The government capacity on industrial pollution management in Shanxi province: A response impulse analysis

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Abstract

This study employs Vector Auto-regression model with Generalized Response Impulse Function to analyse the dynamic nexus between economic growth and the industrial environmental pollution intensity for six specific pollutants in Shanxi province of China from 1995 to 2015. The results show there exists bi-directional effects, with stronger impact running from economic development to industrial pollution is stronger. We also find Shanxi government shows significant capacity in the management of industrial solid waste and waste gas. The provincial government has higher capacity in controlling Sulfur Dioxide compared to soot/dust. Our results verify the existence of Environmental Kuznets Curve through dynamic interactions between industrial pollution intensity and economic growth impulse. Three out of the six environmental pollution intensity responses are in the shape of inverted U curve. There are exceptions for three pollutants: N curve for Chemical Oxygen Demand and U curve for solid waste and waste gas.

Keywords

Environmental pollution intensity; Economic growth; Government capacity; Industrial pollutions control; Environmental Kuznets Curve

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1. Introduction

China has witnessed double-digit economic growth in the past decades. In the meantime, the environmental quality deteriorates as its development. Persistency of haze, as the most dangerous type of weather since 2009, is affecting the life and health of residents all over the country. These effects are more serious than London Smog and Los Angeles Photochemical Smog in the last century. However, energy related environmental issues cannot be easily solved as the low cost fossil fuel energy remains the power of China's economic growth. Shanxi province is famous for its higher coal reserve and good quality coal resource and labelled as "the town of coal". The boom of the coal industry in Shanxi is driven by a significant amount of energy export and consumption. The exploitation of coal in Shanxi brings about prominent and dangerous environmental pollution as well as serious concerns on ecosystem (Yang and Teng, 2016). The capacity of environmental quality recovery is generally ignored. The environmental concern is far lagged behind the provincial industrial development (Carson, 2010; Selden and Song, 1994; Shafik, 1994). Hence, the increasing extraction of natural resources and the accumulation of pollution will eventually exceed the carrying capacity of ecosystem to the pollutants with the economic expansion (Galeotti, 2003).

This paper analyzes the dynamic economy-environment relationship by using the six industrial pollutant intensity indicators. We then show how the government capacity for controlling the pollution emissions differs across pollutants. The hypothesis of environmental Kuznets curve (EKC) is also examined with different environmental indices, namely six environmental pollution intensities (aggregate pollutants emissions divided by GDP).

Our paper contributes to the literature in several aspects. Most of the studies on economy-environment nexus in the literature focus on uni-directional effect only. The existence of the two-directional effects between the economy and the environment is generally ignored. In particular, the study on the impact of environmental change on economic growth is rare. The two are interactive from the perspective of broad natural environment. The economic development brings about changes in environmental quality, while the latter changes also affect the speed and direction of economic growth (Xu et al., 2005; Zhong, 2006). Environment plays three core functions in the process of the economic growth: to provide a wealth of natural resources, to carry pollutants and waste emissions in the process of production and consumption as well as to provide relevant service for environment. The first two functions are directly associated with the manufacturing process. The last one is crucial for the production activities and has direct effect on the overall economic growth (Xu, 2009).

Environmental protection may constrain the pace of economic growth in the short run. Most possibly, the introduction of stringent environmental standards will limit the development of certain industries. However, the implementation of environmental protection will promote technological progress (Bretschger and Zhang, 2017), improve resource utilization and accelerate the optimal allocation of social resources (Pan, et al., 2005; Zhong and Jian, 2005) and economic growth (Karydas and Zhang, 2017) in the long run. Therefore, it has significant policy implication to investigate the impacts of economic growth on the environmental quality. Our paper contributes to the literature by investigating and comparing the two-side effects between economy and environment.

Our second contribution is that studies in the EKC literature use emission stock as the environmental index (Selden and Song, 1994; Roca et al., 2001; Paudel an d Schafer, 2009), while this paper takes six industrial environmental pollution intensities (wastewater, COD, solid waste, soot/dust, waste gas, SO_2) into consideration. Pollution intensity index can be used as an indicator to measure the government capacity on industrial pollution control. Cui and Li (2005) utilize pollution intensity and ponder the sign of pollution load on economic activities, which indirectly reflected the production technology level of economic as well as the ability of pollution management. As suggested by Yu and Wen (2010), it would be preferable to employ pollution intensity as the vital indicator if the environmental degradation was caused by the development of heavy industry. Tan et al. (2015) track wastewater, COD, waste gas, SO_2, soot, dust and solid waste emissions for seven types of industrial pollution intensity to examine the urban economy-environment relationship in 46 Chinese cities. They find that the development of city economy is at the expense of enormous industrial pollution. They also reveal that a lower economy growth with high pollution intensity and low per capita GDP means cities lack of pollution control ability: as the manegement technologies and other existing measurements are fully embedded in the process of industrial prduction, economic growth will cause a reduction of pollution emissions. Furthermore, previous studies have presented different patterns of economy-environment relationship: the inverted U curve (Brajer et al., 2011; Liu et al., 2007; Bao et al., 2005), the U curve (Deacon and Norman, 2004), the N curve (Alvarez-Herranz et al., 2017; Balsalobre et al., 2016) and the linear curve (Burnett, 2009; Stern and Common, 2001).

In terms of methodology, we apply the time series VAR model combined with Generalized Response Impulse Function (GRIF) for this study. It has the advantage of putting many of variables together as a system for prediction (Yin et al., 2007). The VAR model considers the multivariate as endogenous ones and analyzes their interaction by using themselves and their lag terms as explanatory variables (Chen, 2010). In the field of environment, the application of VAR model to carry out environmental and economic correlation analysis is limited (Zhang, 2012). Yan and Zhao (2009) apply VAR model to explore the dynamic relationship between economic growth and environmental pollutants in Shanxi from 1985 to 2006. Liu et al. (2007) employ three types of environmental pollution indicators and per capita GDP to study the relationship between economic growth and environmental contamination in the temporal dimension in Yantai from 1986 to 2003. Peng and Bao (2006) examine the dynamic effects with six categories of environmental pollution indicators and per capita GDP based on the VAR model between 1985 and 2003 in China. Our paper differs from the above mentioned studies from several aspects. First, as have discussed we use pollution intensity instead of pollution stock to proxy the environmental degradation. Second, our data set covers the most recent years where the environmental concerns become increasingly severe as the fast economic growth. Third, we further study the government capacity in managing different sources of industrial pollutants and restoring the environmental quality.

