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Original Research Paper

Investigation on the Relationship Between the Environmental Pollution and Growth of the Industrial Economy in Liaoning Province, China

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ABSTRACT

The rapid development of an industrial economy contributes to environmental pollution, which, in turn, restricts the sustainable development of the industrial economy. As a major industrial province, Liaoning Province has played an important role in the industrial construction of China and gradually increased the industrial pollution in the country. The objectives of this study are as follows: to analyse the relationship between the environmental pollution and the growth of the industrial economy in Liaoning Province, explore the long-term and short-term relationships between these two variables, and quantitatively estimate the environmental Kuznets curve (EKC) for industrial pollution. In view of these objectives, the paper employs the panel data of different cities in Liaoning Province from 2000 to 2013; adopts five industrial pollution indicators, namely, industrial wastewater discharges, industrial SO_2 emissions, industrial soot emissions, industrial dust emissions, and industrial solid waste generation amount; simulates the EKC for industrial pollution; and conducts an empirical test on the relationship between the environmental pollution and the growth of the industrial economy in Liaoning Province. Results indicate the following: the five indicators demonstrate different relationships with GDP per capita; the overall level of the industrial environment constantly rises, whereas pollution is deteriorated with the continual increase in per capita industrial output; the rapid growth of the heavy industry and structural characteristics arising from this growth directly cause the difficulties in reducing the discharges of major pollutants in Liaoning Province. The paper have made significant contributions, including analysing the current situation of the industrial pollution in Liaoning Province, quantitatively estimating the relationship between the environmental pollution and the growth of the industrial economy in Liaoning Province, and proposing suggestions and measures to promote economic growth and alleviate industrial pollution.

INTRODUCTION

Industry is the cornerstone of economic development, and Liaoning Province has taken industrialization as an important strategic goal toward national economic development. Industrial development has significantly promoted the transformation of the traditional socio-economic structure, enhanced local economic development and employment, increased the income of farmers, transformed urban and rural economic ties, and developed the market economy. However, industrial pollution is one of the main sources of environmental pollution. Owing to the extensive economic development, emphasis on local economic interests, and the neglect of ecological value, some underdeveloped regions have achieved economic development at the expense of their environment and ecological resources. For example, some underdeveloped cities in Liaoning Province have encountered a series of serious ecological and environmental problems characterized by complex environmental pollution and directly affecting the sustainable development of China.

In fact, Liaoning Province is an industrial province; its industry plays an extremely important role in its economic development. In 2014, the industrial output of the province accounted for more than 70% of its total social output value, 90% of its industrial and agricultural output, and more than 60% of its domestic income. Since China's reform and opening-up, the industrial economy in the province has experienced rapid growth. After years of construction, the Liaoning economy has adopted the heavy industry as its main industry, accommodated nearly all the industrial categories, enjoyed a strong industrial system, and become the major industrial and raw material base of China. However, with the industrial structure adjustment in Liaoning Province, its energy resources have become scarce, making it an obviously resource-exhausted province. In terms of energy supply, Liaoning Province has gradually expanded the proportion of its non-coal power generation, improved its power structure, developed new energy sources, and promoted a healthy development of its industrial economy by improving the environment since the launching of the 12th Five-Year Plan. Although Liaoning Province has strengthened its governance over industrial pollution, the province still suffers from growing shortage of energy, dwindling mineral resources, severe shortage of water resources, obsolete industrial equipment, and other problems, which exert a considerable impact on environmental pollution. Given that environmental pollution affects the growth of an industrial economy, the relationship between the environmental pollution and the growth of the industrial economy in Liaoning Province in the process of industrialization has become a hot research topic. Without the support of energy, no industry will exist; in the process of industrialization, pollution is inevitably produced. The rapid growth of industrial output increases not only energy consumption but also the pressure on environmental protection. The mutual constraints between environmental pollution and industrial output growth have become the cause restraining the rapid economic growth in Liaoning Province. Industrial output value is an important component of GDP; thus, the relationship between environmental pollution and industrial growth naturally becomes the core issue of sustainable development. Therefore, an in-depth study on the relationship between environmental pollution and industrial growth is of practical significance in developing industrial development strategies and policies for Liaoning Province. Accordingly, this paper aims to provide recommendations for effectively implementing the scientific development concept of Liaoning Province.

