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Relationships Between Environmental Pollution, Population Increase and Economic Development of Henan China

Pingping Qiao
Department of Economy and Management, Henan Polytechnic Institute, Nanyang, Henan, 473000, China

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ABSTRACT

As a significant traditional agricultural province, Henan has seen an increase in environmental pollution and population that has exerted considerable pressure on its economic development, after it experienced a long-term rapid economic development. Henan is facing the challenge of maintaining its environmental quality while continuing its economic growth. Through the STIRPAT model (Stochastic Impacts by Regression on Population, Affluence and Technology), a form achieved by improving the IPAT model, the effects of population, economic growth, and technological level on environmental pollution based on time series data during 2000-2013 were analysed. The investigation results indicate that the population increase in Henan has resulted in an increase in resource demand that causes environmental pollution; economy has a clearly positive correlation effect on environmental pollution; and the improvement of technological level can help enhance the rate of resource utilization and ease environmental pollution. This study proposes that the industrial structure of Henan should be upgraded and that greater efforts should be exerted on supporting the environmental protection industry. The tertiary and advanced secondary industries should be developed further to realize the rapid development of the economy and environmental protection so that environmental pollution can be mitigated and rapid economic development can be guaranteed.

INTRODUCTION

As a significant agricultural province, Henan has an extremely important position in national economic development. After experiencing rapid economic growth for a long time, it is facing conflicts between population and environmental development, with its excessively high gross population exerting a heavy burden on the environment. In the same way, economic growth has inevitably affected the environment because of resource exploitation and the emission of the three wastes (waste gas industrial residue) causing pollution. Population increase and economic growth have led to a growth in resource demand, which brings greater environmental pollution. Moreover, the employment distribution of the population in different industries has caused changes in the effects of population on economic growth, with various industries causing environmental pollution at different degrees. Hence, the population has directly and indirectly affected environmental pollution. However, economic growth accelerates the improvement of technology, which further increases the utilization rate of resources and lowers pollution levels. Population increase and economic development have given rise to an increase in resource demand. However, economic development reduces the consumption level of resources. Hence, maintaining a harmonious developmental relationship among population, economy, and environment has been a significant topic.

After experiencing significant rapid economic growth, Henan is facing conflicts between population and environmental development. At present, the gross permanent resident population in Henan has reached almost 110 million, and this number continues to increase. However, the capacity of the city surely cannot increase unrestrictedly. An excessively high gross population will be a heavy burden on the environment, and similarly, economic growth inevitably influences the environment, because resource exploitation and the emission of the three kinds of wastes (waste gas industrial residue) cause pollution on the local environment. Although, the population increase and economic growth have resulted in an increase in resource demand, thereby causing greater environmental pollution, employment distribution of the population in different industries has also caused changes in the effects of population on economic growth. Different industries have different effects on environmental pollution and hence, the population has directly and indirectly affected environmental pollution. However, economic growth accelerates the improvement of technology, which further increases the utilization rate of resources and lowers pollution levels.

Several studies have conducted a comprehensive consideration of the economy, environment, technological level, and environmental pollution. Studies have also investigated the influential relation among these factors and their effects in China. Other studies have focused on the relationship between these factors.

Studies on the relationship between economic development and environmental pollution level focus mostly on judging and analysing the specific position of economic development of a target city in the environmental Kuznets curve (EKC); by using this curve to conduct fit analysis between economic development and the degree of environmental pollution. The most representative scholars in this aspect are Grossman et al. (1991), who are American economists. As the earliest advocates who studied the relationship between the emission of various pollutants and economic growth, they determined that the indices of water pollution, such as SO_2 and smoke, have a reverse U relationship with economic growth, which is similar to Kuznets curve, thereafter called EKC by scholars. Bartz et al. (2008) studied the relationship between environment and economic growth in America by using the calibration-simulation method and concluded that they do not have a reverse relationship, overturning the EKC hypothesis. This finding indicates that to some extent, the relationship between the environment and economic growth is not very simple, and we cannot take for granted the fact that the improvements in environmental quality can occur with economic growth after the economy develops to a certain level. Al-Rawashdeh et al. (2015) have conducted quantitative analyses on economic growth and the degree of environmental pollution in developing and developed economic entities by establishing a logarithmic function model. They also conducted analyses on target measures on the environmental pollution problem brought about by different degrees of economic development. Studies on the relationship between spatial distribution and economic growth conducted by Kaika et al. (2013) have concluded that the economies in different territories have influenced environmental pollution at different degrees. Ma Xiaoyu et al. (2015) have studied the relationship between pollution and economic growth in Shandong and have proposed environmental protection measures to guarantee economic development.