The rest of the paper is organized as follows. Section 2 introduces the model and the data. Section 3 presents the results with discussions. Section 4 shows a brief overview of current environmental policies in Shanxi province. Section 5 presents relevant policy implications. Section 6 offers concludes.

2. Methodology

2.1 Generalized Response Impulse Function based on VAR model

The VAR is first proposed by Sims (1980) who established a type of multiple simultaneous equations model with endogenous variables in each equation forming a lagged values regression of all endogenous variables. It is convenient to address the dynamic connection among variables and overcome the traditional simultaneous equation model restrictions of deficient theory problems. For a set of *k* observable time series, the general mathematical expression of VAR model is as follows:

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots + A_p Y_{t-p} + \epsilon_t \qquad (1)$$

where $Y_t = (Y_{1t}, Y_{2t} \dots Y_{kt})'$ is a $k \times 1$ time-series endogenous vector with a sample of size t; $A_1, A_2 \dots A_p$ is a number of $k \times k$ coefficient matrix to be estimated for the model. p is the number of lag periods in the model. ϵ_t represents $k \times 1$ vector of the random error with $\text{cov}(\epsilon_j, \epsilon_s) = 0$ ($j \neq s$) and $\epsilon_t \sim (0, \delta^2)$. j, s denote j^{th} and s^{th} observable variables, respectively.

The basic VAR model can reflect most of the dynamic responses between variables due to the lag periods p. When choosing lag times p, we make sure the lag periods are enough to ultimately reflect the dynamic characteristics of the model constructed. However, the more lag periods we use, the less degree of freedom as well as the more parameters we should estimate. This is the shortage of VAR model. It is of significance to make a reasonable choice between the lag periods and the freedom before establishing VAR model. The optimal lag selection of all the variations becomes the solid foundation of GRIF. We initially produce the optimal lag selection by using the Schwartz-Bayes Information criterion (SBIC) introduced by (Schwarz, 1978). The optimal lags for each of the six industrial pollution intensity (wastewater, COD, solid waste, soot/dust, waste gas and SO_2) are 3, 4, 3, 1,1,1, respectively. Additionally, this paper will employ the VAR model combined with the GRIF (Pesaran and Shin, 1998) to capture the bi-directional dynamic interactions between the industrial pollution intensity of six pollutants and economic growth. We label this as GRIF-VAR. The advantage of the new modelling approach (GRIF-VAR) is that it does not rely on the endogenous variables order in the system compared to Cholesky model based on VAR.

It enhances the stability and reliability of the result. The GRIF is thus revised as follows:

$$GI_x(n, \delta_k, \Omega_{t-1}) = E(x_{t+n}|\varepsilon_{kt} = \delta_k, \Omega_{t-1}\ ) - E(x_{t+n}|\Omega_{t-1}) \qquad (2)$$

where δ_k is the standard deviation of ε_{kt}, representing the impulse from the variable k, n is the number of impulse response time, Ω_{t-1} is the results obtained when the impulse occurs. The equation GI_x illustrates the expected value difference x_{t+n} (random error) as a result of impulse impact δ_k. GRIF refers to system response of current and future value in a specified period, through which a variable's random error is shocked by a standard deviation in early phase. The standard deviation of shock derives from Monte Carlo simulation. System will generate numbers randomly to simulate the distributions through Monte Carlo analysis. This approach draws samples of data repeatedly and implement an estimation accordingly each time when a sample is drawn. As the number of simulation increases, the average error will gradually approach to zero. Moreover, the approximate estimator will be close to their true standard deviation. More specifically, we can study how the response changes while the economic growth exerts a shock to pollution intensity of the same size of standard deviation as well as the opposite situation.

2.2 Data

We use the annual time-series data in the period of 1995-2015 for this study. All the data are obtained from the *China Environmental Statistical Yearbook* and *Shanxi Statistical Yearbook*. The data include per capita real GDP, six types of pollutants including wastewater, COD, solid waste, soot/dust, waste gas and SO_2 emissions in

Shanxi province of China. We then calculate the pollution intensity for each of the six pollutants, which is defined as pollution emissions divided by GDP. The emissions include all the three physical phases --- solid, liquid and gas phases, which could depict a full picture of the situation of industrial environment pollution. Furthermore, the variable per capita GDP eliminates the population scale effects. Table 1(a) provides a summary of the variables used in this study and Table 1(b) provides the descriptive statistics. All variables are transformed into logarithmic form.

Table 1: The description of the variables

(a) Summary of variables and units

Variable	Definition	Units of measure	Source
PCGDP	Real per capita GDP	Constant 1995 Yuan	Shanxi Statistical Yearbook
WWI	Total Volume of Industrial Wastewater Discharged/GDP	Ton/100 million Yuan	China Environmental Statistical Yearbook
CODI	Total Volume of Industrial Waste Gas Emission/GDP	Ton/100 million Yuan	China Environmental Statistical Yearbook
SWI	Industrial Solid Wastes Discharged/GDP	Ton/100 million Yuan	China Environmental Statistical Yearbook
SDI	Volume of Industrial Soot/Dust Emission/GDP	Ton/100 million Yuan	China Environmental Statistical Yearbook
WGI	Total Volume of Industrial Waste Gas Emission/GDP	cu.m/100 million Yuan	China Environmental Statistical Yearbook
SO_2I	Volume of Industrial Sulphur Dioxide Emission/GDP	Ton/100 million Yuan	China Environmental Statistical Yearbook

(b) Descriptive statistics of all variables

	PCGDP	WWI	CODI	SWI	SDI	WGI	SO_2I
Mean	4325.9	284545.9	111.1	3033.4	858.5	19503.7	708.3
Median	4289.9	269865.5	103.3	1589.2	759.1	15142.0	664.0

Maximum	5426.6	395285.6	261.6	14509.5	1780.0	42195.0	928.1
Minimum	3515.0	205255.5	38.9	0	454.8	5076.0	577.5
Std. Dev.	658.8	53236.3	66.4	3432.3	371.4	13406.8	107.8

Note: pollution intensity represents pollution emissions per unit of output

2.3 The test for GRIF model precondition

2.3.1 The variables unit root test

Since the GRIF requires that the random error vector satisfies the time-stationary sequence (Pesaran et al., 2004), it is necessary to test them first. In fact, the trends of many time series variables over time are always non-stationary. Such time series are those whose mean, variance and autocorrelation structures are always not constant over time. In that case, it may cause spurious regressions between the two unrelated variables and make the standard t-test and F-test invalid. Therefore, a so-called unit root test (Im et al., 2003) can be used to verify the original variables whether stationary or not.

