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Identification and Implications of Relationships Among Pollutant Emission, Economic Structure and Economic Growth in China Through Multivariate Analysis

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ABSTRACT

The relationship between economic growth and environmental quality is generally considered as linear, N-shaped or inverse-U-shaped curve. However, due to the effects of economic structure on economic growth and pollutant emission, this relationship may not be suitable in China. In this study, multivariate regression modeling was performed to identify relationships among pollutant emission, economic structure and economic growth in China. Estimates obtained from integrated multivariate regression results reveal that local provincial economic growth and pollutant emission demonstrate an inverse-N-shaped relationship that is different from that under the Environmental Kuznets Curve (EKC) hypothesis. Further empirical results also indicate that particularly in China; pollutant emission has a negative effect on economic structure and economic growth; pollutant emission can reduce the positive contribution of economic structure to economic growth; and enforcement of emission reduction policies could stifle economic transformation and maintain sustainable economic growth.

Key words: *pollutant emission; economic structure; economic growth; multivariate regression; inverse-N shape Environmental Kuznets Curve*

INTRODUCTION

The Environmental Kuznets Curve (EKC) hypothesis (*Kuznets 1955*) suggests that the relationship between economic growth and pollutant emission exhibits an inverse-U shape. For instance, with a growing economy, pollutant emission will initially increase but eventually decrease. Related research efforts often focus on the impact of economic growth on pollutant emission despite the fact that the two issues are simultaneously determined (*Cofala et al. 2004*; *Argüelles et al. 2006*; *He and Ran 2009*; *Fodha and Zaghdoud 2010*; *Hong et al. 2012*; *Jaimie et al. 2012*; *Blanca et al. 2013*). In the case of China, the Chinese government and the State Council have prioritized environmental issues over other realms of policy especially after the fourth China's National Environmental Protection Conference in 1996. After the eleventh Chinese Five-Year Plan, the State Council stated that "*the economic structure change has to be compatible with environment protection…we should consider the energy saving and pollutant emission reduction as the keys of the changing economic structure.*" Therefore, there is neither a simple-one nor a two-way relationship between economic growth and pollutant emission. Instead, the two issues are interrelated with many other key issues such as economic structure. as such, pollutant emission reduction would be achieved by changing economic structure while both of these issues can promote economic growth to some extent separately (*Mohtadi 1996*). While pollutant emission would have negative effects in both economic growth and economic structure, this hindrance on economic structure would negatively affect economic growth.

It is therefore imperative to redefine the relationships among pollutant emission, economic structure and economic growth in China. In the definition process, the EKC method was proved to be a useful tool in analyzing the relationships between economy and pollution because of its sound logic when considering a theoretical paradigm of industrialization. The EKC assume that in the first stage, pollutant emissions grow rapidly with increasing material output given the high priority of industrial development. Meanwhile, with the development of industry, jobs and incomes would tend to focus on the water and air management (*Dasgupta et al. 2002*). However, many industry producers with insufficient capital resources need to allocate budget for abatement to prevent environmental damage from accumulating. Therefore, the negative environmental consequences of economic growth are generally disregarded by most industry producers. Thus, in the later stage of industrialization, people will pay more attention to environment improvement and environmental pressure (defined by the levels of pollution, emission, or resource depletion, etc.) reduction that comes with income increases.

However, this perfect inverse-U relationship might be unsuitable for China, as it possesses special national conditions in terms of big population size, limited space, and finite available resources. In the first stage of the EKC hypothesis, this relationship usually implies that the environmental pressure does not immediately translate to the implementation of strict regulations on pollutant emission.

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Whereas, in China, a slight decline in environmental quality would have caused a serious deterioration in the early stages of economic development. Moreover, people were becoming conscious of the harmful environmental side effects of industrialization, which has been illustrated by the earlier experiences of other developed countries. The consciousness of the mass media and government on the issue of emission control in a very early stage of Chinese industrialization was seen as imminent. Additionally, international pressure also encouraged that attention was paid earlier than the EKC prediction.

In consideration of these issues, this paper proposes an inverse-N-shaped EKC to simultaneously address the relationships among pollutant emission, economic structure and economic growth. Such relationships empirically examined through multivariate regression modeling using data from local areas in China during the period 1998 to 2009. The intuition behind the proposed inverse-N shape EKC is reasonable. The EKC analysis essentially estimates how the technically specified measurement of environmental quality varies with the size of the economy of a country or a large community. The environmental quality changes with systematic technical improvement was indirectly caused by the economic growth developing toward high income levels. As economic structure varies with progress in the prevalent industrial techniques, the Chinese government strongly emphasized the importance of technical improvement and structural adjustment in industries. This was usually accompanied with the implementation of strict regulations on emission control. Thus, the new EKC would decline earlier and have a tail that tends to drop again at the end of the curve.