However, studies on the relationship between population and environment discuss mainly the bearing capacity of the environment, the harmonious development relationship between population and the environment, and the influence of population on the environment. Not many studies have considered these aspects. Waggoner et al. (2002) have studied the population size appropriate for sustainable development. A logistic curve estimated through unary linear regression was used in the study, and a comparison made between environmental carrying capacity and forecast of population size. Shi et al. (2013) discussed the sustainable development of population and the environment and concluded that the excessively high increase in population size has imposed significant pressure on the environment, and hence, population size should be appropriately controlled, and population quality improved. Aiming at the relationship between population and environmental pollution, Fu Yunpeng et al. (2015) have conducted macroscopic analysis, and concluded that population has little effect on environmental pollution and that economic factors should be well considered.

A few research results have been found on the interactions among the four factors through the IPAT (Environmental impact (I) = Population (P) × Affluence (A) × Technology (T)) model. York et al. (1981) conducted quantitative appraisals on environmental efficiency, and presented a detailed introduction and empirical application of the STIRPAT model. Yan Caixia et al. (2013) analysed the spatial difference of environment stress in Qingdao and concluded that population has a relatively strong influence on environmental pollution and that the pressure of environmental pollution in this area can be lowered through a control of the population. Zhang Leqin et al. (2012) analysed the influence of carbon emission on the environment in Anhui and concluded that the improvement of environmental pollution must start from controlling the population and transforming the pattern of economic growth.

Overall, existing studies have considered mostly the subjects from the point of a single factor, but the current study starts from the population, economic development, technical improvement, and environmental pollution. Through data and materials collected, the comprehensive influence of each variable on environmental pollution is analysed, and methods to improve environmental quality are proposed accordingly.

METHODOLOGY

Introduction of the model: The IPAT model was proposed by Berry Commoner (an American scholar) in 1971. The model can be considered as an extension of a simple measurement model. In other words, technical index (T) is added after population size (I) and economic growth (A). The interaction among the three factors and environmental pollution can be expressed as below.

$$I = P \times A \times T \qquad ...(1)$$

However, this model is used mostly in the environmental pollution and climatic variation to determine the degree of influence and importance of population for a certain environmental factor. The model can also be transformed into a random statistic model through a certain method to implement statistical analysis and compare the original and terminal numerical value ratio of each variable of the given model within a given period directly, to observe the degree of change of each driving factor and to explain their effects on the environment. The differential treatment on Formula (1) is carried out by difference.

$$\Delta I = \Delta P + \Delta A + \Delta T \qquad ...(2)$$

In Formula (2), the growth rate of the environmental pollution factor I can be expressed as the sum of the respective growth rate of each independent variable. An independent variable is assumed to be kept the same, and the change in environmental pollution factor I is observed while other independent variables change. Alternatively, other independent variables are assumed to be kept the same, then different variations of a specific independent variable are inputted, and the changes of environmental pollution factor I is observed and compared. The advantage of the IPAT model lies in its simple application, and its usability has been verified and is well recognized.

However, IPAT also has certain disadvantages because it does not considers the interactions among variables. For instance, when the direction of the force of the factors on the right of the environment is opposite, the forces may offset mutually, which cannot be reflected in this equation. Regarding the mutually affected driving variables as independent factors does not conform to reality. Dietz & Rosa (1994) improved the Formula (2) as given below (Eq. 3).

$$I = aP^b A^c T^d e \qquad ...(3)$$

Formula (3) is abbreviated as STIRPAT (Impacts by Regression on Population, Affluence and Technology). This model contains regressions of population, fortune, and technology, where A and T refer to the influence of average economic factors and technical factor on environmental pollution, respectively; a, b, c, and d are restrained parameters; and e stands for remnant condition. This function indicates the non-linear relationship between the independent and the dependent variables. The logarithm is taken on both sides of the equation to obtain the formula below.