The hypothesis is

H_0: $\Phi = 1$ The time series with a unit root is non-stationarity

H_1: $|\Phi| < 1$ The time series without unit root is stationarity

For each variable, we test three equations involving individual intercept and trend, individual intercept and none, respectively. If one of three rejects the null hypothesis at the 5% or 10% significance levels, we can accept the stationarity of the series. Otherwise, we should test it in first difference and repeat above steps until it becomes stationarity. Our tests show that the stationarity of waste gas series is at a 5% significant level and for COD it is at a 10% significant level, while other variables are non-stationary sequences at the level. After first order difference, all the variables are stationary sequence. To ensure the stationarity of the series, all variables used to estimate VAR are in first differences.

2.3.2 Johansen co-integration tests

The co-integration test is another preliminary step before conducting VAR model, which can verify the model's specification. Since all the variables are I(1) with a unit root, we rank them up to one vector to test the seven variables employing Johansen's (Johansen, 1988) methodology. Johansen co-integration test is considered as a multivariate generalization which is used to examine the linear combinations of more than two variables for the same unit roots. The null hypothesis is of no co-integration against the alternative of co-integration. If the test shows the existence of co-integration, we could conclude that there exists a long-run relationship between the variables under investigation. The test illustrates that the null hypotheses of zero is not rejected (*p* value is equal to 0.20 and is higher than that of 10% critical value), which suggests the absence of long-term equilibrium relationship.

3. Results and discussion

3.1 The impact of industrial pollution intensities on economic growth

The results in Figure 1 suggest that shocks in industrial solid waste and waste gas intensities affect economic development positively in the first three years. The impacts weaken gradually in the last five years. As showed in Table 2(a), throughout the impulse response period, the aggregate impact of current industrial solid waste and waste gas intensities on cumulative response value of per capita GDP are 0.0402 and 0.0639, respectively. It illustrates that these two industrial pollutant intensities will not have a significant negative impact on economic growth. The conflict between economic growth and environment pollution for these two kinds of pollutants has effectively alleviated. The government capacity for managing industrial solid waste and waste gas discharged are better than other pollution mentioned above.

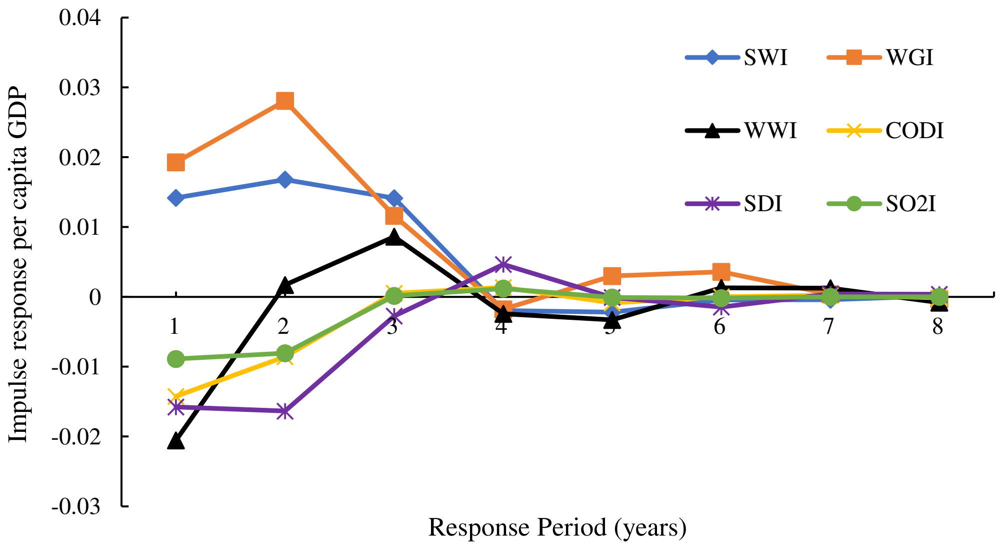

Fig. 1 Response of per capita GDP to industrial pollution intensities

Table 2: Response results between per capita GDP and industrial pollution intensities

(a) Response of per capita GDP to industrial pollution intensities						
	Liquid Pollutants		Solid Pollutants		Gas Pollutants	
	WWI	CODI	SWI	SDI	WGI	SO_2I
ACCUMULATED	-0.0142	-0.0216	0.0402	-0.0310	0.0639	-0.0158

RESPONSES						
(b) Response of industrial pollution intensities to per capita GDP						
	Liquid Pollutants		Solid Pollutants		Gas Pollutants	
	WWI	CODI	SWI	SDI	WGI	SO_2I
ACCUMULATED RESPONSES	0.0415	0.1714	1.5929	-0.1260	0.0433	-0.0074
SHAPE	inverted U-shaped	N-shaped	U-shaped	inverted U-shaped	U-shaped	inverted U-shaped

Figure 1 also points out that industrial wastewater, COD, soot/dust as well as SO_2 intensities have negative effects on economic growth in the first two periods. The impacts weaken gradually. As showed in Table 2(a), throughout the impulse response period, the aggregate impact of current industrial wastewater, COD, soot/dust as well as SO_2 intensities on cumulative response value of per capita GDP are negative. It demonstrates that these four types of pollutants affect economic growth adversely. As illustrated by the cumulative response value, SO_2 has a lower negative influence on economic growth than soot/dust, implying that the government has higher capacity in controlling SO_2 compared to soot/dust.