Economic Growth Impact on Pollutant Emission

The original EKC (*Kuznet 1955*) and related studies have found that the relationship between economic growth and environmental quality exhibits an inverse-U shape (*Grossman and Krueger 1991*; *Panayotou 1993*; *Dasputa et al. 2002*; *Wu 2002*; *Dinda 2004*; *Copeland and Taylor 2004*; *Song et al. 2006*; *Liu et al. 2009*). However, some studies suggest that economic growth has a linear or N-shaped relationship with environmental quality (*Perman and Stern 2003*; *Stern 2004*; *Zhu et al. 2010*). Emission reduction can be accomplished through economic and technological restructuring (*Bruyn et al. 1998*). The adjustment of the economic and technological structures can boost economic development, which depends on sustainable growth and the effect of environmental pollution on current economic growth (*Mohtadi 1996*).

Based on evidence from regional assessments, primary and secondary industries account for large parts of pollutant emissions in China. If the primary and secondary industries form the majority of the economy, environmental pollution would be expectedly very rampant. In other words, the relationship between economic growth and emission would be affected by the established industrial structure. Even given the existing industrial structure (e.g. holding the share of the economy represented by primary and secondary industries constant), the level of industrial centralization has a major impact on pollutant emission. For example, the emissions of iron and steel industry with highly centralized emitters differ significantly from that of the less centralized emitters. Given a high level of industrial centralization, the pollution from emitters with aging technology is often more serious than the emitters using more advanced technologies. Therefore, technical factors are essential to understanding the effect of economic growth on pollution as this effect may be linked with economic structure (represented as industry structure, cluster size, technology), which in turn is determined by the level of economic growth.

Pollutant Emission Impact on Economic Growth

Continuous environmental deterioration has motivated governments and other institutions to pay closer attention to pollution problems. Pollutant emission may significantly constrain and influence economic growth. The environment affects economic growth in many ways including direct effects on production (*Mohtadi 1996*) and indirect restrictions on the abolition of some regulations (*Rosendahl 1997*). Based on exogenous growth theory (*Lucas 1988*), some studies considered the impact of environmental issues in models of economic growth (*Smulders 2005*) and found that economic activity would have negative externalities (*Michel and Rotillon 1995*). A healthy environment would have a positive effect on an economy but economic activities may negatively affect the environment.

The environment is an important resource for economic development. As more environmental pollution results from rapid economic growth and consumers demand for environmental quality improvement, unpolluted areas become precious resources. In this situation, changes of industry output and consumer preference would be influenced by environmental changes, methods of resource extraction and use, and pollutant emission. These changes would likely lead to negative effects on economic growth. In terms of sustainable economic growth, this negative effect is particularly obvious (*He and Ran 2009*).

Environment Regulation Impact on Economic Growth

In the absence of pollution regulations, firms will discharge more emissions to maximize their profits. In the early stage of economic growth, low priority is given to environmental issues, or even ignored sometimes. The resulting emissions will create severe pollution and undesirable external effects, thus negatively influencing the economic growth.

Effective environmental governance, however, would not hinder economic growth and development. In fact, environmental regulations are positively correlated with economic growth but studies on this issue only arrive at a definitive conclusion about the causal relationship at play. Environmental regulations improve productivity, investment efficiency and economic growth (*Jaffe et al. 1995*; *Fredriksson et al. 2003*; *List et al. 2003*; *Ederington et al. 2005*; *Chintrakarn 2008*). On the contrary, others found a significant negative effect (*Berman and Bui 2001*; *Henderson and Millimet 2005*). With increasingly stringent environmental regulations, corporate productive behavior is gradually constrained by the environment.

Economic Growth, Economic Structure and Pollutant Emission

Previous studies had overlooked the role of economic structure in economic growth and environmental pollution. Studies about the environment and economic growth tended to focus solely on the relationship between economic growth and environment while neglecting the two-way feedback mechanism between economic growth and environmental quality. In reality, economic growth, economic structure and pollutant emission interact.

Reasonable economic structure will be beneficial for economic growth and will reduce pollutant emission via industrial policies, technical standards and environmental policies; in turn, this approach will lead to the coordination of economic growth and environmental protection. Meanwhile, pollutant emission reduction will also promote changes in the economic structure and the spillover effect from the environment will benefit economic structure and growth.

