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ORIGINAL PAPER

Economic and environmental evaluation of coal production in China and policy implications

Li Li · Yalin Lei · Dongyang Pan

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Abstract Coal takes up an important position in China's energy structure. The relationship between coal resource, economic growth and environment protection has been in focus in recent research. However, both research methods and research scope need to be expanded to promote the practical effects of research results, especially studies concerning China's situation. Here we present a detailed basis for policy making with the following objectives: (1) to examine the relationship between coal development and economic growth in China with multiple linear regression model, using the data from 1997 to 2010 and the indices of the output of raw coal, the gross value of coal industrial output, the new investment in fixed assets of coal, gross domestic product and the gross value of industrial output and (2) to measure the environmental loss caused by coal mining and washing with the given model of environmental damage cost based on the data of 2010 and the indices of waste water, waste gas, waste residues, crop loss, land resource and soil deterioration. The research results show that there is a significant positive correlation between coal development and economic growth in China. The total environmental loss in coal mining and washing in 2010 took up approximately 2.7 % of the average price of coal. Our study recommends that Chinese government and coal companies should (1) keep moderate speed in coal production; (2) increase investment in technology innovation so as to reduce the environmental damage; and (3) increase environment tax.

Keywords Coal production · Economic growth · Environmental loss · Multiple linear regression · Environmental damage cost model

L. Li · Y. Lei (✉)
School of Humanities and Economic Management, China University of Geosciences, 29 Xueyuan Road, Haidian District, Beijing 100083, China
e-mail: leiyalin@cugb.edu.cn

L. Li · Y. Lei
Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resource, Beijing 100083, China

D. Pan
Central University of Finance and Economics, Beijing 100081, China

1 Introduction

Coal is one of the most important energy resources in the world. Coal resources have occupied a strategic position in national economy and residents' life in China. According to China Statistical Yearbooks 1997–2010, the coal resource makes up about 77 % in energy production and about 69 % in energy consumption (National Bureau of Statistics 1998–2011). Coal resources are predicted to account for about 50 % in energy consumption in 2030 in spite of the development of renewable energy (Zhongyannet 2014). Even though coal resources continue to impact China's economic growth, carbon, sulfur, ash from coal will pollute environment, through waste water (WW), waste gas (WG), coal gangue, tailings, dust and volatile gas.

Several investigations have been carried out on energy development, such as on coal development, electricity development (Zheng et al. 2014; Mustafa and Merih 2014; Gutiérrez et al. 2006) and new energy industries (Paddy and Colin 2014). The relationships among coal development, economic growth and environmental damage have attracted much attention.

However, no consistent results have been achieved on the relationship between coal development and economic growth. Seung-Hoon (2006) noted that there was a bidirectional causality between coal consumption and economic growth in Korea by applying modern time-series techniques. Nicholas and James (2010a, b) used a multivariate panel framework based on the data from 1980 to 2006 and found that bidirectional causality existed between coal consumption and economic growth in both the short and long run in 15 emerging market economies. Subsequently, Nicholas and James (2010a, b) used the same model and the panel data for 1980 to 2005 to examine the relationship between coal consumption and economic development in 25 OECD countries. The results showed a bidirectional causal relationship between the two in both the short and long run. Harry et al. (2012) proved that unidirectional causality existed in which coal consumption promoted the economic output in both short and long run under the supply-side analysis, whereas there was also unidirectional causality running from income to coal consumption in the short and long run under the demand-side analysis using co-integration and vector error correction model and the data from 1960 to 2008 in China. By utilizing Granger causality tests and the data of the period of 1980–2005, Li et al. (2008) discovered that the series were not co-integrated which indicated that no relationship could be found between coal consumption and economic development in USA. Also, no causality relationship existed between coal consumption and economic development in South Africa, India and South Korea, whereas unidirectional causality existed running from GDP to coal consumption in Japan and China. Yemane (2010) found that a bidirectional causality existed between coal consumption and economic development in South Africa and the USA, a unidirectional causality existed running from economic growth to coal consumption in China and South Korea, and a unidirectional causality existed running from coal consumption to economic growth in India and Japan with VAR framework for the period 1965–2005. Li and Guy (2012) discovered that bidirectional causality existed between coal consumption and GDP in the Coastal and Central regions, but causality was unidirectional from GDP to coal consumption in the Western region by causality tests during the period 1985–2008.