3.2 The impact of economic growth on industrial pollution intensities

As showed in Figure 2, in the following response periods, it is obvious that the shapes of industrial pollution responses to economic basically abide by EKC. Furthermore, we define three types of curves according to the difference in identification features: Inverted U-shaped, U-shaped and N-shaped curves. The inverted U-shaped curve refers to the response curve with one significant peak over the whole response period. Similarly, the U-shaped curve is the response curve with one negative turning point over the whole response period; the N-shaped curve highlights the distinction of two (one positive and one negative) turning points. Therefore, all the response curves for the six pollutants can be classified into one of the three categories.

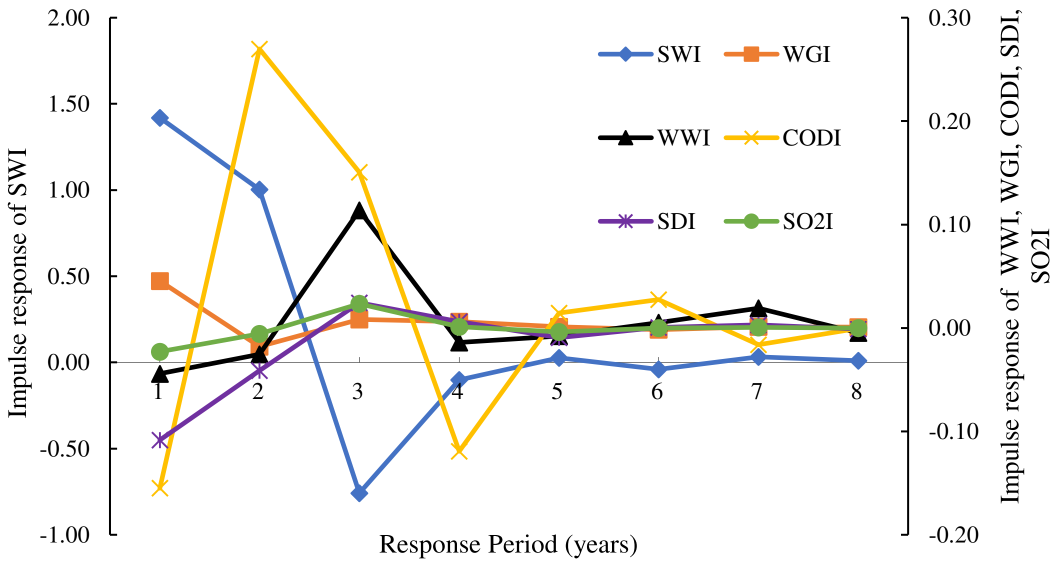

Fig. 2 Response of industrial pollution intensities to per capita GDP

Notes: According to the definitions, given an impulse of per capita GDP, the responses of WWI, SDI and SO2I are inverted-U shape while COD showing N curve and SWI, WGI showing U curve, respectively.

The results in Figure 2 suggest that a shock in economic development affects wastewater, COD, soot/dust as well as SO_2 intensities negatively while having a positive impact on solid waste and waste gas, respectively, within the first two years. After several years' fluctuation, the effects die out and gradually reach their equilibrium situation. Three out of the six environmental pollution intensities follow the similar trajectory of traditional EKC. As showed in Table 2(b), when an positive impulse for per capita GDP is generated, the aggregate impact on wastewater, COD, solid waste and waste gas intensities are positive by calculating the cumulative response value. We conclude that economic growth contributes largely to the severe environmental pollutions. The negative accumulative responses of soot/dust and SO_2 imply that economic growth is not the major reason for the degradation of the environmental quality as a result of these two types of industrial pollutants.

3.3 Variance decomposition of economic growth and environmental pollution intensities

Variance decomposition explains the relevant share of a variable in the interpretation of other variables in the future (Payne, 2002), which is also known as the causal relationship between them. Engle and Granger (1987) believe that variance decomposition supplies more superior results than any other methods in dealing with the VAR environment issues. The results are reported in Table 3.

Table 3: Variance decomposition of the average contribution of pollution intensities

Variance Decomposition	WWI	CODI	SWI	SDI	WGI	SO_2I
PCGDP (%)	2.93	0.89	10.99	5.33	19.03	1.04
Pollution Intensities (%)	43.91	19.27	10.85	8.55	16.62	4.22

It shows that a shock to industrial pollution intensities (including wastewater, COD, solid waste, soot/dust, waste gas and SO_2) can cause fluctuation in per capita GDP by 2.93%, 0.89%, 10.99%, 5.33%, 19.03% and 1.04% on average, respectively. It reflects that industrial waste gas and solid waste account for more than 10 percent change of per capita GDP. The second largest contribution in the explanation of GDP change is industrial soot/dust and wastewater intensities. SO_2 and COD explain a small proportion of the change. The higher contribution of waste gas and solid waste to economic growth reflects more advanced level of production technology as well as the stronger ability of their management compared to others.

The second row of Table 3 also illustrates that, a shock to economic growth results in the largest fluctuation in industrial wastewater intensity (43.91%) and COD intensity (19.27%), followed by waste gas intensity (16.62%), and solid waste intensity (10.85%). The impacts of economic growth on the pollution intensity of soot/dust (8.55%) and SO_2 (4.22%) are smaller compared to others. It is also evident that the economic growth has stronger impact on industrial pollution intensities, while the influence of pollution intensities to economic growth is weaker from the above table, by comparing values in the same columns.

3.4 Local pollutants and pollution embedded in goods export

The impacts of economic growth on various industrial pollution intensities could be not changed in the short run without the change of the economic structure. To understand this, we have to take a close look at the production and consumption of energy in the province. Specifically, we find that the growth rate of energy production is strongly affected by the GDP growth (Figure 3). When the growth rate of GDP changes, the growth rate of energy production tends to fluctuate strongly than that of energy consumption, which confirms that the growth of Shanxi's economy heavily dependents on energy sectors.

