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Empirical analysis of the relationship between economic growth and environmental pollution based on VAR model: A case study of Hubei Province China

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Abstract:

In this paper, the industrial three wastes from 1992 to 2018 in Hubei Province were collected as environmental indicators, and the per capita GDP was used as economic indicators. The study of Kuznets curve showed that industrial wastewater gradually decreased with economic growth, showing an inverted N shape; Both industrial emissions and solid waste will increase with the growth of per capita GDP, industrial waste gas shows a linear relationship, and industrial solids show an inverted U relationship. Then through the VAR model research, it is found that the response of industrial "three wastes" to per capita GDP growth in Hubei Province is positive in the short term. The long-term response of economic development in Hubei province to industrial waste gas and industrial solid waste discharge is positive and decreasing, but the short-term response to industrial wastewater discharge is negative. The variance decomposition analysis reveals that the primary environmental determinants influencing the current economic growth trajectory of Hubei Province are industrial wastewater, industrial waste gas, and industrial solid waste. Fluctuations in economic growth within Hubei Province demonstrate a stronger correlation with variations in emissions of industrial wastewater and industrial solid waste, while exerting comparatively less influence on changes in emissions of industrial waste gas.

Keywords: Kuznets curve, VAR model, impulse response, variance decomposition

1. Introduction

In recent decades, China has made remarkable achievements in economic development. However, high economic growth inevitably causes serious environmental pollution to resources and environment. Many developing countries in the world are faced with such the same dilemma and they should choose between economic growth and environment.

To solve this problem, Grossman(1991) and Krueger(1995) found that the environmental problems of a country or region would present an inverted U-shaped curve, namely the environmental Kuz[1-2]nets curve. S Dinda(2004) explained the EKC curve and believed that after suffering from a dirty economy, it would return to a clean economy [3]. In addition, Stern[4] and Panayotou[5] can be seen in the literature review on this research. Domestic scholars have studied EKC curve in many aspects. Peng Liying et al. (2008) found that the fitting curve of Shanghai's environmental indicators and per capita GDP showed a typical EKC feature, namely an inverted U shape[6]. Wu Kaiya and Chen Xiaojian (2003) established a new environmental Kuznets curve and believed that the EKC curve of Anhui Province was characterized by "U-shaped + inverted U-shaped"[7]. Wang Zhihua et al. (2007) studied the EKC curve of Beijing and showed that the amount of industrial waste gas emission and industrial solid waste production showed an N-shaped [8] shape. In addition, there are many scholars using vector autoregressive model to do research. Peng Shuijun and Bao Qun (2006) found that environmental pollution has a reverse effect on economic growth and they have lag effects compared with the effect that economic growth to environmental pollution [9]. Lu Jian's (2010) research shows that Shanghai's economic growth depends on the increase of industrial waste gas emissions[10].

Based on the existing literature, we find that there may be a "pseudo-regression" problem of time series in most literatures when investigating the EKC curve of economic growth and environmental pollution level. Therefore, the innovation of this study lies in the comprehensive use of EKC curve and VAR model, which can more accurately test the relationship between economic growth and environmental pollution. In addition, most of the studies examined the relationship between economic growth and environmental pollution level in the whole country, and most of the studies at the provincial level focused on the developed eastern coastal provinces, while the research on the central region such as Hubei province still needs to be improved. Considering EKC curve and VAR model, we could find more accurate answers.

2. Study the regional overview and data sources

2.1 Economic and environmental overview

2.1.1 Economic development overview of Hubei Province

Hubei Province is located in the central region of China, with a good overall economic development and good economic performance. In 2023, the GDP of Hubei Province will reach 5,580.363 billion yuan, an increase of 6.0% over the previous year at constant prices, which ranks 7th in China with strong momentum and potential for development.

2.1.2 Overview of environmental development in Hubei Province

In recent years, Hubei Province has made unprecedented efforts to promote ecological environmental protection and management and green development. According to the Statistical Bulletin of Hubei Ecological Environment from 2016 to 2019, waste water pollutants, waste gas pollutants and industrial solid waste pollutants have all shown a significant decline trend, and the government's investment in industrial pollution control has remained high. Funds for environmental protection capacity building are also gradually increasing, and environmental quality has been significantly improved.

2.2 Selection of variables and data sources

According to the principle of comprehensiveness, hierarchy, measurability and comparability of selected data. This paper uses gas pollution emissions, liquid pollution emissions and solid waste to measure environmental pollution indicators, while, the per capita GDP is selected to measure the economic. Environmental indicators and economic indicators data from 1992 to 2018 are selected. Obtaining these information from the Statistical Yearbook of Hubei Province (1990-2018).

