and Selden (1999), Friedl and Getzner (2003), Dinda and Coondoo(2006), Coondoo and Dinda (2008), and Managi and Jena (2008) have tested the EKC hypothesis. Ekins (1997), Dinda (2004), Stern et al. (1996), and Stern (2004, 1998) provided a comprehensive and critical survey on the subject.

[3] A survey of EKC studies on sulfur by Stern et al. (1996) lists several reasons why choice of sulfur is of interest. For example, for sulfur, simultaneity problem in the econometric analysis will be less important as compared to other indicators such as carbon dioxide and deforestation; substitution possibilities are larger for sulfur.

simple linear transformation. ECM integrates short-run adjustments with long-run equilibrium without losing long-run information. Moreover, small sample properties of ARDL approach are far superior to that of the Johensen and Juselius's cointegration technique (Pesaran and Shin, 1999). Furthermore, endogeneity is less of a problem in ARDL technique because it is free of residual correlation. Pesaran and Shin (1999) also demonstrated that the simultaneous estimation of long-run and short-run components and appropriate lags in the ARDL framework remove the problem that are associated with serial correlation and endogeneity problems. Finally, another important advantage of ARDL procedure is that the estimation is possible even when the explanatory variables are endogenous (Pesaran and Pesaran, 1997; Pesaran et al., 2001).

ARDL framework of Eq. (1) of the model is as follows:

$$\Delta c_t = \beta_0 + \sum_{i=1}^{p} \delta_i \Delta c_{t-i} + \sum_{i=1}^{p} \phi_i \Delta e_{t-i} + \sum_{i=1}^{p} \varpi_i \Delta y_{t-i} + \sum_{i=1}^{p} \gamma_i \Delta y^2_{t-i} + \sum_{i=1}^{p} \theta_i \Delta tr_{t-i} + \lambda_1 c_{t-1} + \lambda_2 e_{t-1} + \lambda_3 y_{t-1} + \lambda_4 y^2_{t-1} + \lambda_5 tr_{t-1} + U_t \quad (2)$$

where β_0 is drift component and U_t white noise. Furthermore the terms with summation signs represented the error correction dynamics. While the second part of the equation with λ_i corresponds to the long-run relationship.

The ARDL model testing procedure starts with the bound test. The first step in the ARDL bounds test approach is to estimate Eq. (2) by ordinary least square (OLS) method. The *F*-test is conducted to test the existing of long-run relationship among the variables.

The null hypothesis in the equation is H_0: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = 0$. This means the non-existence of long-run relationship. While the alternative is H_1: $\lambda_1 \neq 0, \lambda_2 \neq 0$, $\lambda_3 \neq 0$, $\lambda_4 \neq 0$, $\lambda_5 \neq 0$

The calculated *F*-statistics value is then compared with two sets of critical values provided by the Pesaran et al. (2001). One set assumes that all variables are I (0) and other assumes they are I (1). If the calculated *F*-statistics exceeds the upper critical value, then null hypothesis of no cointegration will be rejected irrespective of whether the variable is I(0) or I(1). If it is below the lower value then the null hypothesis of no cointegration cannot be rejected. If it falls, inside the critical value band, the test is inconclusive. At this stage of estimation process, the unit root tests are normally carried out on variables entered into the model (Pesaran and Pesaran, 1997).

In order to choose optimal lag length for each variable, the ARDL method estimate $(p+1)^k$ number of regressions. Where p is the maximum number of lags and k is the number of variable in the equation. The model can be selected on the basis of Schawrtz–Bayesian criteria (SBC) and Akaike's information criteria (AIC). The SBC is known as parsimonious model, as selecting the smallest possible lag length. While AIC is known for selecting maximum relevant lag length.

After the selection of the ARDL model by AIC or SBC criterion, the long-run relationship among variables can be estimated. Once a long-run relationship has been established ECM is estimated in the third stage:

$$\Delta c_i = \beta_0 + \sum_{i=1}^{p} \delta_i \Delta c_{t-i} + \sum_{i=1}^{p} \phi_i \Delta e_{t-i} + \sum_{i=1}^{p} \varpi_i \Delta y_{t-i} + \sum_{i=1}^{p} \gamma_i \Delta y^2_{t-i} + \sum_{i=1}^{p} \theta_i \Delta tr_{t-i} + \alpha ECM_{t-1} + U_t \quad (3)$$

The results of the ECM then allow measuring the speed of adjustment required to adjust to long-run values after a short-term shock.

Table 1
Unit root tests.