Some workers investigated from the perspective of the relationship between coal production and economic growth. Taking the data of Inner Mongolia during the period from 1988 to 2009, Sun and Yang (2011) used econometrics model and carried on the co-integration test of coal production and coal demand in Inner Mongolia. Their research showed that there was co-integration relationship between coal production, GDP of Inner Mongolia and coal consumption. Ge and Lei (2013) applied the multiplier decomposition with the incorporation of the Foster, Greer and Thoerbecke poverty measure to evaluate the impacts of mining development on household income and poverty alleviation in China. One of the results was that the coal sector (coal production) contributed most to income growth and poverty alleviation. Qi and Guo (2013) used Granger test to study the relationship between coal production and economic growth and environmental pollution with Shanxi Province as an example. The results indicated that there was bidirectional causality between coal production and economic growth in Shanxi Province, whereas there was unidirectional causality running from economic growth to coal production in China.

As to the influence of coal development on the environment, previous studies mainly focused on recognizing the pollutions which were caused by coal mining (Yu and Wei 2012; Chen and Chen 2010). Earle and Robert (1996) concluded that both coal mining and coal utilization brought about ecological imbalance. Malcolm and James (2010) argued that China might demand much more coal resource and emit much larger volumes of CO_2 than forecasted by many international energy agencies. Bian et al. (2010) recognized that the environmental challenges from coal mining should include coal mine accidents, land subsidence, damage to the water environment, mining waste disposal and air pollution and a conceptual framework for solving mine environmental issues was proposed based on their results that about 39 % of the methane was emitted into the atmosphere and more than 70 % of the mined lands were reclaimed for agricultural purposes in China.

Harry et al. (2012) and Govindaraju and Tang (2013) showed that the amount of CO_2 increased along with the growth of coal consumption. Chaulya et al. (2002) calculated emission rates of suspended particulate matter (SPM) from different types of opencast coal mining activities with some major influential parameters. Bian et al. (2009) took Yanzhou coalfield as an example to analyze the effect of mining on the environment. Qi and Guo (2013) tested that coal production brought about WG, sulfur dioxide and solid waste in Shanxi Province. Li and Liu (2006) measured the ecological and environmental damage in the northern Shaanxi Province caused by coal mining in 2003 using the model of environmental damage cost. The results showed that the environmental loss caused by coal mining and washing was about 36.23 RMB per ton. Qin (2009) recognized the ecological environment loss coal mining brought to coal mining area which included soil deterioration, vegetation deterioration, WW, WG, heavy metal pollution, water soil erosion and land desertification and concluded that the eco-compensation costs in Huainan coal mining region was about 19.44 RMB per ton using the model of environmental damage cost during the period from 2008 to 2073.

From the literature above, we may draw some conclusions as follows:

1. No consistent conclusions have been achieved on the relationships between coal development and economic growth (Table 1). Different workers obtained contrasting results when different regions were analyzed for different time spans. It is necessary to make specific studies according to China's real situation because it is hard to choose the existing research results to guide China's practice.
2. As to the research methods on the relationship between coal development and economic growth, it can be found that many researchers use the models which only inspect the direct relationships among the variables that have been already designed in the model, while no hierarchical relationship has been detected.
3. Many scholars have recognized that the pollutions caused by coal development and detailed results have been presented, especially for provincial areas. However, few

Table 1 Summary of previous studies on the relationship between coal development and economic growth

Author(s)	Objects	Methodology	Period	Conclusion(s)
1. Seung-Hoon Yoo	Korea	Modern time-series techniques	1968–2002	CC $\leftrightarrow$ GDP
2. Nicholas Apergis et al.	15 emerging market economies	Multivariate panel framework	1980–2006	CC $\leftrightarrow$ GDP
3. Nicholas Apergis et al.	25 OECD	Multivariate panel framework	1980–2005	CC $\leftrightarrow$ GDP
4. Harry Bloch et al.	China	Co-integration and vector error correction model	1960–2008	The supply-side analysis : CC $\rightarrow$ GDP the demand-side analysis: GDP $\rightarrow$ CC
5. Jinke Li et al.	South Africa, India, South Korea, USA, China	Granger causality	1980–2005	CC $\neq$ GDP(South Africa, India, South Korea) GDP $\rightarrow$ CC(Japan, China)
6. Yemane Wolde-Rufael	Six major coal consuming countries	VAR framework	1965–2005	CC $\leftrightarrow$ GDP(South Africa, USA, India, Japan) GDP $\rightarrow$ CC(China, South Korea)
7. Raymond Li et al.	China	Modern panel data techniques	1985–2008	CC $\leftrightarrow$ GDP(the Coastal, Central regions) GDP $\rightarrow$ CC(the Western region)
8. Chengzhi Sun	Inner Mongolia	Co-integration test	1988–2009	CP $\leftrightarrow$ GDP
9. Jianping Ge, Yalin Lei	China	Multiplier decomposition	2001–2010	CP $\rightarrow$ GDP
10. Xiaoyan Qi, Pibin Guo	Shanxi Province, China	Granger test	1991–2011	CP $\leftrightarrow$ GDP(Shanxi Province) GDP $\rightarrow$ CP(China)
11. Qi Zhou, Kuan Gao	China	Economic model	1991–2008	CP $\rightarrow$ GDP