Table 1 Selection of indicators

	Variable names	Variable definition (in units)
Environmental indicators	FS	Industrial wastewater discharge (tons)
	FQ	Industrial exhaust emissions (million standard cubic meters)
	FG	Industrial waste emissions (tons)
Economic indicators	PGDP	Gross regional product per capita (yuan/person)

Logarithmic processing was performed on the original data collected. ln FS is used to represent the logarithmic processing data of FS index, ln FQ is used to represent the logarithmic data of FQ index, ln FG is used to represent the logarithmic data of FG index, and ln GDP is used to represent the logarithmic data of GDP index.

2.3 Descriptive statistics of the data

Table 2 Descriptive statistics of data

	Industrial waste	Industrial waste gas	Industrial wastewater	GDP per capita
Average	4611.904	11773.84	11773.84	99649.23
Median	3692	9404.11	96498	11342.32
Max	8472	29519	144625	71097.12
Min	1889	3547	44158	1962.45
Standard	2457.158	7923.734	27292.91	21304.11
Skewness	0.376215	0.704081	0.207158	0.939659
Kurtosis	1.491979	2.144891	2.84364	2.52474

It can be known from the descriptive statistics of three wastes and per capita GDP of Hubei Province that the per capita GDP has increased significantly. The waste water showed a significant decline year by year, and the production of industrial waste gas and industrial solid waste gradually increased. The standard deviation of solid waste was larger than that of industrial waste water in industrial waste gas, so it can be inferred that industrial solid waste had a greater impact to economy.

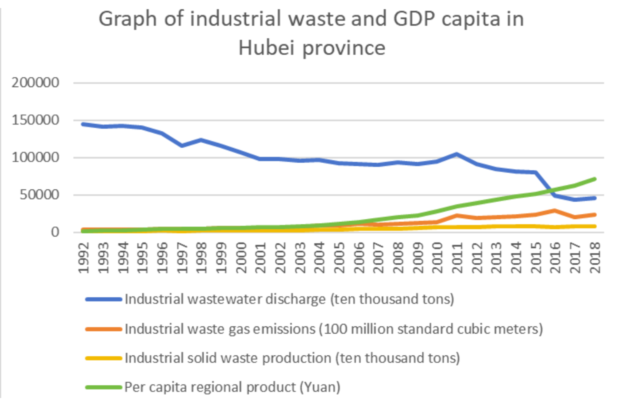

Figure1 Industrial waste and per capita GDP in Hubei Province

3. EKC curve analysis of economic growth and environmental pollution in Hubei Province

3.1 Setting of environmental Kuznets curve model

In 1991, American economists Grossman and Krueger found that at low-income levels, an increase in GDP per capita was positively correlated with an increase in pollution at high income levels, an increase in GDP per capita has a negative relationship with pollution reduction, which was named environmental Kuznets curve. Combined with different shapes of EKC curve, it is more common to use EKC's primary curve, quadratic curve and cubic curve for simulation. The measurement model of the general environment Kuznets curve is as follows:

Primary curve:

$$lnP_{it} = \alpha + \beta_1 ln(GDP_t)$$

Curve of the second degree:

$$lnP_{it} = \alpha + \beta_1 ln(GDP_t) + \beta_2 ln(GDP_t)^2$$

Cubic curve:

\[ln{P}_{it}\]= α+\[{\beta }_{1}ln\left({GDP}_{t}\right)\]+ $\beta_2 ln(GDP_t)^2 + \beta_3 ln(GDP_t)^3$ +ε

Where: P_{it} is the explained variable, indicating the amount of the i pollution level in the t year; GDP_t is the explanatory variable, represents the per capita GDP in year t; α is a constant term; β_1 β_2 β_3 is the regression coefficient; ε is the random error term.

3.2 Model estimate results

Table 3 Model estimation results

Indicators	Coefficient			
	ln (c)	*ln* (GDP)	*ln* (GDP)^2	*ln* (GDP)^3
Industrial wastewater Discharge (FS)	79.7450 (3.999819)	22.08482 (3.431421)	2.381316 (3.471646)	0.085782 (3.544540)
Industrial exhaust Emissions (FQ)	3.179894 (14.25420)	0.631059 (27.31066)	-	-
Industrial solid waste (FG)	45.91214 (3.118149)	12.97922 (2.738479)	1.417657 (2.806532)	0.049278 (2.765019)