	ADF	k		ADF	k
c	−1.38	0	Δc	−4.42***	0
e	0.88	1	Δe	−3.10**	0
y	0.97	2	Δy	−3.36**	1
y^2	1.57	2	Δy^2	−3.07**	1
tr	−1.66	0	Δtr	−4.73***	0

Notes: ADF augmented Dicky–Fuller test. k is the degree of augmentation that is automatically determined by following the procedure of Campbell and Perron (1991). *, **, and *** represent 10%, 5% and 1% level of significance, respectively.

To ensure the goodness of fit of model, the diagnostic and stability tests are also conducted. These include, testing for serial correlation, functional form, normality and heteroscidasticity associated with selected model. Pesaran and Pesaran (1997) suggest using Brown et al. (1975) stability test. This technique is also known as cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ). The CUSUM and CUSUMSQ statistics are updated recursively and plotted against the breaks points. If the plots of CUSUM and CUSUMSQ statistics stay within the critical bonds of 5% level of significance, the null hypothesis of all coefficients in the given regression are stable cannot be rejected.

In order to apply these estimation techniques, time series data has been collected from the World Development Indicators (2007). These include: per capita CO_2 emissions, energy consumption, per capita real GDP and trade ratio over the period of 1971–2005. The per capita GDP is measured in domestic currency. The real per capita GDP is measured as a ratio of real GDP to total population.[4] The real GDP is measured as nominal GDP divided by GDP deflator (2000 = 100). Finally, trade openness ratio *tr* is the total value of exports and imports as a share of nominal GDP.

5. Empirical results

The main focus of this paper is to examine the long-run relationship – cointegration – of environmental pollution and economic growth for China. The ARDL technique is being utilized to test the cointegration among the variables under consideration. The application of the technique requires the following key steps: (1) testing for stationarity to avoid any spurious relationship, (2) selection of the optimal order of lags, (3) establishment of a long-run relationship among the variable through *F*-tests, (4) estimation of long-run and short-run coefficients, and (5) testing the stability of the model through Brown et al. (1975) technique of CUSUM and CUSUMSQ.

The ARDL techniques can be used without considering whether the variable is I(0) or I(1). Ouattara (2004) has suggested that in the presence of I(2) variables, the computed *F*-statistics provided by Pesaran et al. (2001) are not valid. Because the bound test is based on the assumption that the variable is I(0) or I(1). Therefore, the implementation of unit root tests in the ARDL procedure might still be necessary in order to ensure that none of the variable is I(2) or beyond. For this purpose, the study uses the conventional Augmented Dicky Fuller (ADF) test for all the variables. From the test statistics it is evident that c e y y^2 and tr are both level non-stationary and trend non-stationary and the order of integration is one for all series (see Table 1).

[4] Real GDP per capita figure is superior to total real GDP figure, because some of the errors inherent in the estimation of the level of GDP and of population tend to be offsetting (Heston, 1994).

Table 2
Test statistics and choice criteria for selecting the order of the model.

Order	LL	AIC	SBC	LR test	Adjusted LR test
3	532.505	452.505	394.450		
2	515.938	460.938	418.963	CHSQ(25) = 33.13 (0.128)	17.54 (0.862)
1	485.465	455.465	432.570	CHSQ(50) = 94.08 (0.00)***	81.32 (0.00)***
0	232.414	227.414	223.598	CHSQ(75) = 600.18 (0.000)***	317.74 (0.00)***

Note: *** significant at 1% level.
LL = log likelihood, AIC = akaike information criterion, SBC = Schwarz–Bayesian criterion , LR = log likelihood ratio.

Table 3
Pair wise Granger causality test.

Null hypothesis	*F*-statistic	Prob.
c does not Granger cause *y*	0.3654	0.7931
y does not Granger cause *c*	2.9254	0.0412
c does not Granger cause y^2	1.3560	0.2526
y^2 does not Granger cause *c*	3.6051	0.0604

Table 4
ARDL model: long-run estimates

Dependent variable: ***c***		
Regressors	Coefficient	*t*-Values
e	0.5714	2.2293**
y	4.1001	4.7811***
y2	−0.5527	−4.7434***
tr	−0.0665	−0.5896
Intercept	−8.7886	−4.9925***
Diagnostic test statistics		
	Test-stats	*p*-Value
Serial correlation	0.0181	0.860
Functional form	2.5210	0.271
Normality	1.5143	0.386
Heteroskedasticity	0.0151	0.941

Note 1: ARDL (1, 1, 0, 0, 0) selected on the basis of SBC.
Note 2: *, **, and *** represent 10%, 5% and 1% level of significance, respectively.