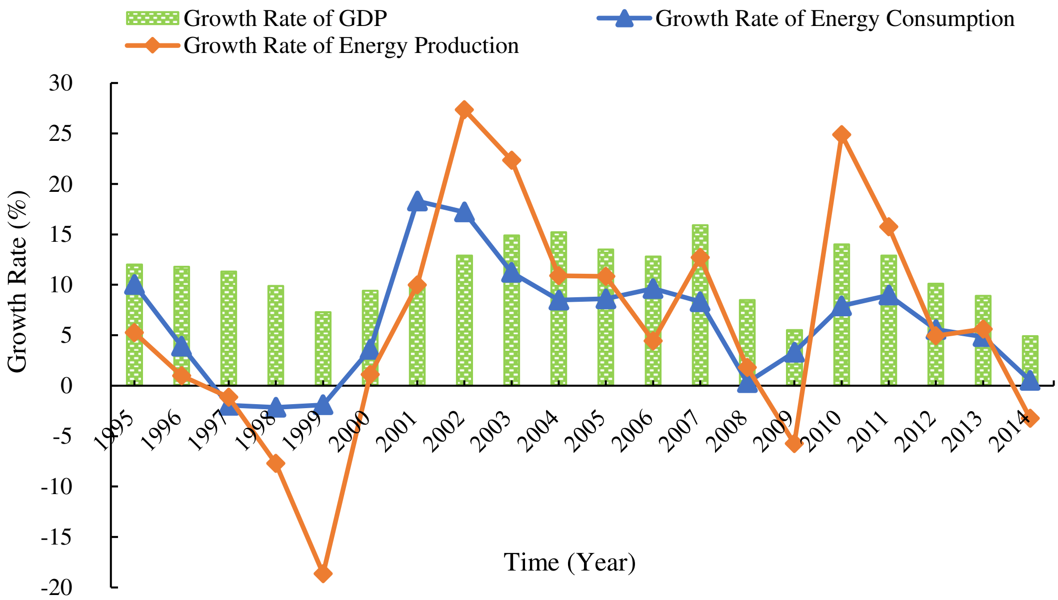

Fig.3 Growth rate of GDP, energy consumption, energy production over Preceding Year (1995-2014)

Shanxi is known for its energy production and export in the last decades. The energy products export (63.587 million tons of SCE in 2014) was significantly larger than those of local consumption (16.325 million tons of SCE in 2014). As observed in Figure 4, trade volume was more than three times of domestic consumption as time goes on.

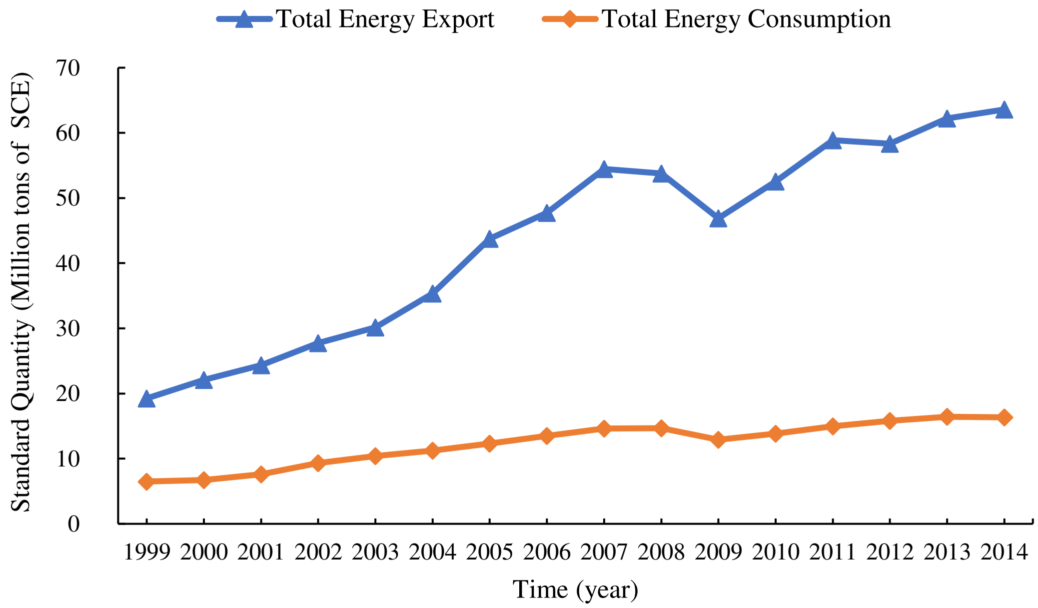

Fig.4 Energy Consumption and export in Shanxi province during 1999-2014

Furthermore, as showed in Figure 5, the coal export accounts for more than 70% of total energy export and is one of the major contributors of Shanxi's GDP growth. Previous research shows the coal industry's mining, washing, transportation and sales process rarely emits air pollution as it is mainly from the four downstream industries including steel, power generation, building materials and chemical (Saboori and Sulaiman, 2013). This implies that economic growth triggered by coal export has marginal effects on the intensity of two pollutants (soot/dust, and SO_2) in Shanxi, since these pollutants are discharged only when being consumed in other regions. The production of coal, steal and coke is associated with wastewater and waste gas. In Shanxi, the high quantity of the industrial products is the dominating reason for industrial solid waste, wastewater and waste gas discharged.