$$\ln I = \ln a + b \ln p + c \ln A + d \ln T + \ln e \qquad ...(3)$$

This equation makes the elastic computing of the influence of each anthropologic factor on the environment easier. The STIRPAT model is used mainly for studying global climate change. This model is multivariable. A common problem exists in the regression analysis in the economic sphere, indicating that a linear relation at different degrees generally exists among independent variables of the economic model because of certain correlativity between independent variables; therefore, multicollinearity may arise. Hence, ridge regression is adopted in this study to reduce the variance of the estimator of parameter. Although it cannot eliminate multicollinearity completely in the model, it can remove the influence of multicollinearity. If multicollinearity exists between independent variables and $|x'x| \approx 0$, then a matrix of positive constant is assumed to be added to $|x'x|$, and then the degree closer to a singular value will be significantly smaller than $x'x$, closer to a singular value. Considering the dimension of the variable, we should first conduct data standardization, and the standardized design matrix should still be represented by X. The formula below can be defined.

$$\hat{\beta}(k) = (x'x + kI)^{-1} X' y \qquad ...(4)$$

The formula is called the ridge regression estimation of β, where k is the ridge parameter. X is assumed to be standardized; therefore, XX is the correlation matrix of the sample of the independent variable. Ridge parameter k is not well-determined and hence, the obtained ridge regression estimation $\hat{\beta}(k)$ is actually an estimation group. The coefficients obtained through regression are actually those in Formula (2), including a, b, c, and d. Specific results of the ridge regression can be obtained through SPSS20.0 programming.

Indicator system: A certain relationship exists between population and economy from the point of population, economy, technical level, and environmental pollution. Economic development has a strong driving force on the increase in population, especially permanent resident population, and population and economy cause more serious environmental pollution. Economic development results in increase in total energy consumed, total resource consumption during production and life, and the wastes after consumption, resulting in more serious environmental pollution. Economic factors also accelerate the enhancement of technological level to ease the pressure of environmental pollution. Moreover, the development speed of different industries also has various effects on environmental pollution. The secondary industry contains many industries with high energy consumption and high pollution, whereas the tertiary industry includes mostly knowledge-intensive and skill-intensive industries, and cause less pollution. Therefore, the different contributions of the secondary and tertiary industries to economic development affect the environment at different degrees. The relationship between population-economy-technical levels and environmental pollution can be expressed as shown in Fig. 1.

Based on existing studies, the indicator system of population, environment, and economic development is established, as depicted in Table 1. All data in Table 1 come from relevant sections of the Henan Statistical Yearbook, China Statistical Yearbook, China Environment Statistical Yearbook, China Environment Yearbook, and Henan Yearly Environmental Report between 2000 and 2013. The related data value of the statistical yearbook are used directly for

Table 1: Indicator system of population, environment and economic development.

Primary Indicator	Secondary Indicator	Unit
Population	Permanent resident population	10000 persons
	Birth rate of permanent resident population;	%
	Death rate of permanent resident population;	%
	Sex ratio of permanent resident population;	%
	Quantity of employment in the secondary industry;	10000 persons
	Quantity of employment in thetertiary industry;	10000 persons
	Employment ratio of two industries;	%
Economic Development	GDP	RMB (10000 Yuan)
	Per capita GDP;	RMB (10000 Yuan)
	Output value of the secondary industry;	RMB (10000 Yuan)
	Output value of thetertiary industry;	RMB (10000 Yuan)
	Proportion of the secondary industry in GDP;	%
	Proportion of the tertiary industry in GDP;	%
	Motor vehicles owned;	Vehicle
	Rate of urbanization;	%
	Fiscal revenue;	RMB (10000 Yuan)
	Engel coefficient;	%
	Per capita disposable income;	RMB (10000 Yuan)
Technical Level	Industrial output value	%
	GDP energy consumption every 10000 Yuan;	Ton standard coal /10000 Yuan
	Annually total energy consumption;	Ton standard coal
Environmental Pollution	Quantity of wastewater effluent	Ton
	Quantity of emission load of sulfur dioxide;	Ton
	Concentration of sulfur dioxide;	ppm
	Concentration of nitrogen dioxide;	mg/m^3
	Particulate matter concentration	g/m^3

