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The Nexus between Technological Innovation and Carbon Dioxide Emissions: Evidence from China

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A B S T R A C T

This study inspects the dynamic effect of technological innovation, financial development, economic growth and energy consumption on carbon dioxide (CO2) emissions. We applied auto-regressive distributed lag (ARDL) model technique for the period from 1980 to 2017. The quantitative outcomes show a negative and insignificant relationship between the technological innovation and the environmental pollution in China during the said period. Furthermore, the long-run assessment results disclose that economic growth; boost-up the environmental quality of China. Thus, the results support the Environmental Kuznets Curve (EKC) hypothesis, which means that the environmental degradation can be resolved inevitably by economic growth. Similarly, results show that the financial sector development exerts positive impact on environmental quality.

Keywords: Environmental Degradation, Technological Innovation, Environmental Kuznets Curve (EKC) and China

1. INTRODUCTION

At present world economies are striving with prime objective to achieve environmental friendly sustainable economic development. The dilemma of global warming is the chief severe issues that nuisance industrialized, emerging, and developing nations because of its consequences of dipping environmental quality. In this eras of severe economic competition, massive utilization of energy and other industrial materials leading to environmental pollution and exerting adverse effects on human health and

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productivity. Additionally, various kinds of pollutants and waste products contribute to the concentration of greenhouse gases, leading to climate change. It is estimated that the sea level will be increased by approximately 16.5 to 53.8 cm by 2100 and the worldwide normal temperature will upsurge from 1.1 to 6.4 ° C (Bernstein et al., 2007). As a result, global warming and climate change can be life threatening to billions of peoples living at coastal areas (Lau et al., 2010). At present China is in transformation phase and striving to move forward to the next ladder of development. China is a unique economy which is growing at fastest rate and heavily relies on fossil fuels such as gas, coal and oil to sustain the steady pace of economic growth. Hence, the rapid economic growth of the country causes the emissions of greenhouse gases in huge amount which distress the quality of environment.

(De Jesus, 2013) argued that climate change is measured as one of the utmost fears to sustainable economic development. The issue of climate change and has been the core of the environmental deterioration; caused by economic and other commercial activities. Presently climate change has become one of the major human concerns connected to pollution control and emission of greenhouses gases. In this regard, inter-governmental agreements have been concluded to diminish the overwhelming effects of climate change. Under this discussion, one of the most important agreements is the Kyoto Protocol on the reduction of greenhouse gas emissions, signed by 192 countries under the United Nations (UN) agenda on climate change.

Presently environmental degradation is one of the world's most contentious issues; numerous researchers and policymakers have deliberated the problem. Nonetheless, the outcomes of their work are inconsistent and produced mixed results. The probable factors which are responsible for climate change and environmental degradation are CO2 emissions, energy consumption, financial development and economic growth among others. Some researchers have created positive relationships among these variables and others have identified adverse or impartial relationships.

Kuznets, (1955) premeditated the connection among per capita income (PCI), environmental quality and income disparity, an inverted U-shape. On the basis to the EKC, the environmental quality will deteriorate with economic growth, nevertheless, later on, after reaching a certain threshold; the quality of the environment starts improving. However, the literature on this relationship has not clearly and inconclusive. Similarly (Farhani et al., 2014) verified the EKC with panel data for 10 MENA economies. The study determined that there is an inverted U-shape connection between environmental quality and income level. Likewise, a cluster of the studies like; (Jebli et al., 2016; Shahbaz et al., 2014;) established inverted U-shape connection between the environmental quality and income level.

Likewise, technological innovations are important to describe environmental problems, particularly the long-term serious environmental issues say climate change (IPCC 1995, Weitzman 1997). There are many reasons to recognize the significance of technological innovation in the environmental pollution in various forms (Bruyn and Sander, 1997). This affirms that climate change and environmental pollution are serious issues which are linked to technological development (Yeh et al., 2011). For instance, Sohag et al., (2015) showed that economic growth and commerce are intensively increasing levels of energy consumption, while improved technological innovation will reduce energy consumption carbine dioxide emissions.