EARLIER STUDIES

Only few studies have been conducted on the relationship between industrial growth and environmental pollution, and most of which focus on the relationship between economic growth and environmental pollution and mainly validate the existence of environmental Kuznets curve (EKC). Many scholars from other countries have investigated the relationship between environmental pollution and economic growth. The earliest study on EKC was conducted by American economist Grossman in the early 1990s; he analysed the potential impacts of specific institutional changes in the North American Free Trade Agreement on the environment. Since the proposal of the EKC hypothesis, it has aroused considerable interest, initiated a research boom in the academic circle, and become the main method for exploring the relationship between economic growth and environmental pollution (Grossman et al. 1991). Vincent examined the relationship between income per capita and various air and water pollutants in Malaysia from the late 1970s to the early 1990s. However, none of the pollutants examined by Vincent demonstrated an inverted U-shaped relationship with income (Vincent 1997). Carson used the data of 50 states and 7 kinds of pollutants to conduct a regression analysis of income per capita; the calculation results were consistent with the EKC prediction results (Carson et al. 1997). Unruh used the data of 16 OECD countries, adopted a nonlinear dynamics model, and considered income the determining factor of carbon dioxide emissions (Unruh et al. 1998). De used the data of New Zealand, West Germany, the United Kingdom, and the United States from 1960 to 1993 to establish simplified models for CO_2, NO_2, and SO_2 emissions; the results obtained by the models indicated that economic growth exerted a positive effect on the emissions, that is, economic growth aggravated environmental pollution (De et al. 1998). Hilton studied the relationship between vehicle exhaust emissions and GNP per capita and found an N-type curve (Hilton et al. 1998). Egli used German time-series data for analysis and found that changes in income did not affect the emissions within a short period; however, in the long term, some contaminants showed an EKC structure, which was inapplicable to all pollutants, and all the estimation results were unsteady (Egli 2001). De obtained the decomposition results of factors affecting industrial CO_2 emissions in the Netherlands by comparative static analysis on the two states of the research object at different times and spaces (De Haan 2001). Lindmark used the data of Switzerland from 1870 to 1997 to study the EKC for CO_2 emissions; the results indicated that very few technical structural changes were associated with the CO_2 emission during the sustained high economic growth period of the country from 1920 to 1960 (Lindmark 2002). Roca used the SDA (Static Data Authentication) method to analyse the nine factors that affect the industrial pollution emissions in Spain, and the analysis results indicated that the changes in final demand and final consumption reflected the changes in economic growth and environmental pollution, and with increased revenue, the emission intensity of pollutants was constantly reduced; thus, the existence of the EKC is verified (Roca et al. 2007). Huang studied the Kyoto Protocol and analysed whether it plays a significant role in easing environmental pollution by studying the situations before and after the Protocol was signed (Huang et al. 2008). Caviglia used the panel data of 146 countries from 1961 to 2000 and adopted ecological footprint to characterize environmental pressure; the empirical results indicated that the ecological footprint had an inverted U-shaped relationship with GDP per capita (Caviglia et al. 2009). In China, many domestic scholars have conducted EKC empirical studies on the environmental pollution in China. Chen Huawen and Chen used the data of Shanghai collected from 1990 to 2001 and found that the EKC hypothesis is invalid for most indicators and different environmental quality indicators demonstrated different inflection points (Chen et al. 2004). Peng used the provincial panel data of China from 1996 to 2002 in conducting an empirical study on the relationship between economic growth and six environmental pollution indicators, including water pollution, air pollution, and solid pollution emissions (Peng et al. 2006). Zhou established a comprehensive list of environmental pollution level indicators and used the provincial panel data of China from 1996 to 2009 to analyse the relationship between the economic growth and pollution in China's eastern, central, and western regions; the results indicated that these regions exhibited significant differences because of their different development stages (Zhou 2011). Gao used the data of 2000–2010, conducted an empirical research on the relationship between economic growth and pollution in each province, and found that the inflection points for the different provinces in China have significant differences, which are mainly caused by the different structural effects and technical effects of the provinces (Gao et al. 2012). The existing literature shows that foreign empirical studies mainly focus on verifying the inverted U-shaped relationship between the growth of industrial economy and environmental quality and adopt diverse environmental quality indicators. By contrast, the studies of domestic scholars on EKC mainly focus on the relationship between environmental pollution (industrial waste discharges) and economic growth and adopt the same indicators. Since 1978, China's industrialization has been accelerated, the proportion of the secondary industry in the GDP has been maintained at 40%, the amounts of industrial energy and resources consumed by the Liaoning Province have been much higher than those by other provinces, and industrial pollution has accounted for a significant portion of environmental pollution. Accordingly, the panel data of various cities in Liaoning Province from 2000 to 2013 are used in this study. Furthermore, a special empirical study on the EKC hypothesis on industrial pollution is conducted. First, five indicators are selected to measure the extent of industrial pollution. Second, the relationships between the growth of the industrial economy and the different industrial pollution indicators are analysed. Third, the various curves for environmental pollution and industrial growth are generated. Fourth, regional economic development and the environment inflection points derived from empirical study are compared. Fifth, the different relationships between economic growth and industrial pollution in different districts are determined. Finally, specific policies and recommendations are proposed according to the actual status of the environmental pollution in Liaoning Province.

