How Can Industrial Upgrading Improve China's Air Quality –Empirical Analysis Based on Multilevel Growth Model

Zining Li

Hebei University of Technology

Congxin Li (✉ licongxin@126.com)

Hebei GEO University <https://orcid.org/0000-0003-2947-6048>

Research Article

Keywords: Industrial upgrading, Air quality, Multilevel growth model

Posted Date: September 13th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-804645/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on March 18th, 2022. See the published version at <https://doi.org/10.1007/s11356-022-19719-5>.

How can industrial upgrading improve China's air quality —empirical analysis based on multilevel growth model

Zining Li^a Congxin Li^{b*}

^a School of Science, Hebei University of Technology, Tianjin city, Tianjin, 300401, China

^b School of Economics, Natural Resources and Capital Research Center of Hebei GEO University,
Shijiazhuang city, Hebei province, 050031, China

* the corresponding author

Zining Li Hebei University of Technology lizinign@126.com (the first author)

Congxin Li Hebei GEO University licongxin@126.com (the corresponding
author)

Abstract: With the rapid development of industrialization and urbanization in China, the ecological environment has been damaged, especially the air quality, which has brought troubles to the production and life of residents. China has taken various measures to improve air quality, and industrial upgrading is one of the measures. How can industrial upgrading improve air quality? This article uses the urban and provincial data from 2015 to 2018, adopts a multilevel growth model, and draws the following conclusions through empirical analysis. Companies aiming at economic profit and survival will eventually lead to overall industrial upgrades that have little effect on air improvement. Industrial structure adjustment under the effect of industrial upgrading can reduce air pollution and have a significant impact on the improvement of air quality. Industrial upgrading under the effect of time will inevitably reduce the impact on environmental pollution, which is conducive to the improvement of air quality. According to the empirical results, this paper puts forward some suggestions to improve the air quality.

Keywords: Industrial upgrading; Air quality; Multilevel growth model

1 Introduction

Reform and opening up and the implementation of the market system have

created opportunities for China's development and promoted rapid economic growth. However, the rapid economic growth is at the cost of heavy environmental pollution. The ecological environment has been destroyed, and air pollution is particularly serious. China's air pollution is on the rise before 2013 (Li et al., 2018). It has a great impact on Residents' health and travel (Kenneth, 2003; Zhang et al., 2014; Zhang et al., 2015). In order to improve air quality, China has adopted a series of measures. At the national level, the punishment for polluting companies have been increased, outdated production capacity has been eliminated, supervision and rectification of polluting industries have been strengthened, and strategic emerging industries have been vigorously promoted. Local governments have also introduced air pollution control measures. The clean air action implemented by the Chinese government has greatly improved air quality (Zhang et al., 2021). However, *the 2020 Global Environmental Performance Index (EPI) Report* jointly released by Yale University and other research units shows that China ranked 137th with an air quality score of 27.1 among 180 countries (Wendling et al., 2020). Improving air quality is still one of the main problems in China.

China is a developing country with a relatively rapid process of industrialization and urbanization, with a more extensive growth pattern and more serious environmental pollution. The influencing factors of air pollution are various, and the process of industrialization is one of the main causes of air pollution. He (2015) analyzed the causes of haze pollution and found that the over-heavy industrial structure was the main cause, and emphasized that air pollution is closely related to

industrial development. The high proportion of regional industrial structure will cause strong regional pollution emissions and affect air quality (Wang et al., 2014). Air pollution follows the process of industrialization. China is currently in the middle and late stages of industrialization. The heavy chemical industry and infrastructure construction account for a large proportion (Jian et al., 2011), which will inevitably generate more pollution emissions and affect air quality. Guide the transformation and upgrading of the secondary industry and gradually reduce the proportion of heavy and chemical industries. Realize the structural transformation of the regional spatial layout of the secondary industry in China, and make the regional layout of various industrial sectors more reasonable. The industrial upgrading can alleviate and eliminate air pollution. Governments at all levels in China have adopted various policies to guide the adjustment of the industrial structure to ensure the realization of economic growth and the improvement of air quality.