Financial expansion is essential to provide a resource for production and to mobilize economic resources, which increases production and contributes to economic growth. By and large, the development of financial sector is magnetizing foreign direct investment and modern environmental friendly technologies (Frankel and Rose 2002 Birdsall and Wheeler 1993). The growth of the financial sector can influence energy consumption and CO2 emissions (Alam et al., 2015 and Islam et al., 2013). Regarding the importance of financial liberalization, it is argued that a nation with a viable and sustainable financial subdivision can guarantee the improvement of the investment development, consequently it can cut back financial risk and improve capital accumulation. This also attracts more investment thus it improves the technological innovation and the quality of the environment. More specifically, it is claimed that financial liberalization can captivate FDI, new projects, crediting funding, purchase of new equipment and boost household's consumption and energy consumption which finally surge CO2 emission (Sadorsky 2010 Zhang, 2011). The fourth IPPC valuation report (IPCC, 2007) suggested that the upsurge in average global temperature must not exceed 2 ° C, hence in this case the average global temperature change can be set below 2 ° C. However, it is possible when unconventional energy technologies are accessible at rational prices (Tol, 2007).

Considering the above literature and various experiential studies, the foremost objective of this study is to empirically examine the impact of the technological innovation on the quality of the environment in China. Additionally, this study varies from the aforementioned studies, not just only in methodology, but also new explanatory variables were introduced in the study. This study is concerned to explore the impact of technological innovations on environmental degradation in China. Furthermore, the study also investigated the validity of the EKC for China. In addition, the study also focuses to draw attention to the impact of financial development onCO2 emission. The rest of the study is planned as follows: Section 2 and 3 refer to methodology and estimation respectively. Finally, section 4 deals with conclusion.

2. RESEARCH METHODOLOGY

2.1. Model Specification

Sohag et al., (2015); revealed that technological innovation have influence on CO2 emissions, energy consumption and the economic growth. Therefore, following Sohag et al., (2015), Greaker and Pade, (2009) and Romer.,(2000) , this study derived the following function to investigate an impact of the technological innovation on CO2 emissions and economic growth.

$$Y_t = f(A, K_t, L_t) \quad \ldots\ldots\ldots.. (1)$$

Whereas: 'Y' is output, 'A' represents technology, 'K' is capital while 'L' shows Labor. Hence to attain the objective of the study for this rationale equation (01) the technology 'A' has replaced by technological innovation (Ali et al 2016). Meanwhile it is apparent from economic relationship of KEC that economic growth affects environmental quality. As the study used the CO2 emissions as proxy for environmental quality, therefore, the functional form of CO2 emissions is as under:

$$CO_2 = f(Y_t) \qquad (2)$$

Henceforth:

$$CO_2 = f(Y_t, K_t, L_t) \quad (3)$$

Furthermore, we can disaggregate capital into two parts (K_e)emitting capital and (K_{ne}) non-emitting capital as shown below:

$$K = K_e + K_{ne} \quad (4)$$

As only emitting capital is accountable for environmental pollution therefore, we can write equation (4) as:

$$CO_2 = f(Y_t, K_e, L_t) \quad (5)$$

Table 1 Variables Description

Notation	Description	Proxy	Source	Reference
CO2	Environmental Pollution	CO2 Emissions	WDI	Ali et al. (2016)
Y	GDP	Economic Growth	WDI	Ali et al. (2016)
Y2	EKC	Square of GDP	WDI	Ali et al. (2016)
TI	Technological Innovation	Patent Application	WDI	Madsen et al. (2010).
K_e	Emitting Capital	Capital		Saboori and Sulaiman,2013
L	Labor Productivity	GDP per capita	WDI	Begum et al. (2015) Khan et al (2013)
FD	Financial Development	M2	WDI	Li et al. (2015)

Henceforth, the specified model of CO2 emissions becomes:

$$CO_2 = f(K_e, Y_t, M2_t, TI) \quad (6)$$

$$lnCO_2 = \alpha_0 + \alpha_0 lnK_e + \alpha_0 lnY_t + \alpha_0 lnM2_t + \alpha_0 lnTI + \varepsilon \quad (7)$$