MODEL AND DATA

Model: In this study, the following simple regression formula for economic growth and environmental quality is adopted to analyse the relationship between the growth of the industrial economy and the environmental pollution in Liaoning Province:

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \beta_4 z_{it} + u_{it} \qquad ...(1)$$

Where, y_{it} is the amount of emissions in the i[th] city in the t[th] year, x_{it} represents the GDP per capita in the i[th] city in the t[th] year, z_{it} represents other control variables that affect environmental quality, and α_i refers to the specific cross-section effect. According to the regression results of Formula (1), environment and income may have several relationship curves, such as the following:

If $\beta_1 < 0$, $\beta_2 > 0$, and $\beta_3 = 0$, then the curve is U-shaped. By contrast, if $\beta_1 > 0$, $\beta_2 < 0$, and $\beta_3 = 0$, then a quadratic relationship curve exists, that is, the curve is inverted U-shaped.

If $\beta_1 > 0$, $\beta_2 < 0$, and $\beta_3 > 0$, then a cubic relationship curve exists, that is, the curve is N-shaped. By contrast, if $\beta_1 < 0$, $\beta_2 > 0$, and $\beta_3 < 0$, the curve is inverted U-shaped.

If $\beta_1 \neq 0$, $\beta_2 = 0$, and $\beta_3 = 0$, then environmental pollution and the growth of an industrial economy have a linear relationship.

Data description: Data availability is considered in this paper; thus, the original data of 14 cities in Liaoning Province from 2000 to 2013 are collected. Five indicators, namely, total industrial wastewater discharges (denoted by "Water"), total industrial SO_2 emissions (denoted by "SO_2"), total industrial dust emissions (denoted by "Dust"), total industrial soot emissions (denoted by "Soot"), and industrial solid waste generation amount (denoted by "Solid"), are adopted to characterize the degree of industrial pollution. The GDP per capita (with year 2000 being the base period), excluding the impact of CPI influence, is used to characterize the growth of industrial economy (denoted by

Table 1: Specific indicators of variables in the models.

