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The Impact of Regional Economic Structural Changes on Smog Control: Empirical Evidence from Hubei, China

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ABSTRACT

The traditional extensive production mode characterized by high energy consumption, high pollution, high resource dependence, and low efficiency has significantly increased the emission of carbon and other air pollutants. As a consequence, China is currently in the midst of a severe environmental and ecological crisis. Smog control can be realized by adjusting the industrial structure, which involves abandoning the traditional industrialization mode and pursuing the development mode of a circular economy characterized by low energy consumption and low pollution. To examine the causes of smog from the perspective of economic structure, the interactive relationship between smog control and the evolution of regional economic structure was analysed by using panel data of 13 prefecture-level cities in Hubei Province, China from 2005 to 2016. Results demonstrate that the relationship between industrial structure and degree of smog pollution shows a U-shaped curve. As such, the scale effect of economic development can reduce the emission of air pollutants. Foreign direct investment does not have a significant role in improving environmental pollution. Construction dust similarly aggravates smog pollution. These conclusions can deepen the understanding of the internal relationship between frequent smog occurrence and industrialization, as well as provide a theoretical basis and decision-making reference to effectively control smog by upgrading the regional economic structure.

INTRODUCTION

In recent years, the acceleration of China's industrialization and urbanization process has caused rapid development of the economy and the society on the one hand, but also rising environmental pollution problem on the other hand. In many northern cities, increasingly serious smog has resulted in grave threats and challenges to the local economic and social construction, as well as people's productivity, life, and health. At present, China's frequent smog weather shows a dynamic trend of entry from the Middle East to the South, spreading to the West in terms of geographical distribution. Its prominent features include a wide geographical range, long duration, and high public attention. The continuous occurrence of smog wields a serious impact on people's health and travel and, to a large extent, restricts the normal and healthy development of China's social economy. In fact, the rapid development of China's economy has led to the general improvement of people's living standards. People's demand for energy consumption is constantly increasing, driving a similar increase in energy supply. However, China's energy industry structure is dominated by coal, which has a low energy utilization rate and poor economic benefits, especially in high-energy-consuming industries. Thus, problems of energy source and structure have become prominent, and constraints of resources and environment have become increasingly severe.

Hubei Province is located in the hinterland of central China. As shown in Fig. 1, Hubei Province has experienced rapid industrial development, increased added value of industry, and high energy consumption in recent years. At the same time, it is also often affected by smog weather. Air quality shows an obvious and continuing downward trend. Smog weather directly affects the air quality of cities, causing frequent traffic accidents and threatening the health and safety of residents. Therefore, at present, Hubei Province considers severe smog weather as one of the central issues that require increased attention. Under the concept of green development, adjusting the industrial structure, energy consumption structure, and living consumption structure, as well as changing production and lifestyles are an urgent concern. Based on the current situation of smog weather control and economic development in Hubei Province, this study explores the ways to comprehensively control smog and upgrade the regional economic structure. It aims to promote green development of the regional economy and society, as well as provide a reference for smog pollution control in other provinces in the central region.

EARLIER STUDIES

Academic circles in developed countries have produced relatively mature research on the causes and countermeasures of smog formation. Many developed countries simi-