METHODOLOGY

Model Formulation

Due to the two-way effect between economic growth and pollutant emission (*He and Ran 2009*; *Fodha and Zaghdoud 2010*), economic structure plays an important role in the economic-environmental system. Therefore, this study proposes the following integrated multivariate regression equations to analyze this relationship:

$$Pollu_t = \alpha_0 + \alpha_1 GDP_t + \alpha_2 GDP_t^2 + \alpha_3 GDP_t^3 + \alpha_4 Tech_t + \alpha_5 Invest_t + \alpha_6 Structure_t + \alpha_7 Fisdis_t + \alpha_8 Pollu_{t-1} + \varepsilon \quad (1)$$

$$Structure_t = \beta_0 + \beta_1 Pollu_t + \beta_2 Structure_{t-1} + \beta_3 GDP_{t-1} + \beta_4 Labor_t + \varepsilon \quad (2)$$

$$GDP_t = \gamma_0 + \gamma_1 Pollu_t + \gamma_2 Pollu_{t-1} + \gamma_3 Pollu_{t-2} + \gamma_4 Pollu_{t-3} + \gamma_5 Structure_t + \gamma_6 Pollu_t \times Structure_t + \gamma_7 GDP_{t-1} + \gamma_8 Invest_t + \gamma_8 Consume_t + \gamma_8 Imp\exp_t + \varepsilon \quad (3)$$

Equation 1 expresses the impact of economic growth on pollutant emission that includes a cubic polynomial in economic growth (GDP, GDP^2, GDP^3) to allow for a nonlinear relationship between economic growth and pollutant emission (*Perman and Stern 2003*; *Stern 2004*; *Zhu et al. 2010*). This equation also accounts for technological (Tech), scale (Invest) and structural (Structure) factors. As the current pollution controls mainly rely on government enforcement, the level of local government expenditure (Fisdis) is also included. The financial strength of local governments determines their investment in environment protection and treatment. The pollution level in the prior period ($Pollu_{t-1}$) is also accounted for.

Equation 2 expresses the impact of emission on economic structure. The economic growth (GDP) in the previous period, the economic structure (Structure) in the previous period and the current level of employment (Labor) are included in this equation.

Equation 3 expresses the impact of emission on economic growth. This equation includes current emission ($Pollu_t$), three lags ($Pollu_{t-1}$, $Pollu_{t-2}$ and $Pollu_{t-3}$) of emission, investment (Invest), consumption (Consume) and imports and exports (Impexp). This controls for the current effects of these variables and for the delayed effect of pollution on economic growth. The influence of economic structure (Structure) for existing economic growth (GDP_t) is also essential to be analyzed. The interaction term between pollutant emission and economic structure ($Pollu_t \times Structure_t$) in equation 3 reflects the impact of pollutant emission on economic growth and economic structure.

Variable Definition

Economic growth is measured by the gross domestic product (GDP). The natural logarithms of GDP, GDP^2 and GDP^3 are used in the regression. As a robustness check, the regional economic growth was reflected as the ratio of regional GDP to the country's total GDP.

Economic structure is comprised of many systems, including the export structure, demand structure, elements structure, industrial structure, distribution structure, technological structure, and labor force structure. It can be characterized by industrial structure, which is defined as the ratio of tertiary industries' GDP to overall GDP (Structure). As robustness check, this study also used the corresponding ratios for the primary and secondary industries to measure economic structure.

Pollutants include industrial emission, industrial sulfur dioxide, chemical oxygen, industrial solid waste, and industrial wastewater. Per capita indicators are used in the regressions. $Pollu_t$, $Pollu_{t-1}$, $Pollu_{t-2}$, $Pollu_{t-3}$ represent current, 1-period lagged, 2-period lagged and 3-period lagged per capita emission, respectively. Gas is per capita industrial gas emission (m^3), SO_2 is industrial sulfur dioxide emission per capita (Mg), COD is chemical oxygen demand per capita (Mg), Solid is industrial solid waste per capita (Mg), and Water is per capita industrial wastewater (Mg). Similarly, the percentage of various regions' pollutant emission in the total emission volume is used in robustness checks to control for the differential levels of emission across all regions.

Investment (Invest) is quantified as the per capita investment of regional fixed assets (Yuan per capita), while per capita local consumption (Yuan per capita) is used to represent consumption (Consume). The net import and export volume represents the import and export variable (Impexp), while the per capita turnover of the technology market (Yuan per capita) is used to represent technology (Tech). Finally, employment (Labor) is estimated as the proportion of employees in the total population, and fiscal spending (Fisdis) is the per capita regional budget expenditure in current year (yuan per capita).