Whereas: for the testing of EKC, the study included Y2in the model. Hereafter, to estimate the short and long run relationship among the variables, the ARDL framework of the equation (7) is as under:

$$\Delta\, ln\, CO_2 = \alpha_0 + \sum_{i=0}^{n} \beta_i \Delta lnK + \sum_{i=0}^{n} \gamma_i \Delta lnY_i + \sum_{i=0}^{n} \eta_i\, \Delta\, ln\, M2_{t-i} + \sum_{i=0}^{n} \psi_i TI_{t-i} + \gamma_1\, ln\, Y_{t-1} + \gamma_2\, ln\, K_{t-1} + \gamma_3\, ln\, Y_{t-1} + \gamma_4 M2_{t-1} + \gamma_5 TI_{t-1} + u_t \quad (8)$$

The variables of the equation (7) is preliminary defined, nonetheless the parameters of variables $\beta_i, \delta_i, \eta_i, \psi_i$ and are ρ_i representing short-run situation: whereas, $\gamma_1, \gamma_2, \gamma_3, \gamma_4$ and γ_5 encompass the long-run evidence. Henceforward, the given hypotheses has been tested for the long-run association among the variables: null hypothesis of no long-run association is as: $H_0 = \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = 0$ an alternative hypothesis of co-integration is as: $H_1 = \gamma_1 \neq \gamma_2 \neq \gamma_3 \neq \gamma_4 \neq \gamma_5 \neq 0$. The study used bounds test to test the hypothesis of long-run association. Finally, after the analyzing the sign of long-run relationship, the following equation can be assessed to confirm the long-run connotation between the variables.

$$\Delta \ln CO_2 = \alpha_0 + \sum_{i=0}^{n} \beta_i \Delta lnK + \sum_{i=0}^{n} \gamma_i \Delta lnY_i + \sum_{i=0}^{n} \eta_i \, \Delta \ln M2_{t-i} + \sum_{i=0}^{n} \psi_i TI_{t-i} + u_t \quad (9)$$

Afterward the validation of the long-run association among the variables then the next step of the study has evaluated the succeeding equation for Error Correction Term (ECM), which illustrates the speed of adjustment from divergence to equilibrium

$$\Delta \ln CO_2 = \varphi + \varphi(ECM) + \sum_{i=0}^{n} \beta_i \Delta lnK + \sum_{i=0}^{n} \gamma_i \Delta lnY_i + \sum_{i=0}^{n} \eta_i \, \Delta \ln M2_{t-i} + \sum_{i=0}^{n} \psi_i TI_{t-i} + \varepsilon_t \quad (10)$$

3. EMPIRICAL RESULTS

The stationary of the variables was examined by applying PP and ADF tests. The outcomes of the test are reported in Appendix 01 and 02 which shows that CO2 emission is stationary at level while economic growth and its squared term is also unit root at level. However, energy consumption and technological innovation are stationary at first difference Moreover, both ADF and PP give us the same results except in case of economic growth. Therefore, based on PP and ADF tests, most of the variables are unit-root at level while some are stationary at first difference. Thus, it is appropriate to apply the ARDL technique to equation (8) to obtain short-term and long-term associations. Moreover, the outcomes of the ARDL test are described in table 2

Table 2 ARDL Results (1,1,1,1,1)			
Variables	**Parameters**	**TV**	**PV**
lnY	0.32671	2.831	0.002
lnY_{t-1}	0.9512	3.761	0.001
lnY^2	-0.5310	0.5432	0.008
lnY^2_{t-1}	-0.8612	3.841	0.002
$lnCO_2$	0.0921	2.763	0.005
$lnCO_{t-1}$	1.0921	3.582	0.001
lnM2	0.0520	3.012	0.000
lnM''_{t-1}	0.5421	2.033	0.006
lnK_{ε}	0.5642	0.742	0.421
$lnK_{\varepsilon t-1}$	0.6521	5.841	2.812
LnTI	0.6492	3.712	2.011
$LnTI_{t-1}$	-0.7321	**0.642**	0.219
R^2	0.8120	Ad: R^2	0.8011
F-Sat	312(0.000)	DW	1.9945