In parentheses is the t value and c is the constant term

Table 4 Results of model statistics

Indicators	Coefficient		
	R^2	F value	Curve shape
Industrial wastewater Discharge (FS)	0.854092	48.7804	Inverted N-shape
Industrial exhaust emissions (FQ)	0.965065	745.8721	Linear
Industrial Solid waste emissions (FG)	0.973890	310.8313	Inverted U

3.3 EKC curve analysis

There exists a negative correlation between per capita GDP and the discharge of industrial wastewater, forming an inverted N-shaped pattern. This suggests that as per capita GDP increases, there is initially decrease in industrial wastewater discharge followed by an increase and then another decline. Moreover, as the economy grows, the emission of industrial waste gas gradually rises, leading to a continuous deterioration air quality. Additionally, the relationship between per capita GDP and industrial solid waste emissions demonstrates a U-shaped curve with its peak at some point.

4. Analysis of the dynamic relationship between environmental pollution and economic growth in Hubei Province

4.1 Model construction

The VAR method enables the simultaneous consideration of multiple endogenous variables. Within the VAR model, each endogenous variable is explained by its own lag or past value, as well as the lag or past value of all other endogenous variables in the model.

The form of the VAR model is shown below

$$x_t = c + \sum_{j=1}^{P} A_j x_{t-j} + \epsilon_t$$

Where, x_t is the vector formed by the time series; p is the order of autoregressive lag; ϵ_t is the white noise sequence vector, A_j is the time series coefficient matrix, and c is the constant term. Satisfy E(ϵ_t)=0, E($\epsilon_t\epsilon_t$¡¯)=Ω, E($\epsilon_t\epsilon_s$¡¯)=0; $\forall_t$≠s.

4.2 Unit root test

First of all, unit root test is carried out on the time variable, and the stationarity test is carried out. According to the result, the original series ln(FG) ln(FQ) $ln(FS)ln$ (GDP) is considered to be unstable if the p-values are all greater than 0.05; The p-values of the sequences (D ln (FG), D $ln(FQ)$,D ln (FS), D ln (GDP)) after the first difference are all less than 0.05. Therefore, it is judged to be stationary.

Table 5 Results of unit root test

Sequence	Inspection form	T statistic value	5% significant level	10% significant level	Prob. value	conclusion
ln FG	(C,T,6)	1.763291	3.595026	3.233456	0.6928	Uneven
D ln (FG)	(C,T,6)	4.586139	3.603202	3.238054	0.0063	Smooth
ln (FQ)	(C,T,6)	3.569517	3.590526	3.233456	0.0526	Uneven
D ln (FQ)	(C,T,6)	7.193539	3.603202	3.238054	0.0000	Smooth
ln (FS)	(C,N,6)	0.269517	2.981038	2.629906	0.9718	Uneven
D ln (FS)	(C,N,6)	4.585582	2.986225	2.632604	0.0013	Smooth
ln (GDP)	(C,N,3)	0.533303	2.986225	2.632604	0.8685	Uneven
D ln (GDP)	(C,N,3)	3.272950	3.004861	2.642242	0.0290	Smooth

4.3 Johansen Cointegration test of VAR model

This study introduces a method based on VAR model to test regression coefficient -Johansen Cointegration test, to analyze whether non-stationary economic series have long-term stable equilibrium relations.

Therefore, this paper establishes a VAR model with three differentially stable environmental indicators and one differentially stable economic indicator as dependent variables and these variables as independent variables. When constructing the VAR model, the trial-and-error method is adopted, different criteria are used to judge, appropriate lagging order is selected, and the VAR model is constructed. The statistical results are shown in Figure. 3.1 below.

LogL	LR	FPE	AIC	SC	HQ
101.0272	NA	3.62e-09	-8.085602	-7.889259*	-8.033512
124.2952	36.84098*	2.02e-09*	-8.691267*	-7.709556	-8.430819*
134.5609	12.83213	3.71e-09	-8.213409	-6.446329	-7.744602

tes lag order selected by the criterion
uential modified LR test statistic (each test at 5% level)
nal prediction error
aike information criterion
hwarz information criterion
nnan-Quinn information criterion

Figure 2 Results of evaluation statistics

According to four criterions, AR can choose 1. Therefore, the model of VAR(2) can be constructed. Then, Johanson cointegration test was performed on the model, and statistical analysis was carried out by using EViews9.0 to obtain each environmental indicator and per capita GDP as shown in the figure below:

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.688043	68.02504	47.85613	0.0002
At most 1 *	0.615010	40.06765	29.79707	0.0023
At most 2 *	0.430565	17.15876	15.49471	0.0278
At most 3	0.140872	3.644092	3.841466	0.0563

Trace test indicates 3 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Figure 3 Results of Johanson test

Figure 3.2 shows that under the significance level of 5%, there is a co-integration relationship between each variable in the VAR model, which also fully indicates that there is a significant co-integration relationship between the emissions of three pollutants in the environment and the four variables of per capita GDP.