CC coal consumption, *CP* coal production, *GDP* economic growth studies have taken the whole region of China as the research objective when calculating the environmental damage cost.

Based on the understanding above, this paper aims to investigate the relationships between coal development and economic growth in China by multiple linear regression model in which deeper relationships may be found with stepwise regression. Furthermore, environmental damage cost is calculated in the general scope of whole China for a better understanding of the degree of environmental damage in the Nation's coal development. Finally, policy suggestions are proposed based on the research results.

The study may serve as a supplementary in research scope and method to the former studies on the relationship between coal development and economic growth. More indices such as the output of raw coal (RCO), the gross value of coal industrial output (GCIOV), the new investment in fixed assets of coal (CFANI), gross domestic product (GDP), the gross value of industrial output (GIOV) are designed to measure the relationship between coal development and economic growth with multiple linear regression model in this paper. Calculation of environmental damage cost will provide more bases for Chinese government to make coal developing and environmental protection policies.

2 Methods and data

2.1 Methods

2.1.1 Multiple linear regression models

As discussed in the introduction above, we apply multiple linear regression model in this paper.

Regression is a common method for investigating the statistical relationship between quantitative variables, which explains the relationship with an equation. The variables in regression model do not necessarily be the time-series data. Correlation of each factor can be measured accurately in regression analysis. There are many methods in regression analysis. Multiple linear regression is one of them and is used to examine the relationship between one dependent variable and two or more independent variables. In studying the actual economic problems, the change of the dependent variable is often influenced by several important factors and multiple linear regression analysis method is then more suitable for choosing more relevant factors as the independent variables to explain the change of the dependent variable. Therefore, multiple linear regression model and stepwise regression analysis method are adopted in this paper.

According to the sample data to estimate the parameters of the model, multiple linear regression uses regression model to determine which independent variables are significant in the model (Viv et al. 2003), where forward regression, backward regression and stepwise regression are included. Forward regression is a method in which a variable will not be rejected once it is chosen in the model. The explanation of some variables tends to become less significant in this situation. Backward regression is a method in which a variable will be excluded forever once it is rejected in the model. Stepwise regression is a combination of forward regression and backward regression, which is often used to select the variables which are relevant to dependent variables. Thus, stepwise regression analysis method is suitable to be used here.

2.1.2 The measurement model of environmental damage cost

Concerning the environmental damage caused by coal development, the environmental value loss caused by coal development is calculated. Here the measurement model of environmental damage cost (Viv et al. 2003) and environmental direct calculation method (Zhong 2012) are utilized to estimate the environmental loss caused by coal development. In the process of coal mining and washing, utilization, transportation and burning, serious damage is brought to the environment, especially in the stage of coal mining and washing. In this study, we only calculate the environmental loss caused by coal mining and washing due to the limited data and the length limit of the paper.

2.2 Indices and data

Coal production is always decided by coal consumption, whereas coal production also affects coal consumption with the mediation of coal price in turn, so that the balance ultimately appears. Coal production is supposed to be equal to coal consumption, so the relationships between coal development and economic growth are to be discussed in general rather than the discussion on coal production and economic growth, coal consumption and economic growth, respectively.