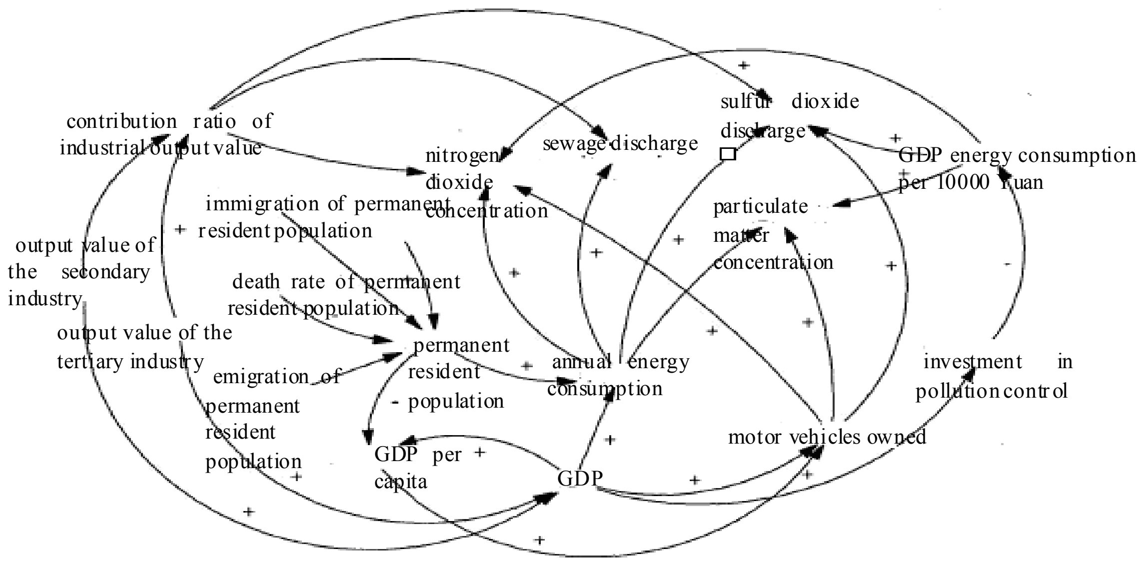

Fig. 1: Interaction between population-economy-technical levels and environmental pollution.

empirical analysis because the collected data are flow data.

EMPIRICAL STUDY

Relationship among permanent resident population, GDP, annual total energy consumption, and quantity of wastewater effluent in Henan: Coefficients of ridge regression can be obtained through programming of collected data in SPSS20.0. The quantity of wastewater effluent is explained variably, and permanent resident population (10000 persons), GDP (10000 Yuan), and annual total energy consumption (ton standard coal) are explanatory variables. The results of the ridge regression of the corresponding relationship are indicated in Table 2. Fig. 2 is drawn according to Table 2.

Table 2 and Fig. 2 show that the three curves, all approach steadiness when *k* is about 0.2. Therefore, when *k* is 0.2, the estimators of the parameters are -0.356, -0.398, and 0.163. Hence, the obtained STIRPAT model is as shown below.

$$\ln y = -0.356 \ln x_1 - 0.398 \ln x_2 + 0.163 \ln x_3 \quad ...(5)$$

Formula (5) is the logarithm transformation of the STIRPAT model, where y, x_1, x_2, and x_3 refer to the quantity of wastewater effluent, permanent resident population, GDP, and annual total energy consumption, respectively. The formula is restored into STIRPAT as given below:

$$y = x_1^{-0.356} x_2^{-0.398} x_3^{0.163} \quad ...(6)$$

Formula (6) indicates the relationship between the permanent resident population, GDP, annual total energy consumption and quantity of wastewater effluent. The natural meaning of the equation states that the permanent resident population, GDP, and annual total energy consumption have different effects on the quantity of wastewater effluent. The economic factors have the most significant effect, followed by permanent resident population and technical factor. When GDP increased by 1 percent point, the quantity of wastewater effluent increased by 0.398 percent points, and when permanent resident population increased by 1 percent point, the quantity of wastewater effluent increased by 0.356 percent points. Lastly, when annual total energy consumption increased by 1 percent point, the quantity of wastewater effluent increased only by 0.163 percent points.

Analysis on the relationship between permanent resident population-motor vehicle-gdp unit energy consumption and concentration of nitrogen dioxide in Henan: The results of the ridge regression of the relationship between permanent resident population-motor vehicle-GDP unit energy consumption and concentration of nitrogen dioxide in Henan are shown in Table 3.