After finding the integrating order, the two-step ARDL cointegration procedure has been employed. In the first stage, AIC, SBC and likelihood ratio (LR) information criteria are utilized to select the optimum lag length of vector autoregressive (VAR). The results are being presented in Table 2. Since the objective is to select the optimal order for the VAR, it is important that at this stage we select high enough order to ensure that the optimal order will not exceed it. Four VAR (p), $p=0$, 1, 2, 3 models have been estimated over the sample period of 1971–2005. However, AIC and SBC criteria implied that the order is 2. The log likelihood ratio statistics, whether adjusted for small sample or not, rejected order 0 and order I, but did reject a VAR of order 2. In the light of these statistics we decided to choose VAR (2) model.

Now that it has been established that none of the selected series is I(2) or beyond and the determination of the optimal order of lag, presence of the long-run relationship (cointegration) has been tested using bounds test. Eq. (2) is being estimated by OLS procedure and the *F*-statistics for the joint significance of lagged levels of variables have been calculated. The computed *F*-statistics for order of lag two turned out to be 5.964, when the dependent variable is *c*. The critical values, provided by Pesaran et al. (2001),

Table 5
ARDL model: ECM estimates.

Dependent Variable: Δc		
Regressor	Coefficient	*t*-Values
Δe	1.1244	4.1687***
Δy	2.4871	3.0990***
$\Delta y2$	−0.3352	−3.0584***
Δtr	−0.0403	−0.5787
ΔIntercept	−5.3310	−2.8741***
ecm(-1)	−0.6065	−3.5504***
Diagnostic test statistics		
R-squared	0.7595	
F (5, 29)	5.6664	
$ecm = c - 0.5714*e - 4.1001*y + 0.5527*y^2 + 0.0664*tr + 8.7886$		

Note 1: ARDL (1, 1, 0, 0, 0) selected on the basis of SBC.
Note 2: *, **, and *** represent 10%, 5% and 1% level of significance, respectively.

are I(0) = 3.76 and I(1) = 5.06 at the 1% level of significance.[5] So it provides sufficient evidence that there is a strong long-run relationship among the variables of the model.

But whether the CO_2 emission has an impact on the economic growth or vice versa is still not established. In order to ascertain the direction of causality, Granger casualty test has been employed and the results are presented in Table 3. *F*-statistic and probability values are constructed under the null hypothesis of no causality. It is evident that there is a causal relationship between two variables of major concern and, importantly, the one way causality runs through economic growth to CO_2 emissions. This result also holds for y^2.

Following ARDL cointegration methodology Eq. (2) has been estimated to get the long-run estimates. The $\overline{R^2}$ criterion, Hannan Quinn criterion, AIC criterion and SBC criterion have been utilized to find the coefficients of the level variables. The long- and short-run results of all models were almost identical. Therefore, we only present here the result of model that has been selected on the basis of SBC. Because, SBC is known as parsimonious model, as selecting the smallest possible lag length and it minimizes the loss of degree of freedom as well.

The long-run results are presented in Table 4. The coefficient of *e* is 0.5714 and statistically significant which implies that 1% increase in per capita consumption of energy will lead to 0.57% increase in the per capita CO_2 emissions in the long run. The finding of positive and significant effect of per capita consumption is consistent with Liu (2005) and Ang (2007, 2008, 2009). Similarly, the coefficient of *y* is 4.1001 and statistically

[5] Pesaran et al. (2001) discusses five different cases involving various restrictions on the trend and intercept. In this paper we follow the case of unrestricted intercept with no trend.

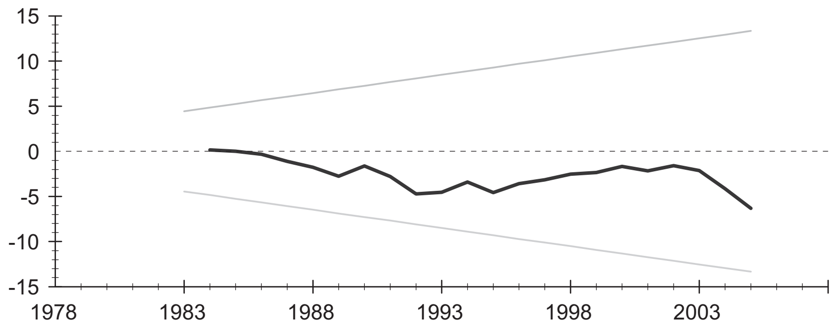

Fig. 1. Plot of cumulative sum of recursive residual.