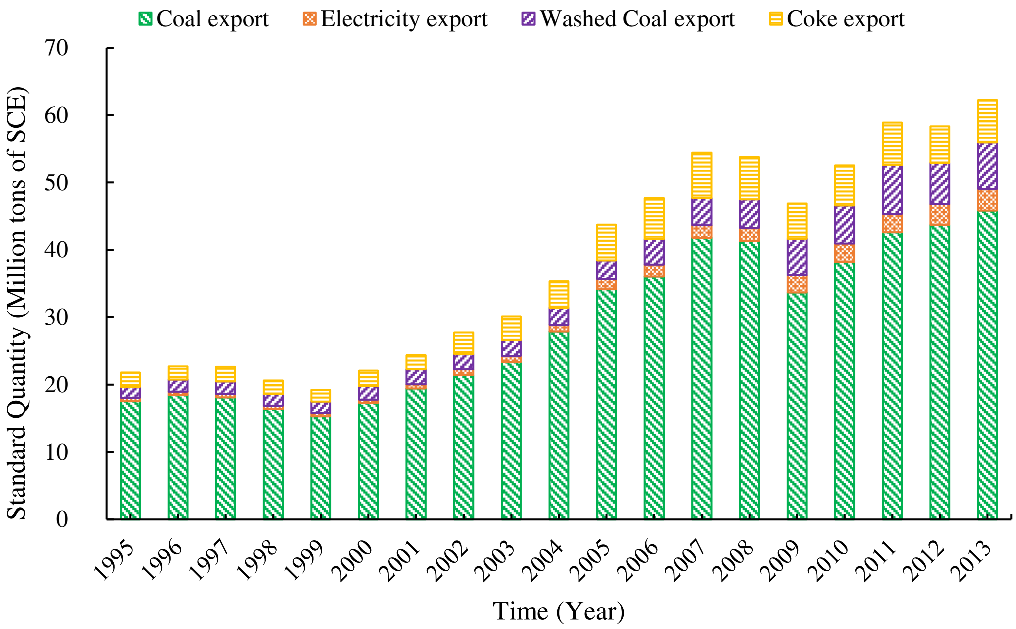

Fig.5 Energy export consumption in Shanxi province during 1995-2013

3.5 Comparison of government capacity and investment in various pollutants management

The results from Table 2(b) and 3, confirm the idea that the government capacities for pollution control on industrial solid waste and waste gas are most effective because they not only contribute the most but also have positive influence on economic growth.

The investment for industrial solid waste control was the lowest in the last several years. However, the dischage of solid waste has been reduced year by year, reaching zero dischage in 2013 and 2014. The solid waste was fully utilized, disposed and stored. (China statistical yearbook on environment, 2014 2015). This proves that the mangement of industiral solid waste is much efficient compared to other pollutants.

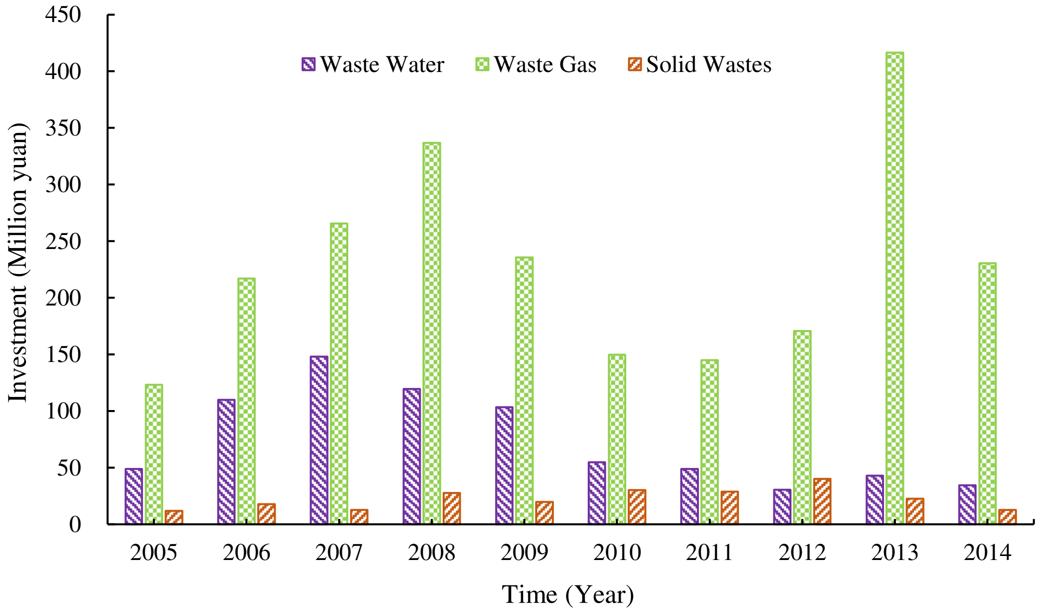

Fig. 6 Investment for industrial pollution control

The report "*The Energy and Air Pollution*" draws attention to the fact that anthropogenic behavior of energy exploitation and usage is the "only critical cause" for air pollution, where 85% of the particulate matter in the air and almost all of SO_x and NO_x come from energy[2]. As Laura et al. (2016) explained, the main components of haze are particulate matter, SO_2 and nitrogen dioxide (NO_2). SO_2 mainly comes from coal and NO_2 is primarily from oil. The government and administrative department have attached great importance to the management of air pollution and the industrial waste gas treatment. It shows in Figure 6 that there was a significant increase in investment of managing industrial waste gas in 2008.

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[2] About haze what you know? Three major pollutant - induced diseases.

Available online: http://news.xinhuanet.com/2017-01/14/c_1120311899.htm

The amount of investment for industrial wastewater control was higher than that of industrial solid waste at the beginning. Its investment decreased gradually from 2007. From Figure 7 and Figure 8, we know that the proportion of wastewater discharged accounts for 2.9% and 3.4% of the total industry water in 2013 and 2014 respectively, even though the industrial water reuse rate was higher than 90% from 2005 to 2014. It indicates that the industrial sewage treatment capacity was low and the environmental burden aggravated in last several years.