To further detect the hierarchical relationships, GDP and GIOV are chosen as the indices of economic growth; RCO, GCIOV, and CFANI are chosen as the indices of coal development. We realize that the data, such as coal production, are usually stated with differences but without specifying the reasons from different sources. To keep consistency, the relevant data are taken from China Statistical Yearbook 1997–2010, China Coal Industry Yearbook covering the period from 1997 to 2010. By referring to many relevant studies and based on environmental economics, the measurement model of environmental damage cost is used to evaluate the environmental cost caused by coal development. We also adopt direct calculation method to measure it (Wang et al. 2005). The environmental pollution and damage caused by coal mining are analyzed in three parts according to the three main pollutions. The first part explains "the three wastes" and theirs calculation, the second part introduces land subsidence calculation, and the third part describes how soil deterioration is measured. Thus, five indices are adopted when evaluating the environmental loss of coal mining and washing, in which WW, WG, WR, LR and SD are from China Statistical Yearbook on Environment 2011 and China Environment Yearbook 2010.

3 Theoretical Models

3.1 Model on the relationship between coal development and economic growth

To analyze the relationship between coal development and economic growth with multiple linear regression model, a linear relationship between dependent variable Y and two or more independent variables X_1, X_2, …, X_k has to be presumed. Then

$$\mathrm{Y} = \beta_0 + \beta_1 \mathrm{X}_1 + \beta_2 \mathrm{X}_2 + \ldots \beta_\mathrm{K} \mathrm{X}_\mathrm{k} + \mu \tag{1}$$

where Y is dependent variable, X_j ($j = 1, 2, \ldots, \mathrm{k}$) is the j independent variable, β_j($j = 0, 1, 2, \ldots, k$) is the $k + 1$ unknown parameter, and μ is stochastic error.

In the choice of the independent variable X_i, first the paper chooses some explanatory variables from the factors relating to coal development which may influence the dependent variable Y. At the same time, the method of stepwise regression analysis is chosen to ensure which independent variable can be adopted in the equation. One or some independent variables may have little effect on dependent variable Y. In such conditions, the choice of the independent variable X may be influence on the regression equation which will be established in the next step.

Secondly, GDP and GIOV are chosen as dependent variables so as to quantify economic growth. That is to say, two regression analyses will be done to find out the relationship between coal development and economic growth, one is regression analysis among RCO, GCIOV, CFANI and GDP, and the other is among RCO, GCIOV, CFANI and GIOV. Then appropriate independent variables may be found out from the variables above which have been chosen.

3.2 Model on environmental loss calculation

According to China Statistical Yearbook on Environment 2011, the total volume of industrial WW discharged came to 21,185.85 million tons in 2010, and coal mining and washing accounted for about 4.9 %; the industrial WG emission reached 519,167 million cubic meters, and coal mining and washing accounted for about 0.45 %; the industrial solid wastes generated amounted to 2251 million tons, in which coal mining and washing accounted for 12.14 %. The environmental problem brought about by coal mining and washing has been affecting many aspects and causing a certain degree of damage to economics and society.

With the latest available data from China Statistics Yearbook on Environment 2011 (National Bureau of Statistics and Ministry of Environmental Protection 2011), China Coal Industry Yearbook 1997–2010 (China Coal Industry Yearbook Editorial Department 1998–2011), China Mining Yearbook 2011 (China Mining Yearbook Editorial Department 2012), the true cost of coal (Mao et al. 2008) and notice on issuing the execution plan of the minimum purchase price of wheat in 2008, 2009, 2010 (National Development and Reform Commission 2008, 2009, 2010), the environmental loss caused by coal mining and washing in China in 2010 was estimated. The model of estimating the loss of environmental pollution is

$$C = C_1 + C_2 + C_3 \tag{2}$$

In this equation, C is the total environmental loss of coal mining and washing, C_1 represents the loss of environment made by the three wastes, C_2 indicates the loss of environment made by land subsidence, and C_3 shows the loss of environment made by soil deterioration.

3.2.1 Three wastes

The loss of environment made by the three wastes C_1 is summed up by C_{WW},C_{WG} and C_{WR}, which, respectively, indicates the environmental loss brought out by WW, WG and WR. The model is

$$C_1 = C_{\mathrm{WW}} + C_{\mathrm{WG}} + C_{\mathrm{WR}} \tag{3}$$

1. WW

Waste water in coal mining mainly comes from two sources. One is from the water level decreasing and the serious loss of water and soil in mining area (Wang and Chen 2007), and the environment loss of which is C_{WW1}. According to the statistical data, in the main mining areas, there is approximately 71 % mining areas in water shortage (Mao et al. 2008). The other is mine water, and the environment loss of it is C_{WW2}.

$$\begin{aligned} C_{WW} &= C_{WW1} + C_{WW2} \\ &= P \times R_1 + P \times Q_2 \end{aligned} \tag{4}$$

In this equation, P is per external cost caused by water pollution, R_1 is the number of people suffering from water shortage in mining area, and Q_2 is the total amount of waste discharged.