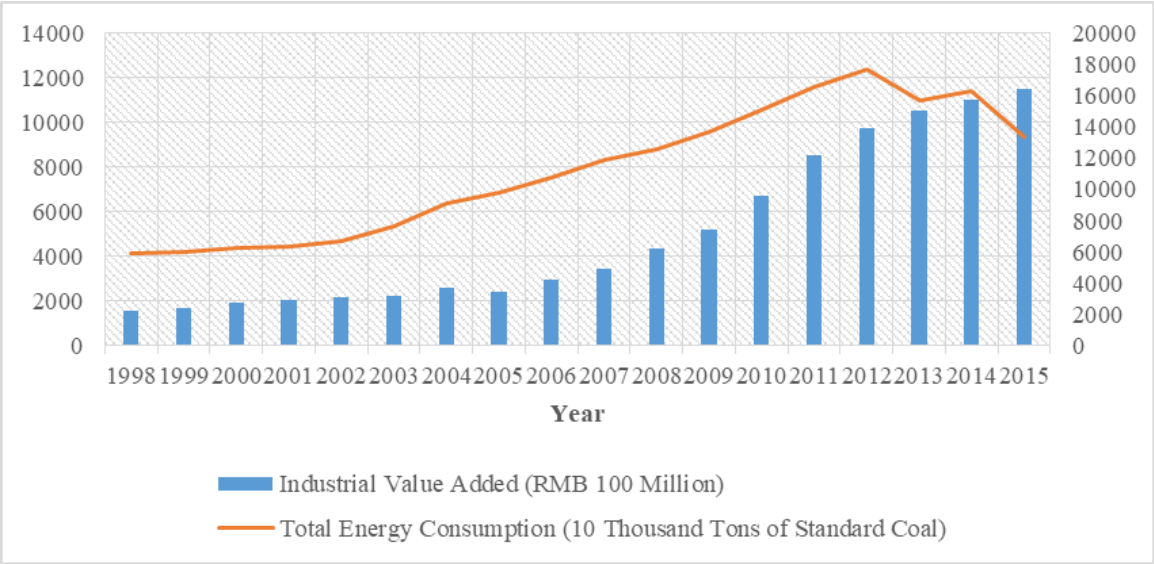

Fig. 1: Industrial value added and total energy consumption in Hubei province from 1998 to 2015.

larly suffered from air pollution in their early stages of industrialization because of their focus on economic development and neglect of environmental protection. Later, understanding the root cause of smog, successful solutions were pursued through a series of measures, including the transformation of their industrial structures. Regarding the interactive effects of environmental pollution, smog formation, industrial structure, and other socioeconomic factors, Shandra et al. (2008) used a panel regression model with lag-dependent variables for 50 samples from poor countries in 1990-2000 and found that structural adjustment and industrial exports increased water pollution. Fodha et al. (2010) studied the relationship between Tunisia's economic growth and pollutant emissions in 1961-2004. The results showed that a long-term cointegration relationship exists between per capita emissions of carbon dioxide (CO_2) and sulphur dioxide (SO_2) per capita GDP. In an empirical study, Mingsheng et al. (2011) found that the energy efficiency of Chinese iron and steel enterprises is closely related to enterprise scale. The study proposed measures to adjust the industrial organization structure to promote energy conservation and emission reduction. Brajer et al. (2011) proposed that China's industrial structure and environmental pollution do not necessarily show an inverted-U relationship. Wei et al. (2012) established an evaluation model for pollution control performance. The results showed that improving China's environmental pollution performance requires government policies that consider industrial restructuring, restrict industrial entry, and increase pollution control as well as research and development investment. Fujii et al. (2013) analysed the management of air pollutants in China's industrial sector in 1998-2009, wherein the increase of industrial production scale led to the increase of SO_2 emissions. Tian et al. (2014) showed that regional industrial structural differences in China have a substantial impact on regional CO_2 emissions. The shift from agriculture, mining, and light industry to heavy industry in terms of resources resulted in a rapid increase in CO_2 emissions at the national level. Huo et al. (2014) considered the two important causes of air pollution in China are the high emission factors of pollution sources and the high emission intensity of the industrial structure. Finding that the service industry had the lowest emission intensity, the study proposed to further develop the service industry and thereby reduce air pollution. Huang et al. (2014) believed that in a country like China with strong industrial emissions and limited emission reduction facilities, coarser particulate matter emissions produce a great impact on health. Although urbanization reduces per capita emissions, the impact on the health of the overall population will increase due to the aggregation effect. Yuan et al. (2015) studied the impact of economic development and industrial structure on energy consumption and air pollutant emissions by comparing developed and underdeveloped regions in China. The unreasonable energy industrial structure led to an ineffective reduction of air pollutant emissions. Meng et al. (2015) showed that consumer demand for electricity and transportation highly increased the emission of air pollutants. Zhou et al. (2017) used data from 945 monitoring stations in 190 Chinese cities in 2014 to evaluate the direction and correlation intensity between socioeconomic factors and PM2.5 pollution. The spatial regression results

showed that population density, industrial structure, industrial smoke (dust) emissions, and road density produced significant positive effects on PM2.5 concentration. Xie et al. (2018) found that population density, industrial structure, geographical features, and climate are closely related to air pollution. Yang et al. (2018) considered the iron and steel industry to be an energy-intensive industry that significantly contributed to China's PM2.5 pollution. To achieve an effective reduction in CO_2 emissions, further technological innovation is necessary to reduce the cost threshold. Existing literature show that smog impacts the regional economy. Without smog control, the economic retrogression caused by environmental pollution in future regional socio-economic development would be fatal. Changing the traditional production methods, adjusting the industrial structure, and promoting regional cooperation could effectively control smog. However, existing literature on smog control seldom discusses the upgrading and transformation of provincial economic structures.