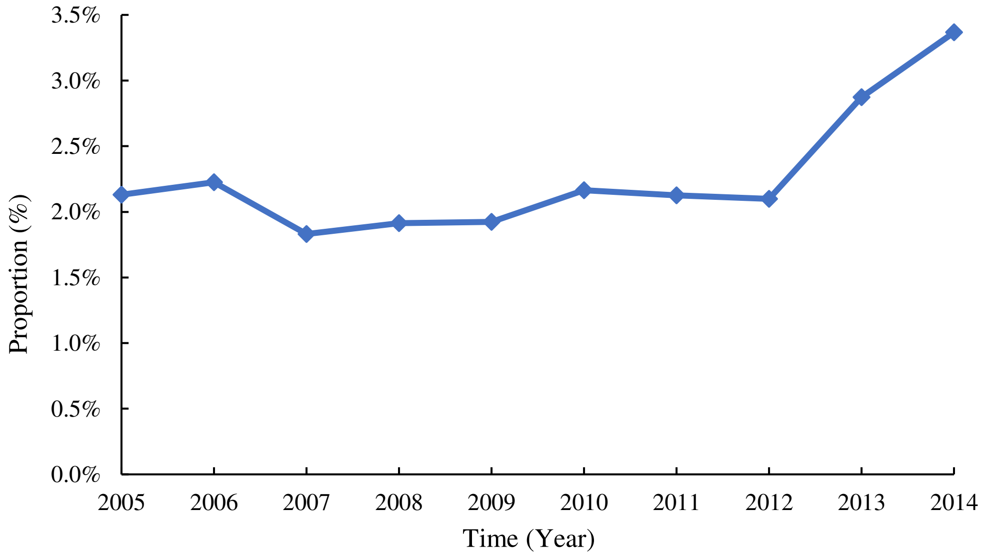

Fig. 7 Proportion of wastewater discharged accounted for total industry water

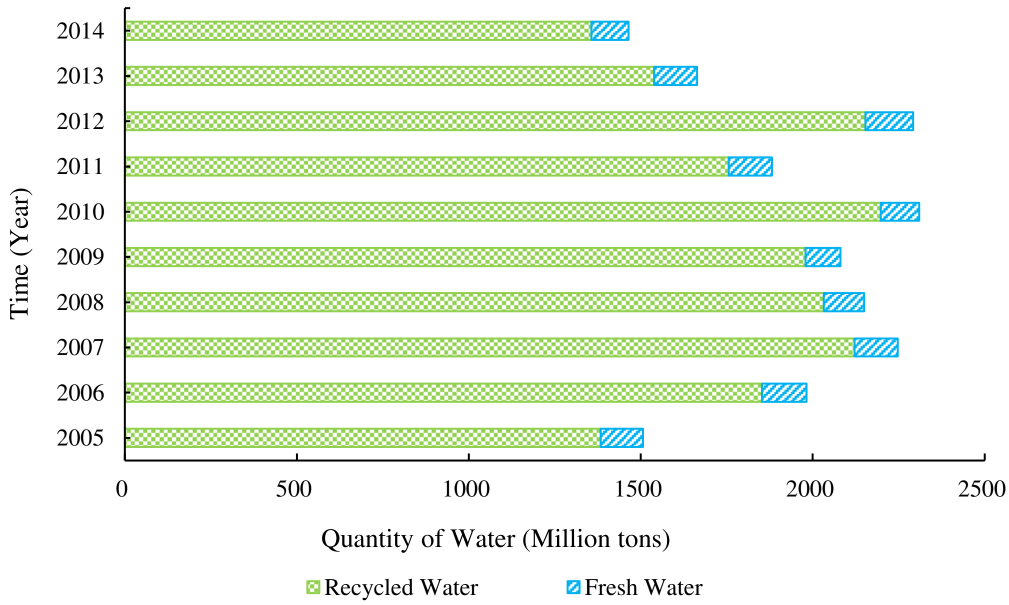

Fig. 8 Quantity of water used by industry from fresh water and recycled water

As shown in Figure 9, there was a significant increase in the amount of soot/dust removed, which was doubled during five years from 2005 to 2010. The amount of SO_2 removed increased by fourfold over the five years, showing the local government's higher capacity in SO_2 control.

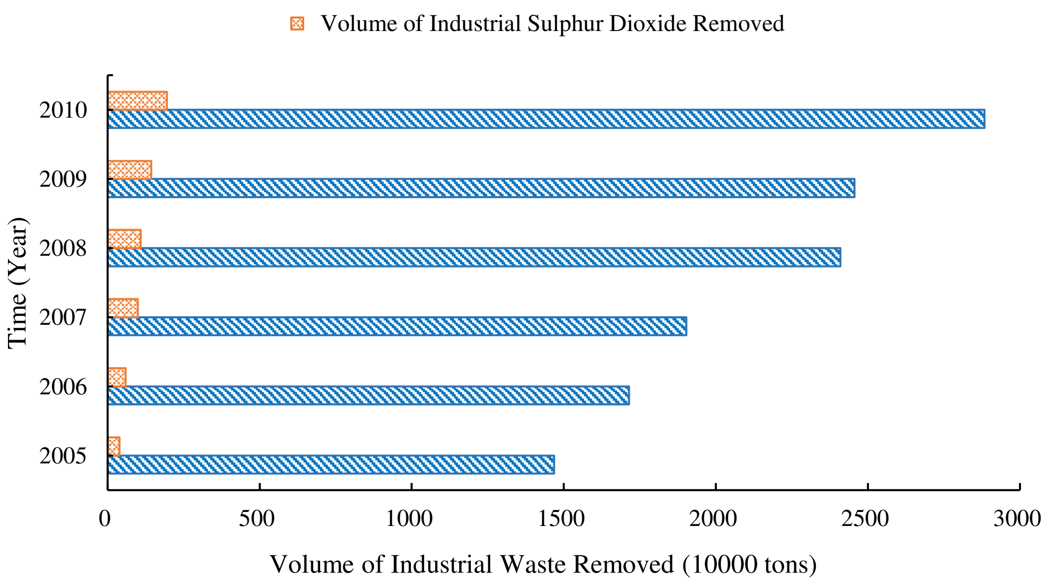

Fig. 9 Comparison between Sulphur dioxide and soot/dust removed

It is worth noting that from Figure 10 that the share of annual expenditure for desulfurization and dusting facilities together was over 75% of the operating costs for waste gas management from 2011 to 2014. The annual cost for desulfurization facilities accounted for a higher proportion than dedusting facilities in the year of 2011 and 2012. Until 2013, the share of annual spending for dedusting facilities was slightly more than desulfurization facilities. It illustrates that, during the past years, Shanxi government considers that controlling industrial SO_2 is rather important than that of soot/dust.