2. WG

Waste gas of coal mining mainly comes from coal bed methane and coal gangue release, industrial soot, SO_2, dust.

$$C_{WG} = \sum (Q_i \times P_{wg}) \tag{5}$$

where Q_i represents the emission of four waste gas and P_{wg} is the unit cost of external environmental controlling of WG.

3. WR

Waste residues (WR) mainly include the place of coal gangue and coal ash, namely Q_3 is the quantity that industrial solid wastes generated minus industrial solid wastes utilized, and P_3 is the treatment cost of WR.

$$C_{WR} = Q_3 \times P_3 \tag{6}$$

3.2.2 Land subsidence

The environmental loss of land subsidence in coal mining C_2 largely comes from the compensation of crop loss C_{CL}, the loss fee of land resource C_{LR} and the compensation fee of the resettlement C_R.

$$C_2 = C_{CL} + C_{LR} + C_R \tag{7}$$

1. C_{CL}

Using the market value method, the compensation of CL should be equaled to the economic loss caused by the change of land quality, the loss of the output and the price of crops.

$$C_{CL} = S_C \times T \times V \tag{8}$$

S_c is the new subsidence of cultivated land in the land subsidence area, and T shows the length of the compensation period, which is generally 5 years. V expresses crop production of every hectare.

2. C_{LR}

According to the market price, the loss fee of land resource C_{LR} is calculated, which may be counted by applying the fee increased for cultivated lands. Non-cultivated lands can be counted in accordance with the fees of recovery and administration.

$$C_{LR} = P_1 \times S_1 + P_2 \times S_2 \quad (9)$$

where P_1 indicates the reclamation fee of cultivated lands per hectare, S_1 is the area of cultivated lands, P_2 represents the reclamation fee of non-cultivated lands per hectare, and S_2 is their area.

3. C_R

The compensation fee of the resettlement for land destruction is usually paid by government and coal enterprise together. Its calculation model is relatively simple as below:

$$C_R = E \times R \quad (10)$$

The price of E was represented by the highest resettlement subsidy standard in 2010, and R was the number of the resettlement people.

3.2.3 Soil deterioration

Soil deterioration represents the amount of the three waste materials and poisonous substances that invaded into the soil which exceeded the capacity of soil self-purification, making the composition, structure and function of soil to reach a certain extent (Gan et al. 1987). The traits of soil deterioration are persistent and long term (Wang et al. 1987). The toxic heavy metal mercury in the WW in coal mining and washing could also cause heavy damage to the farmland.

$$C_3 = P \times M \quad (11)$$

where M is the weight of mercury and P is the loss caused by per ton of mercury.

4 Calculation

4.1 The relationship of coal development and economic growth

With the indexes RCO, GCIOV, CFANI as independent variables and GDP as dependent variable, stepwise regression analysis is taken to perform the first regression analysis and the results are listed in Tables 2, 3, 4 and 5.

Table 2 presents the fitting circumstance of the model. It can be seen that the multiple correlation coefficient R between the independent variable GCIOV and the dependent

Table 2 Model summary

Model	R	R^2	Adjusted R^2	Standard error of the estimate
1	.985[a]	.969	.967	19338.201
2	.996[b]	.991	.990	10721.023

[a] Predictors: (constant), GCIOV

[b] Dependent variable: (constant), GCIOV, RCO

Table 3 ANOVA[c]

	Mode	S	Df	Mean square	F	Sig.
1	Regression	1.414E11	1	1.414E11	378.194	.000[a]
	Residual	4.488E9	12	3.740E8		
	Total	1.459E11	13			
2	Regression	1.447E11	2	7.233E10	629.261	.000[b]
	Residual	1.264E9	11	1.149E8		
	Total	1.459E11	13			

[a] Predictors: (constant), GCIOV

[b] Dependent variable: (constant), GCIOV, RCO

[c] Dependent variable: GDP

Table 4 Regression coefficient[a]

	Model	Unstandardized coefficients		Standard coefficients	T	Sig.
		B	Standard error	Beta		
1	(Constant)	87841.077	7216.911		12.172	.000
	GCIOV	15.306	0.787	.985	19.447	.000
2	(Constant)	−6792.290	18,312.794		−.371	.718
	GCIOV	9.336	1.209	.600	7.723	.000
	RCO	6407.524	1209.984	.412	5.296	.000