This study considers Hubei Province in central China for analysis. On the basis of fully understanding the smog weather and current industrial structure in Hubei Province, combined with the successful experience of foreign countries in smog control, the study presents important reference significance to realize the path towards smog control and upgrade the regional economic structures in many other regions dominated by industries.

MATERIALS AND METHODS

Model Construction

SO_2, nitrogen oxides (NOx) and inhalable particles are the main components of smog. In this study, the sum of the three indexes of smoke dust, SO_2, and nitrogen oxide emissions of cities in Hubei Province is the index considered to measure the smog situation and is expressed as explained variables. The industrial structure of each city is taken as an explanatory variable and expressed as *Str*. Simultaneously, based on data availability and existing local and international research, the economic development level, degree of openness to the outside world, and building construction areas are introduced as control variables. The relationship between the smog pollution level in various cities and the influencing factors are shown in Formula (1).

$$\mathrm{Ln}Env_{it} = \beta_0 + \beta_1 \mathrm{Ln}Str_{it} + \beta_2 (\mathrm{Ln}Str_{it})^2 + \beta_3 \mathrm{Ln}Gdp_{it} + \beta_4 (\mathrm{Ln}Gdp_{it})^2 + \beta_5 \mathrm{Ln}Fdi_{it} + \beta_6 \mathrm{Ln}Hou_{it} + \varepsilon_{it} \quad ...(1)$$

Where, subscripts *i* and *t* of each variable represent city *i* and year *t*, respectively; β_0 represents the intercept term; ε_{it} represents the random error term; variable *Str* represents the industrial structure of each city; *Gdp* represents the economic development level of each city; *Fdi* represents the openness degree of each city to the outside world; and *Hou* represents the building construction area of each city.

Variables and Data

Explained variables: Given that SO_2, nitrogen oxides, and inhalable particles are the main components of smog, this study selects smoke dust, dust, SO_2, and nitrogen oxide emissions as indicators to measure smog.

Explanatory variables: In general, the development of a country's economy from primary to mid-term stage changes the industrial structure from primary to secondary industry, and the development of heavy chemical and manufacturing industries intensifies environmental pollution. However, when a country's economy develops from the mid-term to the high-level stage, the industrial structure gradually changes from secondary to tertiary industry. The rapid development of information, finance, and other service industries play a certain role in promoting and achieving pollution reduction. This study proposes that under industrial structure upgrades and adjustments, a nonlinear relationship may exist between the rationalization and upgrading of the industrial structure and pollution reduction. Therefore, the proportion of secondary industrial output value to GDP is used to measure the role of industrial structure in smog pollution control.

Control variables: The expansion of economic scale can

Table 1: Variable description.

Variable type	Variable symbol	Specific indicators	Unit
Explained variable	Env	Total emissions of smoke dust, SO_2, and nitrogen oxides	Ten thousand tons
Explanatory variable	Str	The proportion of output value of secondary industry to GDP	%
Control variables	Gdp	Per capita GDP	Ten thousand RMB
	Fdi	Proportion of foreign direct investment to GDP	%
	Hou	Building construction area	Ten thousand square meters

Table 2: Regression estimation results of influencing variables.

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
β_0	2.354***	1.541***	2.541**	3.654*	2.547***	7.214***
LnStr	-0.105**	-0.114**	-0.087	1.116**	-0.845	1.785**
$LnStr^2$		0.041**	0.574**	0.874	0.712***	0.965
LnGdp			-1.254	-0.741**	-1.658***	0.752
$LnGdp^2$				0.571**	0.054	-0.684**
LnFdi					0.024***	0.454
LnHou						0.175**

Notes: Models 1 to 6 in the table represent formulas obtained by introducing explanatory variable and control variables in sequence based on Formula (1). The upper corner marks *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

reduce environmental pollution to a certain extent. Moreover, the economic scale effect of a region can reduce the pollution level of smog to a certain extent. On the premise of considering the impact of industrial restructuring on smog pollution, this study also introduces GDP per capita as a control variable. With China's low standards of environmental regulation, the introduction of foreign capital through trade liberalization is likely to increase pollution in China (i.e., the degree of openness increases environmental pollution). This study uses the ratio of foreign direct investment to GDP to measure the degree of openness and verify whether open trade is conducive to improving environmental quality. Soil dust and cement dust caused by construction activities are important components of air pollution particles and are important sources of smog pollution. In the process of urbanization in Hubei Province, the degree of smog pollution will be aggravated as the construction area and construction dust continues to expand and increase, respectively.