Notations of Indicators	Meaning	Unit
Perg	GDP per capita taking the year 2000 as the base period	10,000 yuan/person
Water	Total industrial wastewater discharges	Hundred million tons
SO_2	Total industrial SO2 emissions	Ten thousand tons
Dust	Total industrial dust emissions	Ten thousand tons
Soot	Total industrial soot discharges	Ten thousand tons
Solid	Industrial solid waste generation amount	Ten thousand tons

"Perg"). The data for each indicator are collected from Liaoning Province Environment Bulletin from 2001 to 2014 and relevant chapters in Liaoning Statistical Yearbook. EViews 7 was used for the calculation of all the regression models. The respective meanings of the indicators in the models are presented in Table 1.

ANALYSIS OF EMPIRICAL RESULTS

EKC test on industrial wastewater discharges and GDP per capita: Based on Formula (1), the regression results indicate that industrial wastewater discharges and GDP per capita have an inverted U-shaped relationship. Further calculation indicates that the inflection point of the industrial wastewater discharge curve is located at the 42,000 yuan/person threshold of GDP per capita. This result indicates that, when the GDP per capita is less than 42,000 yuan/person, the industrial wastewater discharges in Liaoning Province will increase with the rise in GDP per capita, but when the GDP per capita exceeds the inflection point because of the further growth of economy, the industrial wastewater discharges in Liaoning Province will begin to decline. This result confirms the existence of the EKC, that is, economic growth aggravates environmental pollution, and provides necessary material foundation for solving environmental pollution problems. Therefore, if economic development reaches a certain extent, the pollution level will show a downward trend, that is, economic growth and environmental pollution have an inverted U-shaped relationship.

EKC test on industrial SO_2 emissions and GDP per capita: The regression results indicate that an N-shaped relationship exists between industrial SO_2 emissions and GDP per capita (Fig. 2). The two inflection points are located at 28,000 yuan/person and 58,000 yuan/person. When the GDP per capita is less than 28,000 yuan/person, the industrial SO_2 emissions in Liaoning Province will increase when the income per capita increases, but when the GDP per capita exceeds the inflection point of 28,000 yuan/person, the increase in GDP per capita will be conducive to reducing industrial SO_2 emissions. However, after the per capita GDP exceeds 58,000 yuan/person, the industrial SO_2 emissions will increase when the GDP per capita increases. Given that pollution and economic growth have an N-shaped relationship, the results are consistent with the "relinking" hypothesis, fully indicating that the material consumption in Liaoning Province will increase again and the environmental quality will deteriorate again when the income level is high; thus, environmental pressure and economic growth have an N-shaped relationship rather than an inverted U-shaped relationship. Owing to the rapid economic development, industrial pollution does not receive due attention, but when the economic growth rate exceeds the environmental carrying capacity, pollution and income will be relined.

EKC test on industrial dust emissions and GDP per capita: Fig. 3 shows that industrial dust emissions and GDP per capita have a linear relationship rather than an inverted U-shaped relationship (EKC). With the rise in the GDP per capita of Liaoning Province, the industrial dust emissions show a corresponding decline: the industrial dust emissions will be reduced by 76,870 tons if GDP per capita is increased by 1 million. Apart from Liaoning Province, many places in China have demonstrated declining industrial dust emissions in recent years. The significant reduction in industrial dust emissions are caused by the implementation of energy-saving emission reduction targets of the 11th Five-Year Plan and the strict government control over industrial dust emissions. Thus, the result has significant government regulation characteristics.

EKC test on industrial soot emissions and GDP per capita: Fig. 4 shows that industrial soot emissions and GDP per capita also have an inverted U-shaped relationship. The two inflection points are located at GDP per capita of 29,000 yuan/person and 56,000 yuan/person. This result indicates that, in a city where the GDP per capita is less than 29,000 yuan/person, the industrial soot emissions will decline when the GDP per capita increases, but when the income per capita exceeds 29,000 yuan/person, the growth in GDP per capita will adversely affect the reduction in industrial soot emissions. Furthermore, if the GDP per capita increases further and exceeds 56,000 yuan/person, the industrial soot emissions will decline when the GDP per capita increases.

