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A 3E Model on Energy Consumption, Environment Pollution and Economic Growth ---An Empirical Research Based on Panel Data

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Abstract

The negative effects of energy consumption and pollution have restrained the Chinese economy from further rapid growth. Therefore to clarify their relationship with economic growth can lay a solid foundation for the decision-making of energy conservation and pollution reduction and ensure the sustainable development of the Chinese economy. Using panel data on the 30 Chinese provinces from 2001 to 2008, this paper builds a 3E model of pollution, energy and production and conducts an empirical study on the interaction between pollutant emission, energy consumption and average GDP.

Keywords-energy consumption; pollutant emission; simultaneous equations

1. Introduction

Because Chinese economic growth still relies on the development of heavy industries, export and the investment in fixed asset, current energy consumption grows rapidly. Energy consumption, which underlies economic growth with other factors of production, is one of the important inputs in most economic activities. Meanwhile, due to limited technologies, pollution is an inevitable byproduct of production. The increasingly prominent environmental and social cost of Chinese economic growth has had very serious negative effects. Given the status quo, the dilemma between economic growth and environment protection, and the coordinated development of energy, environment and economy and the

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achievement of sustainable development have become the center of attention. In order to conduct an empirical research on the interaction between energy, environment and economy, this paper builds a group of simultaneous equations including production function, pollution function and energy function on the basis of the panel data of 30 Chinese provinces. The study examines the interaction and internal feedback mechanism between energy, environment and economy, meanwhile it also examines the effects of exogenous economic variables on the equilibrium of production, pollution discharge and energy consumption, on the basis of which reaches more realistic conclusions and proposes better policy suggestions.

2. The empirical model

2.1 The effects of the environment on economic growth

Pollution as a byproduct of output and energy consumption as a factor of production affect economic growth in different ways. First, given the current science and technology, pollution can not be eliminated from the production process; therefore it can be viewed as a factor of production [1]. Next, energy consumption as a way to consume natural resources is a factor of production, which influences the scale of output. At last, the scale of production is also affected by traditional factors of production including capital (physical capital and human capital) and labor. Building on the above-mentioned analysis, Mankiw [2] establishes the following endogenous growth model:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} (A(t)L(t))^{1-\alpha-\beta} \tag{1}$$

Of which $Y(t)$ is output; $K(t)$ is the stock of capital; $H(t)$ is the stock of human capital; $A(t)L(t)$ is effective labor. On the basis of this model, the new Cobb-Douglas function with the environment as a factor of production is written as:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} E(t)^{\gamma} (A(t)L(t))^{1-\alpha-\beta-\gamma} \tag{2}$$

Of which $E(t)$ is the environment, which includes resource consumption and pollution discharge. Take logarithm on both sides of equation (2) and translate it into the linear form. Then decompose the environment factor into energy consumption and pollution discharge. Given the high ratio of dependence on foreign trade in China's economic growth, we finally set up the following econometric model to measure the effects of environment on output and economic growth:

$$\begin{aligned} \ln g_{it} &= \alpha_0 + \omega_i + \alpha_1 \ln k_{it} + \alpha_2 \ln h_{it} \\ &+ \alpha_3 \ln l_{it} + \alpha_4 \ln ec_{it} + \alpha_5 \ln E_{it} + \alpha_6 o_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

Of which the subscripts i and t stand for province i and year t; g_{it} is income per capita; k_{it} is average fixed asset; h_{it} is average human capital; l_{it} is labor; ec_{it} is energy consumption; E_{it} is pollution; o_{it} is openness (i.e. the ratio of dependence on foreign trade); ω_i is specific cross-sectional effect; ε_{it} is the error term. Energy ec_{it} and pollution E_{it} are incorporated into the production function, representing the comprehensive effects of energy and environment on output.

2.2 The effects of economic growth on the environment

Pollution as a byproduct of production will increase as the scale of production rises. Energy is one of the factors of production and more output requires more input. Meanwhile, when the income per capita has reached a certain level, consumers will ask for a cleaner environment, which will encourage the implementation of more stringent environment regulations, the development of cleaner technology, and the restructuring of industries towards a better environment. In addition, a large amount of pollution will accompany with the process of traditional energy production and consumption. Therefore it is reasonable to incorporate energy consumption into the pollution function in order to measure the effects of energy consumption on pollution discharge. The final pollution function is written as:

$$\ln E_{it} = \beta_0 + \lambda_i + \beta_1 \ln g_{it} + \beta_2 (\ln g_{it})^2 + \beta_3 ig_{it} + \beta_4 \ln p_{it} + \beta_5 o_{it} + \beta_6 \ln ec_{it} + u_{it} \quad (4)$$

The energy function is written as:

$$\ln ec_{it} = \gamma_0 + \eta_i + \gamma_1 \ln g_{it} + \gamma_2 (\ln g_{it})^2 + \gamma_3 ig_{it} + \gamma_4 \ln p_{it} + \gamma_5 o_{it} + \mu_{it} \quad (5)$$

Of which ig_{it} is industrial structure (the ratio of the industrial added value to GDP); p_{it} is the density of population; np_{it} is the number of population; λ_i and η_i are the specific cross-sectional effect of the pollution function and energy function respectively; u_{it} and μ_{it} are error terms. Equation（3）,（4）, and（5）constitute the basic functions of the 3E model.