Data Preparation

The China Statistical Yearbook (1985-2010) was used to collect data on pollutant emission (industrial emission for the period 1991-2009, industrial sulfur dioxide for 1991-2009, the chemical oxygen (COD) content for 2000-2009, industrial solid waste for 1986-2009, industrial wastewater discharge from 1985-2009, local GDP, technology market turnover, fixed asset investment, total population, and the number of workers in 31 provinces.

As a three-period lag is used, some observations have missing data. Removing observations with missing data leaves only 350 points in 30 provinces from 1998-2009. Further, COD data can only be obtained from 2000 to 2008. The final sample contains 180 observations.

RESULTS AND DISCUSSION

The stationarity and cointegration of the time series of pollutant emission and economic growth were first tested.

Unit Root Test

Table 1 presents the results of unit root tests for provincial economic growth and pollutant emission from 1998 to 2009. Phillips-Perron tests reject the unit root hypothesis for economic development (naturallogarithm of GDP) and pollutant emission (gas per capita, sulfur dioxide per capita, per capita solid waste, waste water per capita, per capita chemical oxygen); hence, the data are stationary.

Table 1. Unit Root Test.

	ADF	Phillips-Perron
GDP	-3.6671[a]	-9.7443[a]
Third	-18.7105[a]	-18.7219[a]
Gas	-4.9521[a]	-9.1923[a]
SO_2	-7.0377[a]	-15.4153[a]
Solid	-5.1230[a]	-7.3663[a]
Water	-9.4541[a]	-15.7358[a]
COD	-4.0776[a]	-4.1566[a]

Note: a denotes that the result is significant at 0.01.

Cointegration Test

As the data are stationary, **Table 2** tests for a cointegrated relationship between provincial economic growth and pollutant emission from 1998 to 2009 (Johanson cointegration test). The resultant Trace and Max-Eigen statistics are highly significant. In other words, economic growth (natural logarithm of GDP) and pollutant emission (per capita gas, sulfur dioxide, solid waste, waste water, and COD) are cointegrated.

Table 2. Co-integration Test.

		Trace-Statistic	Max-Eigen Statistic
GDP	Third	107.6446[a]	87.2253[a]
	Gas	86.3087[a]	55.3666[a]
	SO_2	74.5090[a]	45.6792[a]
	Solid	111.6170[a]	75.1311[a]
	Water	145.5810[a]	124.5758[a]
	COD	19.8021[b]	13.1869[c]
Third	GDP	107.6446[a]	87.2253[a]
	Gas	105.8891[a]	80.5837[a]
	SO_2	115.3999[a]	93.6759[a]
	Solid	148.5560[a]	127.6628[a]
	Water	187.9650[a]	144.9094[a]
	COD	59.3786[a]	47.4466[a]

Note: a, b, c denote that the result is significant at 0.01, 0.05 and 0.10, respectively.

Granger-Causality Test

Allowing for a lagged effect (the result using 2 periods of lags is roughly the same). The Granger tests clearly show that the economic growth of China's provinces interacts casually with pollutant emission from 1998 to 2009 (**Table 3**).

The Granger test between economic structure and pollutant emission shows that, except in the case of COD emission, economic structure Granger-causes all types of emissions; pollutant emission also Granger-causes economic

Table 3. Granger-causality Test between Economic Growth and Pollution Emissions.

			Lag	F-value	P-value	Results
Economic Growth and Emissions	The impact of economic growth on emissions	GDP is not a reason for Gas	Lag 3	0.9482	0.4174	Not rejected
		GDP is not a reason for SO_2	Lag 3	3.2541	0.0219	rejected
		GDP is not a reason for Solid	Lag 3	4.4999	0.0041	rejected
		GDP is not a reason for Water	Lag 3	8.7928	0.0000	rejected
		GDP is not a reason for COD	Lag 3	2.4513	0.0652	rejected
	The impact of emissions on economic growth	Gas is not a reason for GDP	Lag 3	7.2685	0.0001	rejected
		SO2 is not a reason for GDP	Lag 3	4.5858	0.0037	rejected
		Solid is not a reason for GDP	Lag 3	4.7293	0.0030	rejected
		Water is not a reason for GDP	Lag 3	2.8374	0.0381	rejected
		COD is not a reason for GDP	Lag 3	0.6804	0.5652	Not rejected
Economic Structure and Emissions	The impact of economic structure on emissions	Third is not a reason for Gas	Lag 3	2.5211	0.0578	rejected
		Third is not a reason for SO_2	Lag 3	6.7757	0.0002	rejected
		Third is not a reason for Solid	Lag 3	34.0569	0.0000	rejected
		Third is not a reason for Water	Lag 3	11.6459	0.0000	rejected
		Third is not a reason for COD	Lag 3	1.6487	0.1800	Not rejected
	The impact of emissions on economic structure	Gas is not a reason for Third	Lag 3	15.7486	0.0000	rejected
		SO2 is not a reason for Third	Lag 3	31.3409	0.0000	rejected
		Solid is not a reason for Third	Lag 3	11.2164	0.0000	rejected
		Water is not a reason for Third	Lag 3	9.7599	0.0000	rejected
		COD is not a reason for Third	Lag 3	0.1875	0.9048	Not rejected

Note: a, b, c denote that the result is significant at 0.01, 0.05 and 0.10, respectively.

structure. That is, from 1998 to 2009, provincial economic structure also interacts with pollutant emission.