EKC test on industrial solid waste generation amount and GDP per capita: The regression results in Fig. 5 evidently indicate an inverted U-shaped relationship (EKC) between GDP per capita and industrial solid waste generation amount. The inflection point of the inverted U-shaped curve is located at the 37,000 yuan/person threshold of GDP per capita. This estimation result suggests that, in a region where GDP per capita is less than 37,000 yuan/person, the industrial solid waste generation amount and GDP per capita will increase simultaneously, that is, with a further increase in GDP per capita, the industrial solid waste generation amount will likewise increase. Furthermore, if the GDP per capita exceeds 37,000 yuan/person, the industrial solid waste generation amount of the region will be reduced. With the economic growth in Liaoning Province, the industrial solid waste pollution will first worsen and then improve.

POLICY RECOMMENDATIONS

Transforming the economic growth mode and developing a circular economy: The industrial pollution in Liaoning Province comprises the bulk of environmental pollution and

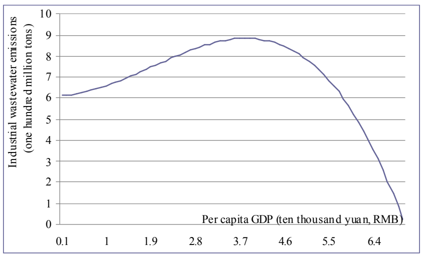

Fig. 1: EKC test diagram of industrial wastewater discharges and GDP per capita.

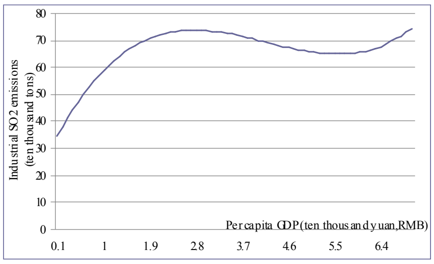

Fig. 2: EKC test diagram of industrial SO_2 emissions and GDP per capita.

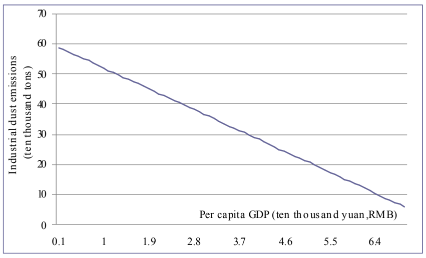

Fig. 3: EKC test diagram of industrial dust emissions and GDP per capita.

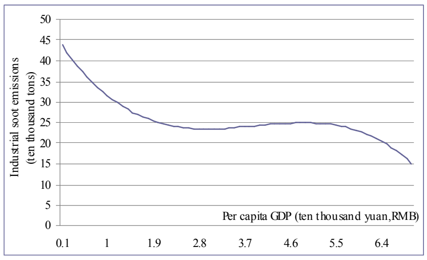

Fig. 4: EKC test diagram of industrial soot emissions and GDP per capita.

exerts enormous pressure on the environment in the economic development process. First, Liaoning Province should transform its economic growth mode and fundamentally control industrial pollution from the source to control the total amount of industrial pollution. Second, the transformation of the economic growth mode should be accelerated to fundamentally relieve the considerable pressure of rapid economic growth on the environment and achieve a coordinated development of economy and environment. Third, technological progress should be expedited, resources saved, and more stringent measures implemented to control emissions. Fourth, a low-consumption and low-emission economic development route should be taken. Finally, the resource consumption per unit output should be constantly reduced, the recycling of resources maximally promoted, pollution emission intensity minimized, recycling economy promoted, and sustainable development always pursued.