4.4 Test of stationarity of VAR model

As shown in the AR table above, this model belongs to a stable system, which accords with the analysis basis of impulse response function, so the analysis of impulse response function will be carried out in the future.

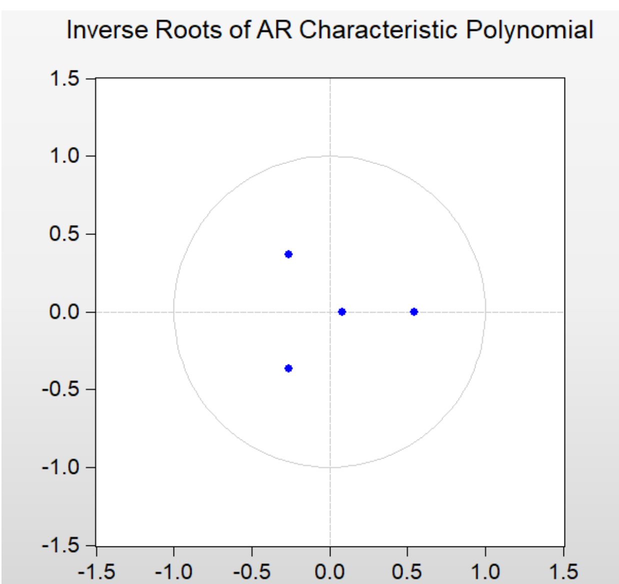

Figure 4 Stability test of VAR model

4.5 Impulse Response

4.5.1 Impact of three industrial wastes on economic growth

After the co-integration test, impulse response is used to study the dynamic impact on endogenous variables when an index is impacted. The results of generalized impulse response of industrial "three wastes" to economic development are shown below the figure.

In Figure (a), under the impact of per capita GDP, the discharge of industrial solid waste showed a trend of first rising and then declining. In the second phase, per capita GDP reached a peak of 0.05, then turned to a downward trend, and dropped to 0 in the fourth phase. It shows that the discharge of industrial solid waste has no particularly significant impact on economic growth. As can be seen from Figure (b), after the impact of per capita GDP, the industrial wastewater in Hubei Province has a trend of significant increase, and the discharge of wastewater reaches 0.33 in the second phase, and then decreases rapidly under the influence, dropping to 0.003 in the fourth phase. Then there is a slight increase, but the overall trend gradually approaches 0 after the 8th phase. This trend change indicates that industrial wastewater has a positive impact on the economy. Figure (c) shows that after a shock to per capita GDP, industrial waste gas shows an increasing trend, reaching a maximum of 0.028 in the third period, and then rapidly decreasing to 0 in the fourth period. After that, there is a slight rise, fluctuation and decline near 0, and it is completely 0 in the 7th period. This trend indicates that the economic impact of industrial waste gas is also positive. It can be seen from the three impulse responses that the following conclusions can be drawn: After the impact of GDP, economic growth will lead to an increase in the degree of environmental pollution, but then the three types of pollutants show a downward trend.

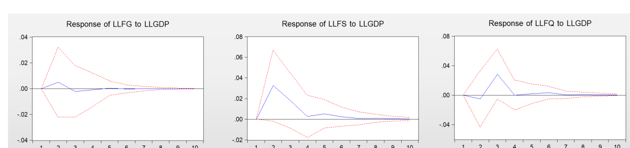

Figure 5 Impulse response of three industrial wastes to GDP

4.5.2 Impact of economic growth on the "three wastes" of industrial pollution

In Figure (a), after the impact of solid waste, the per capita GDP of Hubei Province has a rising trend, rising to a peak of 0.019 in the second phase, and then slowly declining and gradually approaching 0. However, the response of per capita GDP in the whole period is positive. Therefore, it can be concluded that the long-term impact of economic growth on solid waste in Hubei Province is positive. In Figure (b), after per capita GDP is affected by the impact of wastewater, the impact effect value drops to the lowest -0.011 in the third stage, and then gradually approaches 0, but the overall response is negative. Therefore, it can be seen that the long-term impact of economic growth on industrial wastewater in Hubei Province is negative. In Figure (c), after being impacted by GDP, industrial waste gas has a downward trend from the first phase to the second phase, and shows a restraining effect, but gradually approaches 0 after the third phase. It is concluded that the long-term impact of economic growth on waste gas in Hubei Province is positive, and it can be seen from the pulse response chart that GDP has little impact on the emission of waste gas.