[a] Dependent variable: GDP

Table 5 Variable removed[c]

Mode	Beta In	t	Sig.	Partial correlation	Collinearity statistics Tolerance
1 RCO	.412[a]	5.296	.000	.848	.130
CFANI	.110[a]	.340	.740	.102	.027
2 CFANI	.064[b]	.357	.728	.112	.027

[a] Predictors: (constant), GCIOV

[b] Dependent variable: (constant), GCIOV, RCO

[c] Dependent variable: GDP

variable GDP is 0.985, which indicates that GCIOV is highly relevant with GDP. R^2 is 0.969, showing that the regression model is consistent with the data very well. Adjusted R^2 is 0.967, which is closer to R^2, demonstrating the model to be more reliable. Accordingly, the multiple correlation coefficient R among the independent variable GCIOV, RCO and the dependent variable GDP is 0.996, which indicates that GCIOV and RCO are highly relevant to GDP. R^2 is 0.991, showing that the regression model fits the data very well. Adjusted R^2 is 0.990, closer to R^2, which demonstrates the model more reliable.

As can be seen from Table 3, F value of the regression between the independent variable GCIOV and the dependent variable GDP is 378.194 and probability ρ is 0.000.

F value and ρ of GCIOV, RCO and GDP are 629.261, 0.000, respectively. In the significant level of 0.05, it can be considered that linear relationship exists among the dependent variable GDP and the independent variable GCIOV, GDP and GCIOV, RCO.

From Tables 4 and 5, it can be seen that CFANI is rejected and cannot be brought into the equation. And the coefficients and constants of the regression equation can be obtained in Table 3. So with the analysis above, the multiple linear regression equation established is:

$$y = -6792.290 + 6407.524x_1 + 9.336x_2 \quad (12)$$

Next, the second regression analysis is done, and the results are shown in Tables 6, 7, 8 and 9 as following.

Correlation coefficient R between GCIOV and GIOV is 0.980, R^2 is 0.960, and adjusted R^2 is 0.957 in Table 6. Correlation coefficient R between GCIOV, RCO and GIOV is 0.996, R^2 is 0.992, and adjusted R^2 is 0.990.

Table 7 shows that F value between GCIOV and GIOV is 289.888, and probability ρ is 0.000. F value, probability ρ among GCIOV, RCO and dependent variable GIOV are

Table 6 Model summary

Model	R	R^2	Adjusted R^2	Standard error of the estimate
1	.980[a]	.960	.957	8922.367
2	.996[b]	.992	.990	4263.641

[a] Predictors: (constant), GCIOV

[b] Dependent variable: (constant), GCIOV, RCO

Table 7 ANOVA[c]

Mode	S	Df	Mean square	F	Sig.
1 Regression	2.308E10	1	2.308E10	289.888	.000[a]
Residual	9.553E8	12	7.961E7		
Total	2.403E10	13			
2 Regression	2.383E10	2	1.192E10	655.520	.000[b]
Residual	2.000E8	11	1.818E7		
Total	2.403E10	13			

[a] Predictors: (constant), GCIOV

[b] Dependent variable: (constant), GCIOV, RCO

[c] Dependent variable: GIOV

Table 8 Regression coefficient[a]

Model	Unstandardized coefficients B	Standard error	Standard coefficients Beta	T	Sig.
1 (constant)	36105.652	3329.779		10.843	.000
GCIOV	6.183	0.363	.980	17.026	.000
2 (constant)	−9705.187	7282.811		−1.333	.210
GCIOV	3.293	0.481	.522	6.849	.000
RCO	3101.803	481.198	.491	6.446	.000

[a] Dependent variable: GIOV

Table 9 Variable removed[c]

Mode	Beta In	T	Sig.	Partial correlation	Collinearity statistics Tolerance
1 RCO	.491[a]	6.446	.000	.889	.130
CFANI	.054[a]	.148	.885	.045	.027
2 CFANI	.000[b]	.000	.999	.000	.027

[a] Predictors: (constant), GCIOV

[b] Dependent variable: (constant), GCIOV, RCO

[c] Dependent variable: GIOV

655.520, 0.000, respectively. In the premise of the significant level 0.05, it can be judged that linear relationship exists between GIOV and GCIOV and between GIOV and GCIOV, RCO.