The specific definitions of each variable index are shown in Table 1. All variables are processed by taking the natural logarithm to reduce the heteroscedasticity of equation regression. The samples comprise panel data of 13 prefecture-level cities in Hubei Province from 2005 to 2016, obtained from the Statistical Yearbook of Hubei Province and the China Environmental Statistical Yearbook over the years.

RESULTS AND ANALYSIS

In this study, STATA14.0 software was used for quantitative analysis. An explanatory variable and other control variables are gradually introduced, and the influence of each variable on the comprehensive emission of air pollutants in various cities in Hubei Province is tested in turn. The estimated results are shown in Table 2.

Table 2 shows that the coefficient of $LnStr^2$ is significantly positive, whereas the coefficient of *LnStr* is significantly negative. This estimation result shows that the industrial structure and smog pollution level has a U-shaped curve relationship. With the increase in ratio of the output value of the tertiary industry to the output value of the secondary industry, the industry catch-up produces a containment effect on smog pollution emissions to a certain extent. The improvement of Hubei Province's industrial efficiency suggests that the province is far from reaching the level of active deindustrialization of developed countries. Through technological innovation, the traditional manufacturing industry still needs to move forward to the industry 4.0 with high added value. The lagging development of the high-end manufacturing industry restricts the transformation from a producer service industry to the modern service industry. The long-term, low-level development of the modern service industry in Hubei Province serves low-end industrial production more and has not changed its dependence on primary energy. The large proportion and low efficiency of the low-end service industry limit the deterrent effect of industrial upgrading on smog pollution and even aggravates smog emissions. The coefficient of variable *LnGdp* is negative and highly significant, which indicates that the scale effect of economic development in Hubei Province can reduce the emission of air pollutants, effectively reduce the degree of smog, and improve the environmental quality. The estimated coefficient of variable *LnFdi* is 0.024 and passed the significance test. This finding shows that for every 1% increase in the ratio of foreign direct investment to GDP, the emission of air pollutants rises by 0.024%, supporting the "pollution paradise" hypothesis. The possible reason for this finding is that the increase of foreign direct investment in various cities in Hubei Province leads to a large amount of foreign capital contributing to heavy pollution in areas that have not yet been able to fully introduce advanced clean production technology from abroad. On the contrary, it has exacerbated the smog pollution at the source. In the future, the introduction of foreign capital should include full consideration of the use of advanced manage-

ment and technology spillover effects to improve green productivity and control smog pollution, thereby reducing smog pollution levels and promoting green economic development in the province. The regression coefficient of *LnHou* is 0.175 and is highly significant, indicating that for every 1% increase in the building construction area, the total amount of air pollutants will increase by about 0.175%. In recent years, Hubei Province has experienced rapid urbanization, accompanied by the continuous expansion of the average construction area. Consequently, the building dust generated during construction has increased and has aggravated smog pollution in various regions of Hubei Province.

POLICY RECOMMENDATIONS

Optimize and Adjust the Industrial Structure and Develop a Low-carbon Circular Economy

For its future economic development, Hubei Province should optimize its economic structure based on the circular economy mode, construct a low-carbon energy-saving industrial structure, transform low-energy consumption ecological industries to leading regional industries, improve energy utilization efficiency at the core, and ensure low-carbon ecological transformation on the leading industries in the region. We will accelerate the development and utilization of new energy sources, reduce the use of traditional resources such as coal, as well as develop and utilize new energy sources such as solar, wind, and water energies. Full development and utilization of advantageous solar energy can replace traditional energy sources on a large scale and thus reduce pollution sources. We can determine the unbalanced and coordinated development strategy as well as implement the dynamic development of dislocation and complementarity. Further study could continue to improve the scientific and technological content of enterprises, equipment manufacturing, high-tech industries, modern services, and other industries. In addition, market demand could serve as a guide to strengthen the overall low-carbon circular development of Hubei's regional industrial system. We should strengthen the control of local automobile exhaust and domestic exhaust emissions, advocate "low-carbon life", strictly limit construction dust pollution, reduce inhalable particles, and maintain ecological advantages.