3. Data and variables

Based on the earlier analysis and the availability of data, because the total amount of energy consumption in Tibet is unavailable, the data of 30 provinces and autonomous regions from 2001 to 2008 are used in this study. The data source is Chinese Statistic Yearbook, 2001-2009.

3.1 Endogenous variables

Income per capita *g*. Compared with gross output (GDP), income per capita can represent real income and economic growth. Here GDP per capita is used to represent income per capita, which is adjusted with the price deflator index and is the real average GDP measured by the price of the year 2000.

Pollution E. Three types of pollutants are chosen, i.e. industrial waste gas emission *iwg*, industrial waste water discharge *iw* and industrial solid wastes produced *isp*.

Energy consumption *ec*. It is measured by the total amount of energy consumption of all provinces.

3.2 Exogenous variables

Average capital stock *k*. The basic method to calculate capital stock is perpetual inventory method. The basic formula is

$$K_{it} = K_{it-1}(1 - \delta_{it}) + I_{it} \quad (6)$$

Of which K_{it} is the current capital stock of province *i*; K_{it-1} is the capital stock of the previous year; δ_{it} is the depreciation ratio of fixed assets; I_{it} is the current fixed assets of province *i*. Because the real average GDP in this paper is calculated in the base year of 2000, the construction of capital stock index and fixed asset investment price index are calculated in the base year of 2000. We use the data on physical capital stock that Zhang [3] calculated. The depreciation ratio that Zhang used in his calculation of capital stock is 9.6%. We adopt the same ratio in this paper. The fixed asset investment price index in the base year of 2000 is calculated according to the investment price index of the previous year. The detailed calculation process is omitted here.

Average human capital *h*. We use average years of schooling to measure the human capital stock of the workforce. Here the average years of schooling is calculated according to the data source from the Chinese Yearbook of Labor Statistics.

Labor *l*. Because the calculation of human capital stock does not include the uneducated labor force, given the fact that there a few illiterates in the labor, the quantity of labor force is incorporated into the production function in order to examine whether or not the illiterates have significant effects on economic growth. We use the number of employed persons at the end of every year to measure the number of the labor force.

Openness *o*. The openness is defined as the ratio of the total value of export and import to GDP.

Industrial structure *ig*. We use the ratio of the added value of all industries to GDP to measure the change of the industrial structure.

Population density p. It is defined as the ratio of the total population of every province to their area.

3.3 The unit root test

This paper chooses the LLC test with the same unit roots, Fisher ADF and Fisher-PP with different unit roots to carry out unit root test on the original series of proportional variables and the logarithm series of the other variables. The results show that at the 5% significance level, every series is a stationary process.

4. Simultaneous equations models estimation

Given the fact that heteroskedasticity is present in the estimation functions, we choose the cross-section weights regression to estimate the results. Because all provinces are very different with regard to economic development and other social and economic factors, their panel data are different in the individual cross-sectional dimension. Therefore, when estimating the parameters of all equations, we use the individual fixed cross-section effects method to reflect the differences between different regions.

4.1 Production function estimation and result analysis

The estimations of production function are listed in table 1. From the estimations we can see the effects of basic factors of production (physical capital, human capital and labor) and environmental factors (energy consumption, pollution) on output.

Table 1. Estimation Results of the Production Function

Variable	**lng**	**lng**	**lng**
lniwg	0.049200***（6.038270）		
lniw		-0.001823（-0.175906）	
lnisp			0.050005***（4.053077）
lnec	0.13868***（7.972582）	0.149294***（7.375185）	0.143733***（7.397197）
lnk	0.551902***（38.83020）	0.586437***（37.81158）	0.552851***（33.60965）
lnh	0.043345（0.998942）	0.067117（1.470123）	0.044003（0.916903）
lnl	0.251587***（5.241174）	0.301177***（6.138692）	0.281227***（5.379745）
o	0.000975***（4.282522）	0.000877***（4.036504）	0.000979***（4.108232）
α_0	5.218512***（14.69203）	5.130416***（14.23042）	4.983786***（12.63842）
Adjusted R^2	0.998704	0.998668	0.998386

Note：the t-statistic is put in the parentheses，***means that it is significant at the 1% significant level.