Regression Analysis

In equation 1, except for COD, the regression results for the pollutants show that the coefficients of GDP, GDP2 and GDP3 are negative, positive, and negative, respectively (**Table 4**). These results are all statistically significant. This finding implies an inverse N-shaped relationship between economic growth and pollutant emission instead of the expected inverse-U shape under the standard EKC. Technology (Tech) and scale (Invest) also affect pollution to some extent but the effects of local fiscal expenditure (Fisdis) and structure (Structure) are small or non-existent.

For equation 2, the results yield significant and negative coefficients on $Pollu_t$ for all three pollutants. This finding indicates that increased emission would affect the economic structure by shrinking tertiary industries. The coefficients also reveal that pollutant emission have a negative impact on the economic structure. This result supports national energy saving and pollution reduction practices and other environmental policies. Thus, environmental policies that reduce pollutant emission would further improve economic structure.

In equation 3, the coefficient on $Pollu_t$ is significant and positive, while those of $Pollu_{t-1}$ and $Pollu_{t-3}$ are significant and negative. With $Pollu_{t-2}$ being not significant indicates that pollutant emission has a negative delayed impact on economic growth. The coefficient on $Structure_t$ is significant and positive, which means that the economic structure positively affects economic growth and that current industrial restructuring efforts (economic structure) positively affect growth. The coefficient of $Pollu_t \times Structure_t$ is significant and negative, which means that current pollution levels are positively correlated with economic growth (the coefficient on $Pollu_t$ is significantly positive). However, the negative interaction indicates that higher current pollution levels reduce the effect of economic structure on economic growth. Therefore, the current level of pollution also has a negative indirect impact on economic growth. Moreover, the significant and positive coefficient on $Pollu_t$ verifies that a great deal of pollution (heavy- or high-pollution industries) is positively related to economic growth, but the lagged effect is negative as indicated by the significant negative coefficients on $Pollu_{t-1}$, $Pollu_{t-3}$ and $Pollu_t \times Structure_t$. Thus, economic development cannot depend solely on increasing pollution as the improvement of economic structure (the coefficient of $Structure_t$ is significantly positive) can reduce the excessive reliance on this model for economic growth.

Table 4. Gas Emissions, Economic Structure and Economic Growth.

Variables	Gas			SO_2			COD		
	$Pollu_t$	$Structure_t$	GDP_t	$Pollu_t$	$Structure_t$	GDP_t	$Pollu_t$	$Structure_t$	GDP_t
GDP_t	-71.4011			-0.1504			0.0027		
	(-6.69)^a			(-3.38)^a			(0.07)		
$GDP2_t$	9.0051			0.0189			-0.0004		
	(6.71)^a			(3.38)^a			(-0.09)		
$GDP3_t$	-0.3724			-0.0007			0.0001		
	(-6.73)^a			(-3.38)^a			(0.10)		
GDP_{t-1}		-0.0002	0.9955		-0.0007	1.0051		0.0030	0.9936
		(-0.26)	(260.12)^a		(-0.94)	(312.69)^a		(2.69)^a	(286.22)^a
$Pollu_t$		-0.0010	0.1598		-0.1927	15.7759		-0.2963	-3.4198
		(-2.16)^b	(4.13)^a		(-2.52)^b	(4.44)^a		(-1.13)	(-0.40)
$Pollu_{t-1}$	0.9583		-0.0178	0.9825		-3.3317	0.9422		1.2259
	(24.22)^a		(-2.45)^b	(54.51)^a		(-2.62)^b	(31.50)^a		(0.44)
$Pollu_{t-2}$			-0.0022			1.6614			1.3620
			(-0.25)			(1.47)			(0.73)
$Pollu_{t-3}$			-0.0331			-2.9055			-1.3214
			(-3.77)^a			(-3.15)^a			(-0.95)
$Tech_t$	-3.6703			-0.0050			-0.0014		
	(-3.59)^a			(-1.19)			(-0.43)		
$Invest_t$	0.0248		0.0198	-0.0010		0.0239	-0.0001		0.0567
	(0.16)		(2.40)^b	(-1.70)^c		(3.90)^a	(-0.22)		(7.78)^a
$Consume_t$			-0.0025			-0.0047			-0.0053
			(-0.94)			(-1.82)b			(-2.27)b
$Imp\exp_t$			0.1159			0.0132			-0.0544

Note: a, b, c denote that the result is significant at 0.01, 0.05 and 0.10, respectively.