From 2005 to 2019, the National Development and Reform Commission issued 4 editions of the *Industrial Structure Adjustment Guidance Catalog*. The main purpose is to transform traditional industries, develop service industries, cultivate and promote emerging industries, and realize industrial structure adjustment. After years of development, has the industrial upgrading improved the air quality? How to improve the air quality? These problems will help to understand the contribution of industrial structure adjustment and upgrading to air quality improvement, so as to formulate more targeted air pollution control measures, and provide important support for government departments to make decisions to improve air quality. Based on this

research purpose, this article uses multilevel growth model to study the impact of industrial upgrading on China's air quality, and explores the direction of industrial structure adjustment and the influence of industrial policies. These has important theoretical and applied value.

2 Literature review

Domestic and foreign researches on industrial upgrading and air quality mainly focus on two aspects.

First, industrial upgrading improves the overall ecological environment. Under the pressure of energy conservation and emission reduction, China's industrial structure has been continuously adjusted, which has greatly improved the intensity of energy use(Luan et al., 2021), and brought about the reduction in the intensity of pollutants per unit of GDP (Cole, 2000).Hu et al., (2020) pointed out that 186% of economic growth and 30% of pollutant emission reductions can be achieved within five years (2020-2025) by optimizing the industrial structure.China's pollutant emission levels are on a downward trend (Li et al.,2017).Green development is the future development direction of China's economy, and the industrial upgrading is an effective way to alleviate the pressure of the current green economy transformation (Zheng et al,2020;Du et al.,2021).The positive external effects of China' s industrial upgrading are significant, and industrial upgrading can improve eco-efficiency(Han et al.,2021) .The research of these scholars mainly focused on the improvement of the overall environmental quality by industrial upgrading, and did not involve the impact on air quality.But with the improvement of China's overall environmental quality, air

pollution will eventually be contained.

Second, the direct impact of industrial upgrading on air quality. One of the most effective ways to reduce carbon emission in China is to change the extensive economic growth mode and promote industrial upgrading (Li, 2021). The structural upgrade through the increase in the proportion of the tertiary industry can keep within limits significantly waste gas pollution (Li, 2011). In the regions with less dependence on natural resources, the emission reduction effect of industrial structure change will be more obvious (Li et al., 2019; Zhou et al., 2021). Industrial structure upgrading can reduce CO₂ emissions (Dong, 2021). The total amount of CO₂ emission was reduced from 5707.2 million tons to 5452.1 million tons, but the GDP of 825.9 billion RMB was sacrificed (Chang, 2015). Then scholars began to focus on the impact of industrial structure upgrading on air quality (Lei, 2014; Guo, 2016; Feng et al., 2018). They found that the industrial structure upgrading has regional heterogeneity in energy conservation and emission reduction, and the effect on energy conservation and emission reduction in eastern region is more obvious (Xiao et al., 2014). Therefore, the upgrading of industrial structure and rationalization of industrial structure can significantly restrict PM_{2.5}, which is conducive to the improvement of air quality (Guo et al., 2021).

In summary, domestic and foreign scholars mostly use panel models and spatial panel data models to study the relationship between industrial upgrading and air pollution. The data of industrial upgrading and industrial structure adjustment involve provincial and municipal levels and the traditional panel data model and spatial panel

data model can no longer meet the requirements. Therefore, this paper adopts a multilevel growth model to study the impact of industrial structure adjustment and industrial upgrading on air quality at the municipal and provincial levels. At the same time, under the pressure of industrial upgrading at the provincial level, how to achieve the purpose of improving air quality through continuous changes, so that the empirical results of this paper can better reflect the internal relationship between industrial upgrading and air quality, and make the conclusions more stable and reliable.