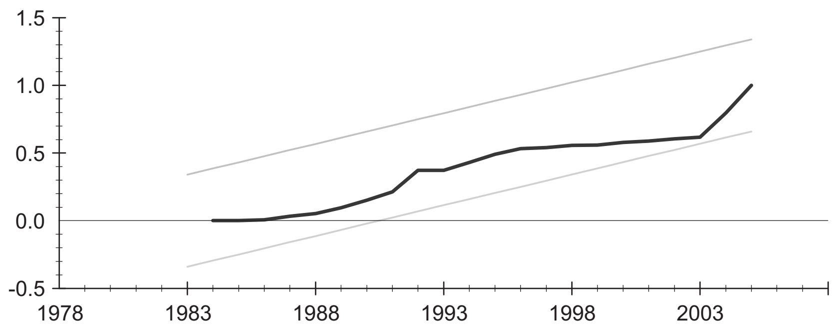

Fig. 2. Plot of cumulative sum of squares of recursive residuals.

significant that implies 1% increase in real per capita capital will lead to 4.1001% increase in the per capita CO_2 emissions. The statistically significant negative sign of y^2 confirms the delinking of CO_2 emissions and income at high levels of income. The turning point of per capita real income, y, turned out to be RMB 12992 compared to the highest value in our sample of RMB 10230.[6] This result gives a support for the EKC hypothesis that the level of CO_2 emission initially increases with income, until it reaches its stabilization point, then it declines.[7] He (2008), Song et al. (2008), and Diao et al. (2009) also confirm the inverted U-shaped relationship between income and environment performance in the case of China for other pollutants.

The sign of tr is negative but not significant. The coefficient of openness ratio in the long run is -0.0665 suggesting the contribution of the foreign trade to CO_2 emissions is rather minimal during the estimation period.[8] It has been discussed earlier that the net effect of trade on pollution could depend on the relative strength of several opposing factors and therefore the insignificance of tr can be justified on these grounds. Ang (2009) finds significant and positive contribution of trade on CO_2 emissions for China. However, these results are not comparable to the results of this study because the sample period employed and the empirical specifications of the model were different.

The model also passes through the diagnostic and stability tests. The results of diagnostic tests, serial correlation, functional form specification, normality and heteroskedasticity, are being reported in the lower part of Table 4. The diagnostic test statistics do not suggest the presence of any serial correlation and heteroskedasticity. The estimated model also passes the diagnostic tests of functional form specification and normality.

The short-run results are presented in Table 5. It is evident that Δe Δy and Δy^2 are statistically significant with priori expected signs. However, Δtr is insignificant. The coefficient ECM_{t-1} is correct in sign and significant. However, it is fairly large, that is, 0.6065. This implies, nearly 60% of the disequilibria in real per capita CO_2 emission of the previous year's shock adjust back to the long-run equilibrium in the current year. R_2 indicates that it is a relatively good fit.

The last stage of ARDL estimation is to check the stability of the model. This study applies CUSUM and CUSUMQ techniques based on ECM of Eq. (2). As can be seen from Figs. 1 and 2, the plots of CUSUM and CUSUMSQ statistics are well within the critical bounds, implying that all coefficients in the ECM model are stable.[9]

6. Conclusion

The primary objective of this study is to test the environmental Kuznets curve for China over the period of 1971–2005. The EKC hypothesis is tested under the ARDL framework by using per capita carbon dioxide (CO_2) emission as an indicator of environmental conditions. The empirical results suggest the existence of a robust long-run relationship between the variables. Specifically, the positive sign with income and negative sign with the quadratic term of income confirms the existence of EKC for CO_2 emission in the case of China. The results of Granger's causality test imply that there is one way causality runs through economic growth to CO_2 emissions. CUSUM and CUSUMSQ

[6] Graphical representation does not clearly show the turning point under EKC hypothesis and therefore it is not presented here. This result is in line with the findings of Lise (2006) and Halicioglu (2009).

[7] EKC for a longer time series has also been estimated (from 1960 to 2005) to examine the robustness of results. The signs and significance of coefficients for the larger sample were consistent with the results for the sample period employed in this paper.

[8] It is important to mention here that several models have been employed to test the sensitivity of this sign and significance level. And we could not establish a significant relationship.

[9] The straight lines, in Figs. 1 and 2, represent critical bounds at 5% significance level.

technique applied on the ECM model shows that the estimated coefficients of the model are stable. The results also indicate that the energy consumption is another significant determinant of CO_2 emission. And negative and insignificant coefficient is also observed in the case of trade openness.

The fact that the empirical results of this study find significant evidence for the existence of EKC is encouraging. It shows that the China's 11th Five Year aimed at reducing CO_2 emissions seems to have some impact in controlling environmental degradation. However, these results are based on aggregate data and therefore they should be interpreted with some caution. There are significant differences in the growth patterns of the eastern, central and western provinces of China. Therefore it is important to extend the work of this study at provincial level to get further insight of the impact of these policies.

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