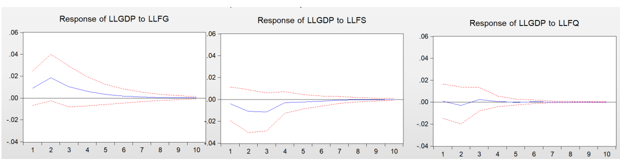

Figure 6 Impulse response of GDP to three industrial wastes

4.6 Variance decomposition

Based on the results of variance decomposition, the contribution of waste water, waste gas, and waste to the economic growth index of Hubei Province is 7.33%, 0.45%, and 15.86%, respectively. Moreover, the contribution of the economic growth index of Hubei province to the three industrial environmental pollution indicators of industrial wastewater, industrial waste gas, and industrial solid waste is 8.39%, 2.31%, and 0.35%, respectively. This suggests that the alteration of economic growth in Hubei Province has a greater impact on the change of industrial wastewater and industrial waste gas, while having a lesser impact on the change of industrial solid waste.

Table 6 Contribution rate between economic growth and environmental pollution

	The contribution rate of environmental pollution index to economic growth			The contribution rate of economic growth indicators to environmental pollution		
period	DFS	DFQ	DFG	DFS	DFQ	DFG
1	1.039855	0.036738	5.020428	0	0	0
2	5.020259	0.383184	15.62842	7.901228	0.107417	0.313701
3	8.321980	0.518205	16.54863	9.397923	2.869582	0.380327
4	8.332203	0.51428	17.19118	9.370066	2.857857	0.395234
5	8.405461	0.509187	17.33586	9.510469	2.861474	0.395783
6	8.449483	0.510741	17.36575	9.536478	2.891485	0.397326
7	8.451411	0.510476	17.38042	9.53905	2.891435	0.397477
8	8.453708	0.510351	17.38382	9.542205	2.892066	0.397477
9	8.454511	0.510364	17.38474	9.542781	2.892496	0.397506
10	8.454603	0.510356	17.38509	9.542904	2.892507	0.397508
Average	7.3383474	0.4513882	15.8624338	8.3883104	2.3156319	0.3472339

5. Conclusions and policy recommendations

5.1 Conclusions

The study of Kuznets curve showed that industrial wastewater gradually decreased with economic growth, showing an inverted N shape; Both industrial emissions and solid waste will increase with the growth of per capita GDP, industrial waste gas shows a linear relationship, and industrial solids show an inverted U relationship. Through the VAR model research, it is found that the response of industrial “three wastes” to per capita GDP growth in Hubei Province is positive in the short term. The long-term response of economic development in Hubei province to industrial waste gas and industrial solid waste discharge is positive and decreasing, but the short-term response to industrial wastewater discharge is negative. The variance decomposition analysis reveals that the primary environmental determinants influencing the current economic growth trajectory of Hubei Province are industrial wastewater, industrial waste gas, and industrial solid waste. Fluctuations in economic growth within Hubei Province demonstrate a stronger correlation with variations in emissions of industrial wastewater and industrial solid waste, while exerting comparatively less influence on changes in emissions of industrial waste gas.

5.2 Policy Recommendations

5.2.1 Adjust the industrial structure appropriately

Hubei Province needs to further optimize the structure of the tertiary industry and accelerate the development of the service industry and they should strengthen the development of strategic emerging industries.

5.2.2 Improve environmental laws, regulations and policies

Hubei Province needs to formulate and strengthen energy conservation and emission reduction policies, encourage enterprises to implement energy conservation and consumption reduction measures, and improve resource utilization efficiency. A reward mechanism should be set up to encourage enterprises to introduce advanced cleaner production technologies and avoid the old path of "pollution first, treatment later".

5.2.3 Strengthen cross-regional cooperation

The main environmental factor affecting the economic growth of Hubei Province is the amount of waste water and we know Yangtze river across Hubei province, so it is necessary to establish a cooperation mechanism with neighboring provinces to jointly form a good ecological environment.

5.2.4 Encourage non-governmental participation in cooperation

The government needs to guide green investment and formulate relevant policies to encourage private capital to invest in green projects. A public participation mechanism should be established to allow residents and non-governmental organizations to participate more directly in environmental decision-making. Provide information transparency, hold public hearings, and promote cooperation and oversight.

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