BOUND TEST VALUES		
Critical Level	LB	UB
10%	2.6442	3.9078
5%	3.9078	4.6477
1	3.41	4.78
***p<0.01, **p<0.05, * p<0.10		

*Note: Estimation Based on Schwarz Bchwarz Criterion, Upper Bound (UB, Lower Bound (LB), T-Test Value (TV) and Probability Value (PV)

To discover the long-term association among the variables, the study has adopted the bound test, which revealed that the calculated F-Stat: value is larger than tabulated values. Therefore, according to (Pesaran et al., 2001), we accept the alternative hypothesis of co-integration and it is established that the long-run association among the variables exist.

TABLE 03. ARDL Results for long run		Note: ***p<0.01, **p<0.05, * p<0.10.	
Variables	**Parameters**	**TV**	**PV**
lnY	0.1843	3.5230	**0.003**
lnY^2	0.8745	4.0932	**0.000**
$lnCO_2$	0.34276	1.0934	**0.015**
lnM2	0.72103	2.9845	**0.001**
lnK_{ε}	0.0452	1.5621	**0.021**
LnTI	0.1137	2.9564	**0.011**
lnY	0.6743	3.5230	**0.003**

Table 3reports long-term results of ARDL which suggest that economic growth is positively associated with CO2 emissions. If national economic growth increases by a 1%, this will lead to an upsurge in CO2 emission by 18%. Henceforth, it is indicated that Chinese economic growth is encouraging ecological pollution and provides evidence of application of EKC. Moreover, the technological innovation is negatively associated with environmental pollution, even though; the magnitude of the coefficient is very small but statistically significant. It is revealed that1% upsurge in technological innovation leads to 0.11% environmental degradation. The coefficient of the financial development is statistically insignificant; nevertheless, the results confirmed that financial development is environmentally friendly. Moreover, the results of the study confirmed the EKC hypothesis for China throughout the period under the investigation as the study has established a negative connection between high income (GDP square) and CO2 emissions. Hence, it is revealed that the connection between high economic growth and pollution is inverted U-shape, which validate EKC for China. Since the energy consumption has a positive impact on pollution and its impact cannot be ignored, however, the use of energy sources in China is not the single cause of environment pollution. The results of the diagnostic tests confirmed that all the variables are normally distributed; furthermore, there were no evidence of serial correlation found in the model.

Table 4 Short run Results of ARDL

Variables	Parameters	TV	PV
Δ lnY	0.2138	2.9120	0.003
Δ lnY^2	0.6120	2.8712	0.002
Δ lnCO_2	0.2150	1.8912	0.011
Δ lnM2	0.7712	3.0912	0.004
Δ lnK_e	0.1240	2.9813	0.005
LnTI	0.6182	4.1020	0.001
$ECM(-1)$	0.1021	2.0120	0.002
R^2	0.8410	Adj: R^2	0.8210
AIC		SBC	
DW	1.8910	F-Sat(4,35)	120.00

Note: ***p<0.01, **p<0.05, * p<0.10

The short-run outcomes exhibit that the lag of the endogenous variable effect carbon emissions. Similarly, the effect of energy consumption is also positive but statistically insignificant which is aligned to long-run results. The short-term effect of economic growth is encouraging as economic activity generates more pollution especially in case of developing and less technological advance county. In the meantime, although the short-run impact of technological innovation is negative, it indicates that technical progress in China is still in its early stage and China has been striving to improve the quality of the environment. In addition, the impact of financial development on the quality of the environment has positive, as loans and investment are effective in improving the quality of the environment. The results of the study indicated that in the short-run economic growth worsens the environment. Hereafter in the short-run the EKC hypothesis is not valid empirically for China. This result of the study did not find any evidence of EKC hypothesis in the short-run. Nevertheless, the impact of energy consumption on the environment pollution is negligible. Furthermore, the short-term outcomes are reported in table 4. Finally, the model is suitable for estimation as evident from diagnostic tests, including heteroscedasticity, serial correlation and test of normality. The study also applied the CUSUM and CUSUMSQ tests to test the stability of the parameters, the outcomes of the study also qualified the said test.