The effects of the environment on production. From Table 1 we can see that the discharge of industrial waste gas and solid waste have both promoted the economic growth, but the estimated elasticity of production is around 0.05, which is not very high compared with traditional factors of production. The estimated coefficient of waste water is not statistically significant. This shows that the discharge of waste water has little effect on production while the other pollutants have significant impact on China's output, which means that the growth of output results in the inevitable increase in industrial pollution. The productive elasticity of energy consumption is above 0.13, which is in conformity with the earlier theoretical predictions in this paper. Energy consumption has an important impact on China's output, which means that China's economic growth is still dependent on industries of high energy consumption. In the first quarter of 2010, the six industries of high energy consumption (steel and metallurgy, building materials, petrochemistry, chemical industry and electricity) has increased 19.6%, which is 17.3% faster compared with the same time of 2009. The elasticity of energy consumption was below 1.0 before 2003; but from 2003 to 2006, it was above 1.0 and even reached 1.84 in 2005, which means that in China's economic growth the high energy consumption sectors still play an important part. Therefore, China has a lot of challenges in terms of energy conservation and pollution reduction without slowing down the economic growth.

The effects of basic factors of production on output. From the estimations in Table 1, we can see that average physical capital stock and labor force have important impact on China's output, but human capital has no significant effect on output, which means that physical capital and labor force are the major driving force of economic growth. The contribution of physical capital to economic growth is over 50% and it is the decisive factor in the expansion of output scale. The contribution of labor force to economic growth is over 25%, which is just secondary to physical capital. The accumulation of human capital has no significant effect on output, one of the possible reasons for which is that we use the average years of schooling of the employed persons to measure human capital. Because this indicator is based on the random sample taken every year in November, it has some discrepancies with the real human capital stock in each year, and the human capital of the unemployed labor force is included. At the same time, because human capital stock is the result of schooling, on-the-job training and migration, this paper does not include the human capital stock through on-the-job training, learning-by-doing, and labor migration, which undermines the impacts of human capital stock on economic growth.

The effects of openness. In the three equations, the ratio of dependence on foreign trade has significant effects on output. But the productive elasticity is relatively low, to be exact, below 1‰.

4.2 The estimation results and analysis on the pollution and energy equations.

In the pollution and energy equations, the focus of estimation is to test whether there is an inverted U-shaped relationship between environment and economic growth and the effects of the other variables of energy consumption and pollution discharge on the relationship between environment and economic growth. The estimation results of the pollution and energy equation are listed in Table 2.

Table 2. Estimation Results of the Pollution & Energy Function

Variable	lniwg	lniw	lnisp	lnec
lng	4.568810***（6.767416）	-0.549279***（-6.30604）	0.702687***（12.69830）	2.615209***（9.164654）
lng^2	-0.190696***（-5.64177）			-0.091039***（-6.30403）
ig	0.007994**（2.394552）	0.028110***（9.928193）	0.023179***（9.697519）	0.006160***（3.520450）
lnp	0.766572**（2.475058）	1.004658***（4.156618）	0.536686***（3.501924）	0.559305***（8.421185）
o	-0.001437**（-2.23270）	-0.002645***（-3.73883）	-0.002839***（-7.31480）	0.000814***（5.766698）
lnec	0.120070（1.488118）	0.413527***（4.866410）	0.094734*（1.760945）	
β_0	-22.64849***（-5.61434）	5.911670***（4.464194）	-3.103993***（-3.75599）	
γ_0				-10.99107***（-6.87045）
Adjusted R^2	0.988023	0.990686	0.994743	0.998787

Note: the t-statistics of the parameters are in parentheses, *, **, *** means that they are statistically significant at the 10%, 5%, 1% significance level.

From the estimation results in Table 2, we can see that only the industrial waste gas discharge and energy consumption have a weak inverted U-shaped relationship with economic growth, of which the turning points are 159420.7 yuan and 1729122 yuan respectively, far beyond the maximum of the real income per capita in the sample period. Therefore, their relationship can be seen as approximately linearly increasing. Thus, only the waste water discharge declines with the rise of average income, but the other environmental indicators are all increasing with the rise of average income. This means that although the relationship of some resources and pollutants with economic growth supports the inverted U-shaped curve, in reality the Chinese economy is still on the left part of the U-shaped curve, i.e. the rise of average income still goes along with the depletion of energy, the increase in pollution, and the deterioration of the environment.