Adjust the Energy Structure and Improve the Efficiency of Energy Utilization

Unreasonable energy consumption structure dominated by coal consumption is an important contributor to smog weather in Hubei Province. Realizing smog control entails optimizing and adjusting the energy structure, vigorously developing low-carbon energy, and improving the utilization of renewable and alternative energy resources. Laws and economic policies must promote the diversification of energy consumption and coal utilization, as well as guide the adjustment of energy consumption structure to reduce the total emission of various pollutants. In addition, we must increase the transformation and upgrading of the traditional coal industry, continue to extend the industrial chain, and improve the added value. Extending the industrial chain of the coal energy industry would greatly reduce the transaction cost, thereby increasing the added value, gross production value, and profit of the energy industry. Based on material energy conservation and recycling, a series of measures have been adopted to optimize the coal industry organization, guide the establishment of an effective competitive market structure, avoid over-exploitation and waste of energy resources, improve Hubei's environmental performance, enhance the economic strength of relevant enterprises, encourage the use of sufficient funds to innovate and improve coal mining and production processes, and further promote the realization of sustainable development in Hubei Province as a whole.

Increase Investment in Smog Control and Encourage Technological Innovation in Enterprises

We propose to establish special funds for environmental protection and low-carbon technology research, as well as for new energy development and technological innovation. These funds should support relevant research and development (R&D) to improve the scientific and technological level of energy structure optimization and environmental quality protection in Hubei Province. The government could increase financial support for technological innovation, increase the proportion of R&D on low-carbon and energy-saving technologies in public financial expenditures, and increase capital investment in scientific research institutions. Clean energy technological innovations can achieve the following: effectively reduce the emission of atmospheric pollutants; encourage traditional industry enterprises to improve their energy utilization efficiency; promote clean energy technology; reduce the emission of pollutants, air pollution, and the particles that form smog; as well as promote industrial structure upgrading and economic structure adjustment. Various policies could likewise encourage industrial enterprises to actively promote and use new clean energy technologies, improve energy utilization efficiency, and pay close attention to energy-saving production.

Advocating Green Consumption Pattern and Intensifying Environmental Protection Publicity

A dynamic mechanism that includes internal interest incentives and external behaviour constraints and advocates a

green consumption view can be constructed. We should strengthen the guidance for residents' income and relevant advanced ideas to encourage people's daily routines to conform to the consumption concept of a circular economy, choose a reasonable green consumption mode, and promote a low-carbon life. Government departments have issued several relevant policies or bills to encourage people to consciously use low energy consumption resources and public transportation resources; adopt less pollution, more healthy consumption and travel methods; and, to a certain extent, inhibit the rapid expansion of high-energy consumption services. These policies promote the formation of a conservation-oriented consumption system in the whole society. The necessity and importance of controlling smog and developing a low-carbon economy should be publicized in a targeted manner through various forms, such as television, radio, newspapers, and knowledge competitions. Through the government and media guidance and the efforts of social public welfare organizations, the residents of the whole society would gradually realize that adjusting their consumption structure is the basic premise for smog control and the development of a low-carbon economy, and thus consciously establish a low-carbon life.

CONCLUSIONS

With the frequent occurrence of heavy smog pollution incidents, the contradiction between smog control, coordination of regional economic development, and air pollution has become a prominent research topic. Analysing the formation mechanism and influencing factors of smog pollution in urban agglomeration in different provinces is of high practical significance to promote the coordinated and sustainable development of energy, environment, and economy in the regions, as well as ensure the smooth progress of smog pollution control. This study explores the interactive relationship between smog control and the upgrading of the regional economic structure. The relationship between industrial structure and smog pollution degree shows a U-shaped curve, meaning that economic development can reduce the emission of air pollutants. Foreign direct investment does not produce a significant effect in improving environmental pollution. Construction dust also aggravates smog pollution. In the future, in-depth research can focus on the degree of correlation between smog and industrial development, the dynamic relationship between urbanization and smog, the temporal and spatial distribution characteristics of smog and its correlation, the adjustment of industrial structure, and the improvement of green productivity.

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