Table 3 and Fig. 3 show that the three curves all approach steadiness when *k* is about 0.3. Therefore, when *k* is 0.3, the estimators of parameter are -0.203, -0.338, and 0.331. Hence, the obtained STIRPAT model is shown below:

$$\ln y = -0.203 \ln x_1 - 0.338 \ln x_2 + 0.331 \ln x_3 \quad ...(7)$$

Formula (7) is the logarithm transformation of the STIRPAT model, where y, x_1, x_2, and x_3 refer to the concentration of nitrogen dioxide, permanent resident population, and total GDP energy consumption per 10000 Yuan, respectively. The formula is restored into STIRPAT as follows:

$$y = x_1^{-0.203} x_2^{-0.338} x_3^{0.331} \quad ...(8)$$

Formula (8) indicates the relationship between the permanent resident population–motor vehicle–GDP unit energy

Table 2: Results of ridge regression of permanent resident population, GDP, annual total energy consumption, and quantity of wastewater effluent.

K	Permanent resident population	GDP	Annually total energy consumption
0.000	-0.456	1.250	-0.045
0.050	-0.452	-0.553	-0.032
0.100	-0.435	-0.462	0.077
0.150	-0.362	-0.421	0.132
0.200	-0.356	-0.398	0.163
0.250	-0.352	-0.395	0.181
0.300	-0.349	-0.392	0.193
0.350	-0.331	-0.385	0.201
0.400	-0.312	-0.382	0.207
0.450	-0.301	-0.381	0.210
0.500	-0.291	-0.374	0.212
0.550	-0.286	-0.372	0.214
0.600	-0.285	-0.369	0.214
0.650	-0.281	-0.368	0.214
0.700	-0.272	-0.365	0.214
0.750	-0.272	-0.362	0.213
0.800	-0.269	-0.358	0.212
0.850	-0.698	-0.351	0.211
0.900	-0.685	-0.350	0.210
0.950	-0.685	-0.349	0.209
1.000	-0.678	-0.348	0.200

Table 3: Results of the ridge regression on the relationship between permanent resident population-motor vehicle-GDP unit energy consumption and concentration of nitrogen dioxide.

K	Permanent resident population	Motor vehicle	GDP energy consumption
0.000	0.831	-0.598	1.026
0.050	0.062	-0.514	0.490
0.100	-0.084	-0.429	0.414
0.150	-0.145	-0.391	0.379
0.200	-0.173	-0.369	0.357
0.250	-0.192	-0.352	0.342
0.300	-0.203	-0.338	0.331
0.350	-0.211	-0.327	0.321
0.400	-0.214	-0.318	0.313
0.450	-0.217	-0.309	0.305
0.500	-0.219	-0.302	0.299
0.550	-0.221	-0.299	0.293
0.600	-0.221	-0.291	0.287
0.650	-0.223	-0.285	0.282
0.700	-0.223	-0.281	0.277
0.750	-0.221	-0.278	0.272
0.800	-0.219	-0.271	0.268
0.850	-0.218	-0.269	0.264
0.900	-0.217	-0.269	0.260
0.950	-0.216	-0.271	0.256
1.000	-0.217	-0.272	0.252

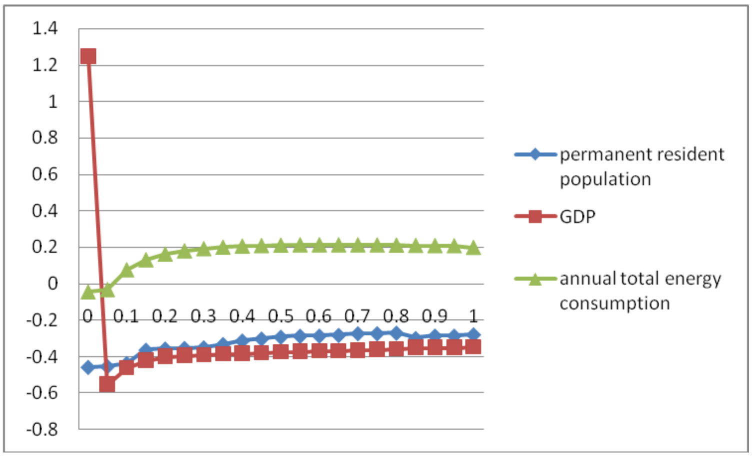

Fig. 2: Ridge regression of permanent resident population, GDP, annual total energy consumption and quantity of wastewater effluent.