Energy consumption will increase the discharge of industrial waster and the production of industrial solid waste, but it has no significant impact on the industrial gas emission. In China, Coal is the main source of energy. In 1991, Coal accounted for 76.1% of total energy consumption, while petroleum and natural gas accounted for 17.1% and 2.0% respectively. After 10 years in 2001, coal, petroleum and natural gas accounted for 66.7%, 22.9%, and 2.6% respectively. The consumption of coal dropped by 10%, while petroleum consumption rose slightly. However, starting from 2003, the consumption of coal began to rise again and reached 69.5% in 2007, while the consumption of petroleum declined in the same period. One of the explanations to this is that the high price of petroleum restrained the high demand for petroleum and firms and consumers sought other alternative energy sources. Electricity and heating industries are the main source of industrial SO_2 and industrial soot emission, and the emission of the two industries account for one half and one third of the total emission of industrial SO_2 and industrial soot. Meanwhile, the two industries produce the most waste water and solid, and they also account for one half of the total coal consumption. Therefore, energy consumption, especially coal consumption is the main source of industrial SO_2 and industrial soot. Because in the pollution and energy consumption equations pollution is measured by industrial waste gas emission, which does not include industrial SO_2 and industrial soot, the estimation result is not statistically significant. However, energy consumption will significantly increase the discharge of waste water and solid waste. In 2008, the total discharge of waste water is 21.7 billion tons, of which the waste water discharged by the electricity and heating industries account for 1.8 billion tons. The total amount of industrial solid waste is 1.8 billion tons, of which the electricity and heating industries account for 417 million tons. Therefore, energy consumption is closely related to the discharge of industrial waste water, waste gas and solid waste.

The percentage of industries, population density and the openness all have significant impact on industrial gas emission. The percentage of industrial added value in GDP has significant impact on energy consumption and the pollution. Although in developed countries the change in industrial structure has little effect on pollution discharge, in developing countries the change in industrial structure is an important factor that has significant impact on the relationship between environmental quality and economic growth, and especially in the process of industrialization the change in industrial structure is often the key factor that affects the production and discharge of pollutants [4]. Because industrial energy consumption accounts for 90% of the total energy consumption, while household energy consumption accounts for less than 10%, the increase of the industrial added value in GDP will push up energy consumption.

Population density has a positive impact on pollution and energy consumption, which means that the pollution and energy consumption of populous areas are higher than those of less populous areas. The increase in population will result in more production and consumption along with more pollution and energy consumption. One explanation to this is that populous areas are relatively advanced in economic development. Because population density is closely related to economic development, faster economic development will provide more jobs, therefore the average income in populous areas is relatively high, which will produce more pollution and energy consumption.

Foreign trade has significant effects on environmental quality and energy consumption. The rise of foreign trade is conducive to the reduction of pollution, but it will increase energy consumption. This is against the pollution haven hypothesis because foreign trade does not increase pollution but help improve the environment quality. Therefore in China in the current stage, the rise of the ratio of dependence on foreign trade will be conducive to pollution reduction but not energy conservation.

5. Conclusions

This paper build a 3E model on environment pollution, energy and production on the basis of the panel data, carries out an empirical analysis on the interaction between industrial pollution emission, energy consumption and average GDP, and clarifies the feedback mechanism among the three factors.

The estimation results of the production function show that in the current stage of Chinese economic development production will increase with the rapid growth of the economy. The increase in energy consumption which is an important input in the production process will lift up the output. The pressure of energy conservation and pollution reduction is still very high and governments, enterprises and individuals should cooperate in order to reduce energy consumption and production discharge. In the production function, traditional factors of production such as physical capital and labor are still the main driving force of China's economic growth.

The estimations of the pollution and energy equations show that the discharge of waste water will decline as average income rises but other environmental indicators rise along with the increase of average income. The turning point of pollution and energy consumption has not yet arrived. This means that the rise of average income will push up pollution and energy consumption, therefore the increase in capital stock will bring about more industrial pollution and energy consumption.

According to the empirical research of this paper, the solution to the negative externalities of pollution, energy consumption and resource depletion is to internalize the externalities, clarify ownership, impose pollution and resource tax and optimize the industrial structure (increase the percentage of service industries in the national economy, lower the percentage of heavy industry). Government regulations and incentives can also play a crucial role in this process.

Environmental deterioration results from many factors. Countries in different stages of economic development can take relevant actions to slow down environmental deterioration. China as a developing country could coordinate economic growth and environment. China must implement effective environmental regulations so that firms and consumers can be properly encouraged to reduce pollution and energy consumption because the rise of income is only a necessary condition for the formulation and implementation of environmental policies. The investment in pollution reduction and the development of clean technology must coordinate with the environmental regulations to reduce pollution and promote stable economic growth in order to realize the balanced development of the economy and the environment.

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