The coefficient on investment (Invest) is significant and positive, indicating the contribution of investment to the local economic growth. This finding is consistent with the fact that the central and local governments make vast investments to achieve economic growth. The import and export (Impexp) coefficient is significant and positive in the gas regression alone. This result implies that the import and export variable has a positive impact on economic growth. Furthermore, the coefficients on consumption (Consume) in the three regressions are not significant possibly because of the low proportion of domestic consumption in the overall economy that would mean that consumption cannot dramatically boost the economy.

The relationship between economic growth and pollutant emission in China's provinces from 1998 to 2009 follows an inverse-N-type curve (**Table 4**). Pollutant emission negatively impacts economic structure and growth. In addition to having lagged negative effects, pollution also reduces the positive effect of economic structure on economic growth.

In the regression equation 1, an inverse-N-shaped relationship appears for solid wastes and wastewater, which is consistent with the results in **Table 4**. In the regression equation 2, the Pollu coefficient for solid waste is significant and negative, but the coefficient on wastewater is not statistically significant. This finding indicates that solid waste generation have a significant and negative impact on economic structure while the negative impact of wastewater is negligible.

The results from estimating equation 3 are basically the same for solid waste and gas emissions while the coefficient on wastewater emission $Pollu_t$ is positive but not significant. The coefficients on both $Pollu_{t-1}$ and $Pollu_{t-3}$ are significant and negative. However, the coefficient on $Pollu_t \times Structure_t$ is not significant, which means that the concurrent impact of pollutant emission and economic structure on GDP is much slight. Provincial economic growth is linked with pollutant emission by an inverse-N-shaped curve. Pollutant emission has a negative impact on both economic structure and economic growth, and this impact is often delayed.

Industrial structure is used to replace economic structure, which can measure the degree to which the tertiary industry accounts for the total economy. As a robustness check, the contribution of the primary or secondary industries to overall GDP is also considered as the proxy for economic structure (**Table 6**). The first three columns are the results using the ratio of GDP of primary industries to the full economy while the final three used the analogous variable for secondary industries. The regression equation 1 is consistent with the previous regression. However, in the regression equation 2, the coefficients of Pollu are not significant. Consistent with equation 3 were also obtained wherein regardless of the economic structure characterized by the share of primary, secondary or tertiary industries, economic growth is related to pollutant emission in an inverse-N-shaped curve. Clearly, pollutant emission has a negative lagged impact on economic growth.

Results show that the pollutant emission per capita. It is found that the emission differs significantly by regions. Pollutant emission can be measured by volume or as a share of the overall pollution structure. With this that the emission difference can be estimated as the proportion of the regional pollutant emission to the overall pollutant volume. As a further robustness check, **Table 7** provides the ratio of the regional pollutant emission to the total emission and inspects the impact of this measure on provincial economic structure (the proportion of tertiary industries in the total GDP) and regional economic growth (the proportion of provincial GDP in the total GDP). Note that the emission variable (Pollu) is the total pollutant emission for a certain region divided by the total national pollutant volumes, emission differ among regions. In model 3, the dependent variable is the proportion of regions' GDP to the total GDP. As an explanatory variable, $Pollu_t$ is the ratio of the regional pollutant emission to the national emission. Investment, consumption and import and export

Table 5. Other Pollutants Emissions, Economic Structure and Economic Growth.