And the same situation is shown in Tables 4 and 5, where CFANI cannot be introduced into Tables 8 and 9. Consequently, the multiple linear regression equation established is:

$$y = -9705.187 + 3101.803x_1 + 3.293x_2 \tag{13}$$

4.2 Environmental loss

4.2.1 Three wastes

1. WW

According to the related standards in 2010 (Mao et al. 2008), P was about 3.7 RMB/ton, R_1 was the number of people suffering from water shortage in mining area, about 9.719 million people, and Q_2 was the total amount of wastewater discharged, about 1048 million ton.

$$\begin{aligned} C_{\mathrm{WW}} &= C_{\mathrm{WW1}} + C_{\mathrm{WW2}} \\ &= P \times R_1 + P \times Q_2 \\ &= 3913.56 \end{aligned} \tag{14}$$

Via estimating, the total environmental loss of waste water C_{WW} was approximately 3913 million RMB.

2. WG

Q_i represents the emission of four WG, which were, respectively, 16.64 million tons, 0.116 million tons, 0.160 million tons and 0.150 million tons. P_2 is the unit cost of external environmental control of WG and requires 6.1 RMB (Mao et al. 2008).

$$\begin{aligned} C_{\mathrm{WG}} &= \sum (P_2 \times Q_i) \\ &= 104.103 \end{aligned} \tag{15}$$

Thus, the loss of WG reached about 104 million RMB.

3. WR

The weight of WR was Q_3, about 64.1 million tons. The unit price of dealing with waste residues P_3 was about 4.9 RMB (Mao et al. 2008).

$$\begin{aligned} C_{WR} &= P_3 \times Q_3 \\ &= 314.09 \end{aligned} \tag{16}$$

By calculation, the loss of WR reached around 314 million RMB.

4.2.2 Land subsidence

1. C_{CL}

S_c was 87,000 hm^2 here. And according to the regulation of the land management law, T was generally 5 years (Zhong 2012). V was about 0.047 million RMB/hm^2 (National Development and Reform Commission 2008, 2009, 2010).

$$\begin{aligned} C_{CL} &= V \times S_c \times T \\ &= 20445 \end{aligned} \tag{17}$$

The result of the compensation of CL obtained was approximately 20,445 million RMB.

2. C_{LR}

P_1 indicated the reclamation fee of cultivated land per hectare, about 0.01 million RMB. S_1 was the area of cultivated land, 34,851.481 hectares. P_2 was about 0.006 million RMB per hectare, and S_2 was its area, 61,958.189 hectares.

$$\begin{aligned} C_{LR} &= P_1 \times S_1 + P_2 \times S_2 \\ &= 720.264 \end{aligned} \tag{18}$$

After calculating, the result was about 720 million RMB.

3. C_R

Taking the highest resettlement subsidy standard 0.03 million RMB in 2010 as the price of E, the number of the resettlement R was about 64,000.

$$\begin{aligned} C_{RCF} &= E \times R \\ &= 1920 \end{aligned} \tag{19}$$

So the compensation fee of the resettlement for land destruction was around 1920 million RMB.

4.2.3 Soil deterioration

According to the standards and statistical calculation, P was about 67 million RMB per ton and there were about 570 tons of mercury in the WW in coal mining and washing in 2010.

$$\begin{aligned} C_3 &= P \times M \\ &= 38190 \end{aligned} \tag{20}$$

By calculating, soil deterioration brought out 38,190 million RMB to crops.

4.2.4 Total environmental loss

According to the model of estimating the loss of environmental pollution and the results of C_1, C_2 and C_3 above, the total loss of environmental pollution brought by coal mining and washing could be summed up as follows:

$$\begin{aligned} C &= C_1 + C_2 + C_3 \\ &= 65607 \end{aligned}$$

$$\begin{aligned} &C/\mathrm{GDP} \\ &= 0.16\ \% \end{aligned}$$

The results showed that environmental loss brought by coal mining and washing in 2010 reached 65,607 million RMB which accounted 0.16 % of the GDP.

5 Results, discussion and policy implications

5.1 Results and discussions

5.1.1 Coal development and economic growth

The relationships between coal development and economic growth in China have been inspected above by using multiple linear regression models in which deeper relationships have been found with stepwise regression. The results are summarized below.