3 Variable description and research method

3.1 Variable description

The explained variable is air quality. Air quality is measured by the Air Quality Index (AQI). The air quality index is a non-linear dimensionless index describing the air quality. The reference standard for classification calculation is GB 3095-2012 *Ambient Air Quality Standard* (current). The pollutants involved in the evaluation include SO₂, NO₂, PM₁₀, PM_{2.5}, O₃, CO, etc. Because the air quality index is objective and true, most scholars (Zhang et al., 2019; Shen et al., 2019; Liu et al., 2020) use this index to measure air quality. The air quality index ranges from 0 to 500. The larger the value, the higher the degree of air pollution. When the air quality index is less than 100, there is no significant impact on human health. When the air quality index is greater than 100, it has various effects on human health. Therefore, this study uses air quality index to represent air quality. The air quality index is urban data.

The core explanatory variables are industrial structure adjustment (Isa) and industrial upgrading (Isu). Referring to the literature of Li et al. (2019) and Luan et al.

(2021), this paper uses the proportion of secondary industry (%) to measure the industrial structure adjustment. In the secondary industry, there are many polluting industries, which produce a large number of pollutants, which will have an impact on air quality. The decline in the proportion of the secondary industry means that the adjustment of the industrial structure is developing in a favorable direction. The calculation of industrial upgrading refers to the calculation formula of Fu (2010). Industrial upgrading means that as the economy grows, the proportion of the three industries continues to rise along the order of the first, second, and third industries. According to its calculation standard, the larger the value, the higher the level of industrial upgrading. Industrial upgrading is conducive to the improvement of air quality. Industrial structure adjustment is urban data, and industrial upgrading is provincial data.

The control variables are the intensity of science and technology input (Sti), sewage discharge fee collection amount (Sda), and public supervision (Pus). Referring to Li et al. (2020), the intensity of science and technology input is calculated by dividing the science and technology input (100 million yuan) by the gross regional product (100 million yuan). If scientific and technological investment is used for ecological protection, the larger the value, the more conducive to air quality improvement. Sewage discharge fee collection amount (100 million yuan) is a constraint on polluting industries. The government hopes to force the transformation and upgrading of polluting industries through the collection of sewage charges, so as to achieve the goal of improving air quality (Li et al., 2020). Public supervision (pieces)

is measured by the number of proposals undertaken by the People's Congress and the number of proposals undertaken by the Chinese people's Political Consultative Conference (CPPCC). The intensity of science and technology input is urban data, and the amount of sewage charges and public supervision is provincial data.

3.2 Research method

Referring the multilevel model coefficient relationship diagram of Krefy (1998), the multilevel growth model of this study is shown in Figure 1. The first layer is time. The influence of time on air quality can be linear or nonlinear. The second layer is cities, and the independent variables and constant terms at the city layer have an impact on the regression coefficients of the first layer. The third layer is provinces, and the independent variables and constant terms at the provincial layer have an impact on the regression coefficients of the second layer.

Figure 1 The relationship between the coefficients of the multilevel growth model with a three-layer structure

According to Figure 1, the setting form of the multilevel growth model is as follows. The first layer is linear growth model,

$$AQI_{ij} = \beta_{0ij} + \beta_{1ij}T_{ij} + u_{ij} \quad (1)$$

Where, AQI represents urban air quality. T represents the time variable. i represents different cities in China. j represents different provinces. β_{0ij}, β_{1ij} represent the regression coefficient. u_{ij} represents the random error term. If the time variable in formula (1) become T^2, T^3 , then the linear growth model is converted to a curve growth model.