Variables	Solid Waste			Water		
	$Pollu_t$	$Structure_t$	GDP_t	$Pollu_t$	$Structure_t$	GDP_t
GDP_t	-7.2327 (-2.82)[a]			-158.4062 (-4.06)[a]		
GDP^2_t	0.9215 (2.86)[a]			19.80468 (4.03)[a]		
GDP^3_t	-0.0385 (-2.89)[a]			-0.810902 (-4.01)[a]		
GDP_{t-1}		-0.0005 (-0.77)	0.9994 (193.45)[a]		-0.0004 (-0.56)	1.0014 (288.47)[a]
$Pollu_t$		-0.0015 (-1.65)[c]	1.1682 (5.94)[a]		0.0001 (0.31)	0.0020 (0.63)
$Pollu_{t-1}$	1.0479 (70.68)[a]		-0.3104 (-7.45)[a]	0.9530 (55.51)[a]		-0.0029 (-1.84)[c]
$Pollu_{t-2}$			-0.0422 (-1.23)			0.0012 (1.01)
$Pollu_{t-3}$			-0.0095 (-0.33)			-0.0022 (-2.32)[b]
$Tech_t$	-0.6727 (-2.87)[a]			-3.3610 (-0.83)		
$Invest_t$	0.0149 (0.43)		-0.0007 (-0.07)	-0.7299 (-1.28)		0.0361 (6.62)[a]
$Consume_t$			-0.0026 (-0.65)			-0.0038 (-1.33)
$Impexp_t$			0.0789 (2.48)[b]			-0.0002 (-0.01)
$Fisdis_t$	0.1340308 (1.37)			0.4370 (0.27)		
$Structure_t$	-0.0894 (-0.42)		1.8536 (4.75)[a]	-3.1584 (-0.86)		-0.0705 (-0.70)
$Structure_{t-1}$		0.9377 (57.47)[a]			0.9672 (61.53)[a]	
$Labor_t$		0.1094 (5.15)[a]			0.0732 (3.64)[a]	
$Pollu_t \times Structure_t$			-2.1509 (-4.71)[a]			0.0036 (0.54)
N	350	350	350	350	350	350
R^2	0.9516	0.9585	0.9936	0.9184	0.9572	0.9977

Note: a, b, c denote that the result is significant at 0.01, 0.05 and 0.10, respectively.

Table 6. Emissions, Different Economic Structures and Economic Growth.

Variable	the proportion of the first industry in GDP			the proportion of the second industry in GDP		
	$Pollu_t$	$Structure_t$	GDP_t	$Pollu_t$	$Structure_t$	GDP_t
GDP_t	-59.6241 (-7.91)[a]			-14.5685 (-1.99)[b]		
GDP^2_t	7.5030 (7.92)[a]			1.8374 (1.99)[b]		
GDP^3_t	-0.3097 (-7.92)[a]			-0.0761 (-2.00)[b]		
GDP_{t-1}		0.00001 (0.02)	1.0033 (240.83)[a]		-0.0008 (-0.94)	1.0009 (242.41)[a]
$Pollu_t$		0.0001 (0.15)	0.1618 (5.77)[a]		0.0007 (1.32)	0.2394 (7.32)[a]
$Pollu_{t-1}$	0.9780 (29.57)[a]		-0.0705 (-5.87)[a]	0.9993 (33.54)[a]		-0.0229 (-3.02)[a]
$Pollu_{t-2}$			-0.031 (-2.42)[a]			-0.0030 (-0.32)
$Pollu_{t-3}$			-0.0619 (-5.83)[a]			-0.0419 (-4.55)[a]
$Tech_t$	-2.2130 (-3.68)[a]			-1.3560 (-1.82)[c]		
$Invest_t$	0.0653 (0.53)		0.0181 (1.76)[c]	0.1544 (1.30)		0.0233 (2.53)[b]
$Consume_t$			-0.0005 (-0.19)			-0.0028 (-0.92)
$Imp\exp_t$			0.0034 (0.14)			-0.0320 (-1.69)[c]
$Fisdis_t$	0.3110 (0.97)			0.0827 (0.26)		
$Structure_t$	0.1362 (0.24)		0.2526 (1.79)[c]	-0.4009 (-0.63)		0.6194 (5.84)[a]
$Structure_{t-1}$		0.9497 (93.41)[a]			0.9788 (75.76)[a]	
$Labor_t$		-0.0044 (-0.37)			-0.0875 (-5.69)[a]	
$Pollu_t \times Structure_t$			-0.2303 (-2.44)[b]			-0.3594 (-6.06)[a]
N	350	350	350	350	350	350
R^2	0.7780	0.9858	0.9949	0.8993	0.9661	0.9969

Note: a, b, c denote that the result is significant at 0.01, 0.05 and 0.10, respectively.

are also regional values that were compared to the national values.

In the regression equation 2, the coefficients on Pollu are not significant implying that the effects of regional pollution structure on the regional industrial structure are not significant.

For equation 3, the impact of the coefficient on $Pollu_t$ is significant and positive, but the coefficient on $Pollu_{t-1}$ is significant and negative for all pollutants except for Water. The coefficients on $Pollu_{t-2}$ and $Pollu_{t-3}$ are also not significant(**Tables 4** and **5**), respectively, showing that regional pollution structures have a negative lagged impact on the regional economic structure. All the coefficients on $Pollu_t \times Structure_t$ are negative, which means that the difference in local pollution will reduce the positive effect of the regional industrial structure on regional economic growth. Current pollution also has a negative effect on economic growth.