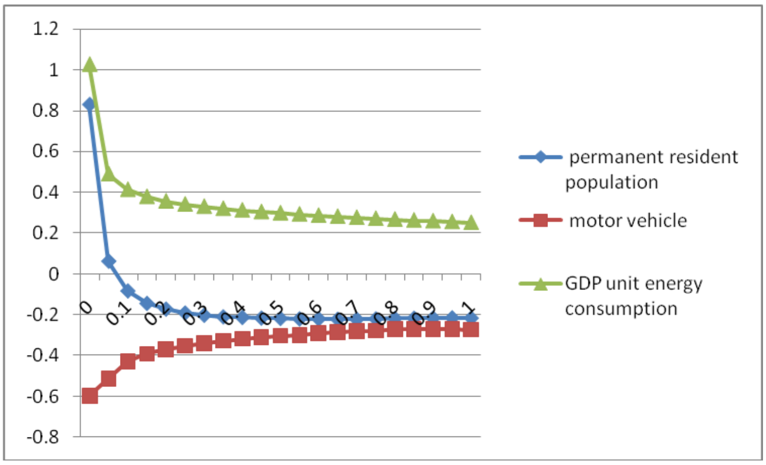

Fig. 3: Ridge regression on the relationship between permanent resident.

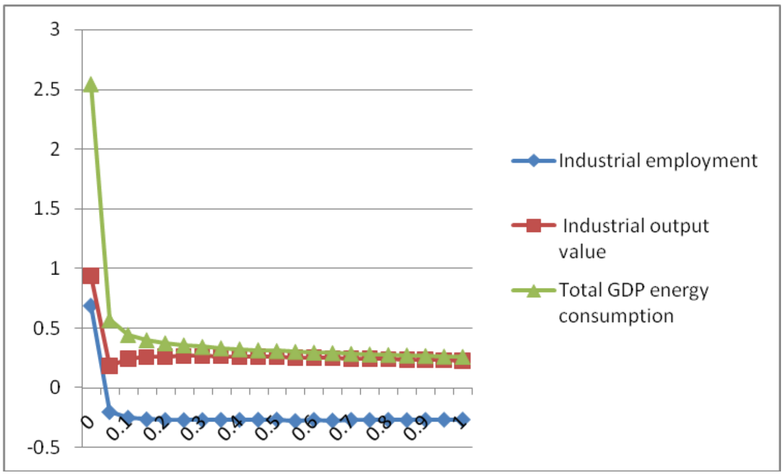

Fig. 4: Results of the regression on industrial employment ratio, industrial output value ratio, total gdp energy consumption per 10000 yuan and sulfur dioxide emission quantity.

Table 4: Results of the regression on industrial employment ratio, industrial output value ratio, total GDP energy consumption per 10000 yuan, and sulfur dioxide emission quantity.

K	Industrial employment	Industrial output value	GDP energy consumption
0.00	0.685	0.937	2.545
0.05	-0.202	0.186	0.567
0.10	-0.249	0.245	0.442
0.15	-0.263	0.261	0.398
0.20	-0.268	0.267	0.372
0.25	-0.269	0.269	0.355
0.30	-0.269	0.269	0.341
0.35	-0.267	0.268	0.331
0.40	-0.267	0.266	0.322
0.45	-0.266	0.264	0.314
0.50	-0.265	0.261	0.307
0.55	-0.277	0.258	0.300
0.60	-0.267	0.255	0.294
0.65	-0.273	0.253	0.289
0.70	-0.267	0.250	0.284
0.75	-0.268	0.247	0.279
0.80	-0.267	0.244	0.274
0.85	-0.269	0.241	0.270
0.90	-0.267	0.238	0.266
0.95	-0.266	0.235	0.261
1.00	-0.265	0.233	0.258

consumption and concentration of nitrogen dioxide. The natural meaning of the equation states that the permanent resident population, motor vehicles owned, and total GDP energy consumption per 10000 Yuan have different effects on the concentration of nitrogen dioxide. The economic factors have the most significant effects, followed by energy consumption per unit and population factor. When motor vehicles owned increased by 1 percent point, the quantity of wastewater effluent increased by 0.338 percent points, and when permanent resident population increased by 1 percent point, the quantity of wastewater effluent increased by 0.203 percent points. When total GDP energy consumption per 10000 Yuan decreased by 1 percent point, the quantity of wastewater effluent decreased by 0.331 percent points.

Relationship between industrial employment ratio–industrial output value ratio-total GDP energy consumption per 10000 yuan and sulphur dioxide emission quantity in Henan: The results of the regression of the industrial employment ratio, industrial output value ratio, total GDP energy consumption per 10000 Yuan, and sulphur dioxide emission quantity are shown in Table 4.