The second layer is the city model. The core explanatory variable of the second layer is industrial structure adjustment. If $q=1$ in Figure 1, the form of the city model is as follows,

$$\beta_{0ij} = \gamma_{00j} + \gamma_{01j}Isa_{ij} + \varepsilon_{0ij} \quad (2)$$

$$\beta_{1ij} = \gamma_{00j} + \gamma_{01j}Isa_{ij} + \varepsilon_{0ij} \quad (3)$$

Where, Isa is industrial structure adjustment. $\gamma_{00j}, \gamma_{01j}, \gamma_{10j}, \gamma_{11j}$ represent the regression coefficient. $\varepsilon_{0ij}, \varepsilon_{1ij}$ represent the random error term.

The third layer is the province model. The core explanatory variable of the third layer is industrial upgrading. If $k=1$ in Figure 1, the form of the province model is as follows,

$$\gamma_{00j} = \delta_{000} + \delta_{001}Isu_{ij} + v_{00j} \quad (4)$$

$$\gamma_{01j} = \delta_{010} + \delta_{011}Isu_{ij} + v_{01j} \quad (5)$$

$$\gamma_{10j} = \delta_{100} + \delta_{101}Isu_{ij} + v_{10j} \quad (6)$$

$$\gamma_{11j} = \delta_{110} + \delta_{111}Isu_{ij} + v_{11j} \quad (7)$$

Where, Isu is industrial upgrading. $\delta_{000}, \delta_{001}, \delta_{010}, \delta_{100}, \delta_{101}, \delta_{110}, \delta_{111}$ represent the regression coefficient. $v_{00j}, v_{01j}, v_{10j}, v_{11j}$ represent the random error term.

Formula (4) - (7) is substituted into formula (1) ,

$$\begin{aligned}
 AQI_{ij} = & \delta_{000} + \delta_{001}Isu_{ij} + v_{00j} + (\delta_{010} + \delta_{011}Isu_{ij} + v_{01j})Isa_{ij} + \varepsilon_{0ij} \\
 & + (\delta_{100} + \delta_{101}Isu_{ij} + v_{10j})T_{ij} + (\delta_{110} + \delta_{111}Isu_{ij} + v_{11j})Isa_{ij}T_{ij} \\
 & + \varepsilon_{1ij}T_{ij} + u_{ij}
 \end{aligned} \tag{8}$$

Formula (8) has been sorted out,

$$\begin{aligned}
 AQI_{ij} = & \delta_{000} + \delta_{100}T_{ij} + \delta_{010}Isa_{ij} + \delta_{001}Isu_{ij} + \delta_{011}Isa_{ij}Isu_{ij} + \delta_{101}Isu_{ij}T_{ij} \\
 & + \delta_{110}Isa_{ij}T_{ij} + \delta_{111}Isu_{ij}Isa_{ij}T_{ij} + (v_{00j} + v_{01j}Isa_{ij} + \varepsilon_{0ij} + v_{10j}T_{ij} \\
 & + v_{11j}Isa_{ij}T_{ij} + \varepsilon_{1ij}T_{ij} + u_{ij})
 \end{aligned} \tag{9}$$

Substituting the control variables the intensity of science and technology input (Sti), sewage discharge fee collection amount (Sda) and public supervision (Pus) into formula (9), the following model is obtained,

$$\begin{aligned}
 AQI_{ij} = & \delta_{000} + \delta_{100}T_{ij} + \delta_{010}Isa_{ij} + \delta_{001}Isu_{ij} + \delta_{011}Isa_{ij}Isu_{ij} + \delta_{101}Isu_{ij}T_{ij} \\
 & + \delta_{110}Isa_{ij}T_{ij} + \delta_{111}Isu_{ij}Isa_{ij}T_{ij} + \gamma_{12j}Sti_{ij} + \delta_{022}Sda_{ij} + \delta_{023}Pus_{ij} \\
 & + (v_{00j} + v_{01j}Isa_{ij} + \varepsilon_{0ij} + v_{10j}T_{ij} + v_{11j}Isa_{ij}T_{ij} + \varepsilon_{1ij}T_{ij} + u_{ij})
 \end{aligned} \tag{10}$$

The explanatory variable in formula (10) is related to the random disturbance term, but the actual estimation uses multilevel growth model, so the coefficient estimation satisfies linearity, unbiasedness and validity. δ_{011} represents the coefficient of $Isa_{ij}Isu_{ij}$. It is actually how the urban industrial structure adjustment is under the pressure of provincial industrial upgrading to improve air quality. δ_{101} represents the coefficient of $Isu_{ij}T_{ij}$. The essence is how the industrial upgrading can improve the air quality with the change of time.