4. CONCLUSION

China is one of the rising developing country in the world. Amid the existing problem of environmental degradation, policymakers are striving to find ways to effectively solve the issue. Any policy, with respect to the utilization of energy, has to asses to adverse impact on environmental quality on one hand, while considering implications for sustainable economic growth on the other hand. The results of the study accomplished that the country's economic development does not help environmental standards that are unfavorable to the environment and indicates that the government needs to pay more attention to preventive measures to manage pollution. Moreover, for China, still long way to go to achieve green and sustainable economic growth. The study also revealed that in the long-run the development of the financial sector could improve the quality of the environment by increasing spending on environmental related technology. Therefore, more attention needs to be paid to invest in environmental friendly technologies. If managed properly, it can reduce pollution to a sizable level. To conclude, the study shows that investing more in technology will help to reduce the CO2emissions and call for alternate policy where the authority needs to reconnoiter other modes of energy consumption (e.g. green energy) in order to reduce the continuous environmental degradation in the country.

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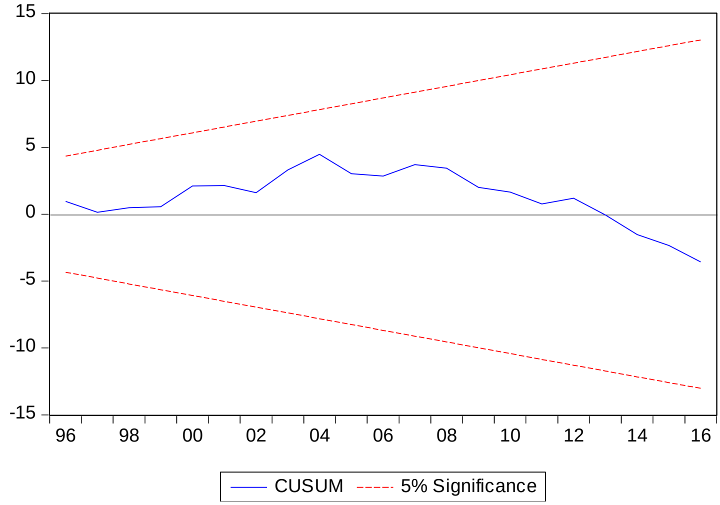
Appendix 01. Stationary Test (Augmented Dickey-Fuller Test and Phillips-Perron Test)		
ADF TEST		
Variables	**With Intercept**	**Without Intercept**
lnY	-0.991	-1.431
Δ lnY	-3.001***	-4.620***
lnY2	-1.892	-2.001
Δ lnY2	-4.101***	-5.883***
lnCO2	-2.718	-1.892
Δ lnCO2	-4.080***	-5.101***
lnM2	-1.821	-2.801
Δ lnM2	-4.292***	-5.022**
$\ln K_e$	-0.823	-1.931
Δ $\ln K_e$	-4.012**	-5.003***
lnTI	-2.192*	-3.060*
Δ lnTI	-4.022**	-4.373**

Note: ***p<0.01, **p<0.05, * p<0.10.

Appendix 02. Stationary Test (Augmented Dickey-Fuller Test and Phillips-Perron Test)		
Phillips-Perron Test		
Variables	**With Intercept**	**Without Intercept**
lnY	-0.823	-1.0521
Δ lnY	-4.902***	-5.812***
lnY2	-0.192*	-0..060*
Δ lnY2	-4.110***	-5.400***
lnCO2	-0.100*	-0.860*
Δ lnCO2	-4.179**	-4.898***
lnM2	-0.131*	-0.160*
Δ lnM2	-4.001***	-4.018**
$\ln K_e$	-0.672	-1.425
Δ $\ln K_e$	-3.002***	-4.240***
LnTI	-0.122	-1.031
Δ lnTI	-4.019***	-5.123***

Appendix 03

Plot of CUSUM



Plot of CUSUMSQ