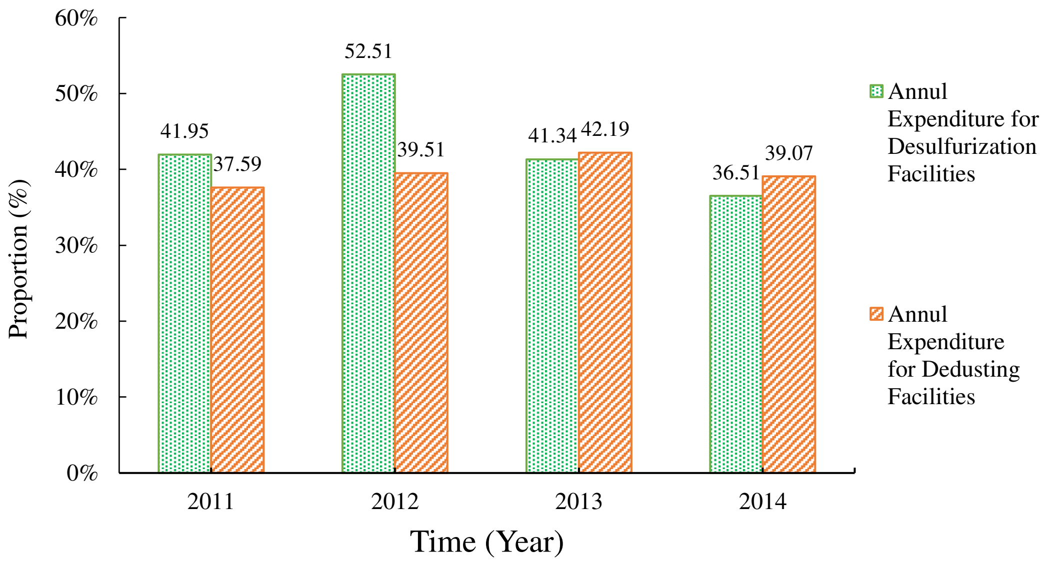

Fig. 10 Proportion of annual expenditure for desulfurization and dusting facilities

4. Policy discussions

4.1 Current Environmental Policies in Shanxi

In the last decades, the government has carried out concrete policies to deal with the industrial pollution in Shanxi province. During the “11th Five Year Plan (2006-2010)”, the local authorities enacted several environmental regulations, such as measurement for the control of key industrial pollution sources, to facilitate its industrial pollution governance. In line with such regulation, the government in Shanxi province concentrated on controlling and forcing to close enterprises and devices discharging pollutants illegally. At the same time, 375.3 million yuan was invested on environmental protection in Shanxi, up to 1.6 times compared to the level of "10th Five Year Plan", on which industrial pollution sector accounts for nearly 53.7%[3]. Subsequently, at the end of year 2010, the State Council introduced resource-based economy reform policy aiming at Shanxi province (CPG-PRC, 2010), which came into force during the period of "12th Five Year Plan (2011-2015)". This energy related environmental regulation aimed to build a resource-efficient and environment-friendly society by means of adjusting and optimizing the structure of industry as well as prompting technology innovation. Although government in Shanxi province has taken active actions to tackle industrial pollution and achieved significant effect to some extent, there is still a long way to go to reach the goal of sound ecological environment and sustainable economic growth.

4.2 Policy Implications

Several policy implications can be derived from above analysis. Firstly, the deficiency of government capacity in managing the industrial pollution needs to be improved further. It has been confirmed that innovation increasingly plays a critical role in the

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[3] Available online: http://www.mep.gov.cn/home/ztbd/gzhy/ywgzh/wfxch/jlfy/200902/t20090220_134485_wap.shtml

long-term evolution of environmental pollution levels (Bilgili et al., 2016; Balsalobre et al., 2016). The government of Shanxi province may consider sustainable policy to enforce innovations in energy production process. We suggest that the local authority allocates public budget on implementing product and process innovation (Aghion et al., 2014), aiming to improve energy efficiency and enhancing industrial pollution management.

Moreover, the national energy administration promulgated *13th Five Year Plan for the development and utilization of shallow coalbed methane (CBM)* in December 2016. The *Plan* pointed out that, as an emerging industry in China, CBM presents small scale and lacks of market competition. It is reported that Shanxi's CBM accounts for about a quarter of the country total reserve[4]. Hence, the Plan can help to solve the problem of over-exploitation of coal resource by increasing clean energy exploration such as natural gas and unconventional gas like CBM.

Finally, as one of the central government policies is for sustainable development and the whole economy is under transition to the "New Normal" growth regime, the local government shall strive for the promotion of environmental friendly industry. This will not only help greening the economic structure of Shanxi province, but also create new

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4 Available online: http://yeslng.com/p/18738

job opportunities and improve the capacity of the government in tackling environmental issues.

5. Conclusions

This study employs GRIF-VAR to analyze the dynamic relationship between economic growth and the six specific industrial environmental pollution intensity indicators (wastewater, COD, solid waste, soot/dust, waste gas and SO_2) in Shanxi province during the period of 1995-2015. Specifically, the dynamic shocks using GRIF are from two directions, from per capita GDP to pollution intensity and vice versa. The shock response periods have been set to be eight. The level of these industrial environmental pollution intensities reflects the carrying capacity and the technology level of the government in pollution management.

Our analysis shows that the carrying capacity of the government on wastewater and COD of industrial production is relatively low, as reflected from the response of economic growth to the pollution intensity impulse. The carrying capacity of SO_2 is higher compared to soot/dust, although the impulse response suggests an adverse impact on economic growth in the long term. The positive response of economic growth to industrial solid waste and gas indicates sufficient governmental capacity and technology level for these two industrial pollutants.

The response of pollution intensity to the economic growth impulse confirms the existence of the traditional EKC. Three out of the six environmental pollution intensity responses are in the shape of inverted U curve. The pollution intensity of COD represents a N-shaped, while solid waste and waste gas show U-shaped curves.

By conducting the variance decomposition, our results re-confirm that the industrial pollution intensity has a less serious inhibiting impact on economic development; while economic development is the principal reason for degradation of the industrial environmental burden in Shanxi province. In fact, as mentioned in the 4 section, in the last decade the government has implemented various environmental policies aiming at regulating these pollutants at the firm's level, due to the high level of environmental pollutions and increasing public concerns. In spite of the recent economic downturn, the share of governmental investment for environmental treatment still accounts for a higher share of provincial GDP. Our results imply that provincial economic growth does not have a direct impact on two industrial pollutants, namely industrial soot/dust, and SO_2. This is due to the fact that a large share of the industrial products is exported to other regions of the country. Hence, the two industrial pollutants discharged from energy consumption are emitted elsewhere rather than Shanxi province.

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