Table 4 and Fig. 4 show that the three curves, all approach steadiness when *k* is about 0.1. Therefore, when *k* is 0.3, the estimators of parameter are -0.249, 0.245, and 0.442. Hence, the obtained STIRPAT model is shown below:

$$\ln y = -0.249 \ln x_1 - 0.245 \ln x_2 + 0.442 \ln x_3 \quad ...(9)$$

Formula (9) is the logarithm transformation of the STIRPAT model, where y, x_1, x_2, and x_3 refer to sulphur dioxide emission quantity, employment ratio between the secondary and tertiary industries, and output value ratio between the secondary and tertiary industries, respectively. The formula is restored into STIRPAT as follows:

$$y = x_1^{-0.249} x_2^{-0.245} x_3^{0.442} \quad ...(10)$$

Formula (10) indicates the relationship between industrial employment ratio, industrial output value ratio, total GDP energy consumption per 10000 Yuan, and sulphur dioxide emission quantity in Henan. The natural meaning of the equation states that the industrial employment ratio, industrial output value ratio, and total GDP energy consumption per 10000 Yuan have different effects on sulphur dioxide emission quantity. Moreover technical level has the most significant effect, followed by economic factors and population factor. When the industrial contribution ratio decreased by 1 percent point, sulphur dioxide emission quantity decreased by 0.245 percent points, and when total GDP energy consumption per 10000 Yuan decreased by 1 percent point, sulphur dioxide emission quantity decreased by 0.442 percent points.

POLICY SUGGESTIONS

Continuing to transform an economic growth pattern and accelerating the upgrading of an industrial structure: Upgrading an industrial structure not only refers to changing the component ratio of each industry, but also includes improvements in the industry. The tertiary industry has a significant effect on the promotion of economy and employment. As a significant traditional agricultural entity, Henan province has carried out considerable upgradation of its industrial structure, which has had an obvious effect on the promotion of economic growth. Although the secondary industry is the important basis of the comprehensive strength of a country, it causes high energy consumption and pollution. Hence, excessive efforts toward the development of the secondary industry to improve the economic level will inevitably give rise to more pollution. Furthermore, if we want to maintain environmental quality, more manpower and capital invested in environmental protection industry are required. To realize the rapid growth of the economy and environmental protection, Henan should develop a mature and firm secondary industry and a strong tertiary industry.

Investing more in environmental protection and energy conservation and reducing environmental pollution: The environmental protection industry has the most direct and significant influence on the governance of environmental pollution, and the result of the development of the environmental protection industry is a reduction in unit GDP energy consumption. The production and consumption of products and services require consumption of energy and resources, which accelerates economic growth and intensifies environmental pollution. To reduce the pressure of environmental pollution, two problems need to be addressed. First, unit GDP energy consumption and pollution and wastes caused by the low utilization of energy and resources during production and consumption from the use outdated technology should be reduced. Second, the governance on existing environmental pollution should be enhanced to reduce the effects of pollutants on the environment. Only in this way, we can realize the economic growth and environmental protection at the same time.

Improving population quality and reasonably adjusting population distribution in industries: The sustainable development of economic society requires more highly competent people who can promote economic development and stronger environmental awareness. The size of permanent resident population cannot be restricted effectively, but the population distribution in industries can be used for adjusting the environment. A better distribution of the population in the tertiary industry will enable the tertiary industry to develop well. Furthermore, the tertiary industry has a significant effect on the promotion of the economy and may cause less environmental pollution. Consequently, providing reasonable guidance in the adjustment of the industrial structure that could lead more people to work in the tertiary industry can promote the development of the tertiary industry, consequently realizing economic growth and environmental protection.

CONCLUSIONS

In this study, the comprehensive relationship among population, economy, technology, and environment in Henan is determined through the STIRPAT model based on the improvement of the IPAT model and according to the time series data on population, economy, technological level, and environment of Henan between 2000 and 2013. The increase in population in Henan caused an increase of resource demand that resulted in environmental pollution. The economy has a significant effect on its positive correlation with environmental pollution. The improvement of technological level resulted in an improvement in the rate of resource utilization, which could alleviate environmental pollution at different degrees. Hence, the industrial structure should be upgraded to offer stronger support to the environmental protection industry. The tertiary and advanced secondary industries should be developed to realize the rapid economic development and environmental protection while reducing environmental pollution.

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