Encouraging industrial and technological progress and improving the quality of economic growth: The government should constantly develop new energy technologies and sewage technology to achieve the coordinated development of economic growth and environment protection. Furthermore, advanced foreign technologies should be actively used to reduce industrial pollution, and considerable importance should be attached to the mastery of these technologies. The introduced advanced foreign technologies can reduce the costs of technological innovation, shorten the time of technical innovation, reduce the risk of technological innovation, and accelerate the pace of China's scientific and technological progress. Synchronously, the independent research and development (R&D) capacity of China should be enhanced, innovative studies on technologies that may promote the development of the national economy in Liaoning Province undertaken, the transformation and diffusion of technology strengthened, the contributions of science and technology to economic growth increased, energy-saving technologies and environmental technologies in industrial areas promoted, technology market vigorously developed, and conditions to harness science and technology for practical productivity provided.

Optimizing the industrial structure adjustment and taking a new route to industrialization: Liaoning Province is still in the era of heavy industry. Thus, it should optimize its industrial structure; change its industrial layout; eliminate high consumption and heavy pollution, as well as dangerous and backward processes and products; adopt a low-input, low-consumption, low-emission, and high-efficiency economic growth mode and production; use information technology to stimulate industrialization; harness industrialization to promote information technology; and take a new industrialization route with high technological content, good economic returns, low resource consumption, minimal environmental pollution, and considerable human resource advantages. Furthermore, the technologies of key industries should be transformed; the replacement of old equipment should be expedited; investment in research and environmental protection should be augmented; science and technology should be used to promote the industrial pollution abatement process; independent R & D should be promoted; new technologies should be introduced and harnessed; and the core technologies for environmental protection and enhanced production capacity of key environmental products should be mastered.

Enhancing the Environmental Enforcement Capacity and Improving the Environmental Protection Atmosphere: Environmental protection is a social issue that cannot be solved by a single environmental protection department. Thus, the government should establish an environmental protection responsibility system, strengthen the criminal legislation on environmental protection, and warn against or

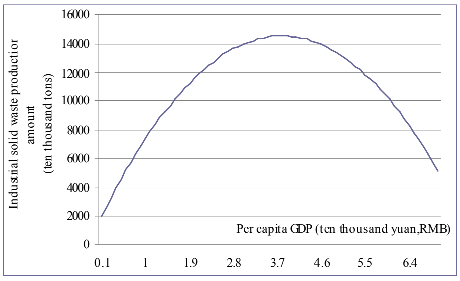

Fig. 5: EKC test diagram of industrial solid waste generation amount and GDP per capita.

enforce higher financial penalties for environmental pollution behaviours. To strengthen the management of the environmental protection department for the industry sector, the sewage discharge behaviour of enterprises should be suppressed to some extent such that enterprises cannot afford the external costs of environmental pollution. The government should optimize the use of radio, television, newspapers, and other media to promote public awareness. It should also strengthen environmental education by including an environmental protection course in the basic curriculum and promoting a compulsory education curriculum for environmental protection. Furthermore, the government should improve incentives for pro-environment behaviours and reporting system for environmental violations, expand channels and systems for public participation, and encourage and guide the public and civil society to participate in environmental protection activities.

CONCLUSION

As a major industrial province, Liaoning Province plays an important role in the industrial construction of China. Accordingly, in this study, five industrial pollution indicators, namely, industrial wastewater discharges, industrial SO_2 emissions, industrial soot emissions, industrial dust emissions, and industrial solid waste generation amount, are adopted. The EKC for industrial pollution is simulated, and empirical tests on the relationships between environmental pollution, via the five industrial pollution indicators, and the growth of the industrial economy in Liaoning Province are conducted. The research results indicate that the five industrial pollution indicators demonstrate different relationships with GDP per capita. Finally, the paper proposes targeted measures and suggestions on various aspects, such as transforming the economic growth mode, developing recycling economy, encouraging industrial and technological progress, improving the quality of economic growth, optimizing industrial restructuring, taking a new industrialization route, enhancing environment enforcement capacity, and improving the environmental protection atmosphere. Our future research will further explore whether the spatial distribution of different cities in Liaoning Province is correlated with environmental pollution and whether the sustainable development of the industrial economy in the province can be achieved by cross-regional integrated treatment of industrial pollution.

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