1. There is a linear relationship between RCO, GCIOV and GDP, which does not exist been between CFANI and GDP, as seen from Tables 2, 3, 4 and 5. Similarly, from Tables 6, 7, 8 and 9, it can be judged that there is linear relationship between GIOV and GCIOV and between GIOV and GCIOV, RCO, which is not found between CFANI and GIOV. At the same time, CFANI is rejected and cannot be brought into the multiple linear regression equation obtained in this paper when the relationship is measured between coal development and economic growth.

The reason for CFANI being rejected is probably that CFANI dropped significantly in 1998, 2001 and 2002 which indicated that coal supply exceeded coal demand in those years according to China Coal Industry Yearbook.

2. Bidirectional relationship has not been found among RCO, GCIOV, GIOV and GDP. Hierarchical analysis among the relationship of coal development and economic growth needs to be studied more in the future.
3. Unidirectional relationships run from RCO, GCIOV to GDP and from RCO, GCIOV to GIOV. There is a positive correlation among RCO, GCIOV to GDP as shown in Table 4. The result is in accordance with the studies of Chengzhi Sun, Jianping Ge and Yalin Lei, Xiaoyan Qi and Pibin Guo, Qi Zhou and Kuan Gao, which further suggest that China’s economy is promoted by energy consumption to some extent.

Similarly, there is a positive relationship running from RCO, GCIOV to GIOV shown in Table 8. These results substantiate those from previous research such as those by Lei et al.

(2013), which showed that coal development may enhance the GCIOV, and it also enhances the relative industrial output.

5.1.2 Environmental assessment

1. The total environmental loss

By using the model of environmental damage cost and environmental direct calculation method, the total environmental loss caused by coal mining and washing was about 65,607 million RMB, which accounted for 0.16 % of GDP in 2010.

According to the output of RCO in 2010, the environmental loss caused by coal mining and washing was about 20.33 RMB per ton, which accounted for approximately 2.7 % of the average price of coal 753.4 RMB in 2010. This result is close to the results of Qin (2009), who took Huainan coal mining region as an example. However, the result in this paper appeared a bit larger compared with the result of GP Li and ZG Liu, which showed that the environmental loss caused by coal mining and washing in the northern Shaanxi province was about 36.23 RMB per ton in 2003. Two implications may be derived from the comparisons that much progress of environmental protection has been achieved in China in the recent years as compared to the past. Meanwhile, environmental damage was serious in the northern Shaanxi Province since Shaanxi acts as one of the energy bases of China.

2. Three wastes, land subsidence and soil deterioration

According to the computations presented in this paper, the loss of three wastes reached around 4331.753 million RMB in 2010 which took up 6.65 % of total environmental damage cost in coal mining and washing process. The land subsidence was about 23,085.264 million RMB and soil deterioration loss reached 38,190 million RMB, with which together 93.35 % of total environmental damage cost was taken up. We may consider that the destruction of land accounts for the most part of environmental damage loss in the process of coal mining and washing.

5.2 Policy implications

Resource, economy and environment constitute an interdependent system, on which humans have been relying for both life and work. As a responsible, big and developing country, China has been making great efforts to cope with the problems in coal developing as well as to keep the economic growth and protect our environment well. Considering the situation that China's energy structure will still be dominated by coal resource for quite a long time in the future, some policy suggestions are proposed based on the results in this paper.

1. Keep moderate speed in the development of coal industry. According to the results achieved in this paper, there are linear relationships from RCO, GCIOV to GDP and from RCO, GCIOV to GIOV. RCO and GCIOV play a promoting role in enhancing GDP and GIOV. Although China is listed the second largest economy in the world in 2013, the GDP per capita of $5414 still ranked behind 80th in the world. Many remote regions are still at the poverty level nowadays. So keeping moderate economic growth is still an important task for Chinese people and corresponding growth of coal development is still necessary.
2. Increase investment in technology innovation so as to reduce the environmental damage. As shown in the results, land subsidence and soil deterioration compensation

take up 93.35 % of total environmental damage cost in coal mining and washing. It is urgent for China to promote such technologies as disseminate clean coal technology, coal liquefaction or coal seam gas. It is also a good choice for China to use advanced stoves in heating so as to save coal resource and protect environment.

3. Increase environment tax. As the results shown in this study, the environmental loss caused by coal mining and washing account for approximately 2.7 % of the average price of coal. The environmental loss actually should be much larger if we calculate the cost in coal mining and washing in the overall way. A big part of cost producing in coal transportation and utilization has not been included yet in this paper. So it is necessary to add environment tax if the price composition keeps the same.

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