Overall, pollutant emission and economic growth can affect each other via economic structure. In China, the relationship between provincial economic growth and pollutant emission has been an inverse-N. In addition,

Table 7. The Impact of the Proportion of Regional Emissions in Total Pollution to Regional Economy.

	Gas		SO_2		COD		Solid		Water	
	$Structure_t$	GDP_t	$Structure_t$	GDP_t	$Structure_t$	GDP_t	$Structure_t$	GDP_t	$Structure_t$	GDP_t
GDP_{t-1}	0.0431	0.9273	0.0166	0.9310	0.1011	0.9093	0.0189	0.9387	-0.0583	0.9348
	(1.06)	(79.59)[a]	(0.44)	(85.51)[a]	(1.76)[c]	(47.76)[a]	(0.64)	(84.43)[a]	(-1.09)	(81.85)[a]
$Pollu_t$	-0.0571	0.1438	-0.0131	0.1023	-0.0769	0.3845	-0.0344	0.1093	0.0835	0.1040
	(-1.12)	(3.85)[a]	(-0.24)	(2.30)[b]	(-0.93)	(3.80)[a]	(-0.99)	(2.30)[b]	(1.51)	(2.71)[a]
$Pollu_{t-1}$		-0.0262		-0.0142		-0.0114		-0.0300		-0.0132
		(-2.08)[b]		(-0.67)		(-2.90)[a]		(-1.89)[c]		(-0.58)
$Pollu_{t-2}$		0.0003		0.0003		-0.0114		0.0035		-0.0036
		(0.02)		(0.02)		(-0.26)		(0.26)		(-0.19)
$Pollu_{t-3}$		0.0036		-0.0023		0.0113		-0.015		-0.0091
		(0.28)		(-0.18)		(0.38)		(-1.34)		(-0.69)
$Invest_t$		0.0795		0.0711		0.0944		0.0766		0.0745
		(10.56)[a]		(9.42)[a]		(7.37)[a]		(10.41)[a]		(9.91)[a]
$Consume_t$		-0.0180		-0.0211		-0.0236		-0.0203		-0.0202
		(-1.41)		(-0.91)		(-1.63)		(-0.69)		(-0.74)
$Imp\exp_t$		0.0154		0.0148		0.0219		0.0115		0.0136
		(6.79)[a]		(6.73)[a]		(5.02)[a]		(5.66)[a]		(6.05)[a]
$Structure_t$		0.0038		0.0010		0.0024		0.0008		0.0007
		(2.12)[b]		(0.78)		(1.05)		(0.50)		(0.53)
$Structure_{t-1}$	0.9367		0.9427		0.9936		0.9384		0.9468	
	(53.81)[a]		(56.20)[a]		(42.27)[a]		(54.91)[a]		(57.31)[a]	
$Labor_t$	0.1056		0.1003		0.0460		0.1026		0.1082	
	(4.89)[a]		(4.56)[a]		(1.23)		(4.78)[a]		(4.89)[a]	
$Pollu_t \times Structure_t$		-0.3162		-0.1826		-0.3975		-0.1733		-0.1942

Note: a, b, c denote that the result is significant at 0.01, 0.05 and 0.10, respectively.

pollutant emission is detrimental to economic growth, exhibiting both lagged negative effects and a decrease in the positive contribution of economic structure to growth. In our empirical tests, pollutant emission is expressed in per capita terms (industrial waste gas, industrial sulfur dioxide, industrial solid waste, industrial waste water and COD) and as a share of the overall emission profile (the ratio of local emission to national emission). The economic structure variable includes the ratio of tertiary industries' GDP to the national value and the corresponding values for the primary and secondary industries.

CONCLUSION AND RECOMMENDATION

This study investigated the effect of economic structure on pollutant emission and economic growth during the period between 1998 and 2009 in China. The results from the multivariate regression modeling approach revealed that local provincial economic growth, economic structure, and pollutant emission Granger-caused each other from 1998 to 2009; and local provincial economic growth and pollutant emission displayed an inverse-N-shaped relationship and not the inverse-U shape as predicted by EKC.

Further empirical results also indicated that pollutant emissions do not only negatively affect economic growth with a lag but also reduced the positive contribution of economic structure to growth. Moreover, pollutant emission has been shown to have a negative effect on economic structure and economic growth. Moreover, as China is now in the later stage of industrialization and urbanization, the environmental impacts on economic growth should become increasingly significant. As such, structural transformation received a common consensus. Pollutant emission reduction and environmental protection would stifle economic transformation and maintain sustainable growth. Therefore, government should enforce the process of emission reduction policies and environmental protection simultaneously.

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