3.2 Data source

The object of this study is China's 286 prefecture-level cities from 2015 to 2018, with a total of 1144 samples. The air quality index from 2015 to 2018 comes from various monitoring websites of China Meteorological Bureau. The proportion of secondary industry, investment in science and technology and the gross regional product are from China's Urban Statistical Yearbook in 2016-2019. The pollutant discharge fee collection, the number of proposals undertaken by the National People's Congress, and the proposals undertaken by the CPPCC come from *China Environmental Yearbook* in 2016-2019. Stata16.0 is used for data analysis.

4 Empirical analysis

4.1 Multilevel structure test—Empty Model

In order to test whether the data has a Multilevel structure, we build an empty model with no explanatory variables. The specific form of the empty model is as follows,

$$AQI_{ij} = \beta_{0ij} + u_{ij} \quad (11)$$

$$\beta_{0ij} = \gamma_{00j} + \varepsilon_{0ij} \quad (12)$$

where, $u_{ij} \sim N(0, \sigma_u^2)$, $\varepsilon_{0ij} \sim N(0, \sigma_e^2)$, and $\text{cov}(u_{ij}, \varepsilon_{0ij}) = 0$. σ_u^2 represents the within-group variance. σ_e^2 represents the between-group variance. Substituting formula (12) into formula (11), a variance analysis model with random effect is obtained,

$$AQI_{ij} = \gamma_{00j} + \varepsilon_{0ij} + u_{ij} \quad (13)$$

Estimating formula (13), we get $\sigma_u^2 = 44.581$, $\sigma_e^2 = 365.426$. The intraclass correlation coefficient (ICC) $ICC(\rho) = \frac{\sigma_e^2}{\sigma_e^2 + \sigma_u^2} = 0.8913$. This shows that about

89.13% of the total variability is caused by the differences between the research cities,
so the multilevel model can be used for analysis.

4.2 Unconditional linear growth model test

The linear growth model is shown in formula (1), and the unconditional model
is as follows,

$$\beta_{0ij} = \gamma_{00j} + \varepsilon_{0ij} \quad (14)$$

$$\beta_{1ij} = \gamma_{10j} + \varepsilon_{1ij} \quad (15)$$

The curve growth model is as follows,

$$AQI_{ij} = \beta_{0ij} + \beta_{1ij}T_{ij} + \beta_{2ij}T_{ij}^2 + u_{ij} \quad (16)$$

If the growth model is a curve growth model, the unconditional model should
add another unconditional model in addition to formulas (14) and (15),

$$\beta_{2ij} = \gamma_{20j} + \varepsilon_{2ij} \quad (17)$$

Test the unconditional growth model to judge whether to use linear growth
model or curve growth model. According to formula (1) and formula (14) - (17), the
calculation results are shown in Table 1,

Table 1 Results of linear and curve growth model

	Linear growth model	Curve growth model
	Model1	Model2
T	-2.649*** (-17.47)	-2.382*** (-2.77)
T^2		-0.053 (-0.31)

cons	81.937*** (67.80)	81.67*** (55.33)
Wald statistics	305.16	305.3
Observations	1144	1144

Note: The value in parentheses is the z statistic, *** means significant at the level of 0.01

It can be seen from Table 1 that in Model 1, the influence of time variables on air quality is significant, indicating that as time changes, the value of AQI is decreasing and air quality is gradually improving. In Model 2, the time variable T has a significant impact on air quality, while the time variable T^2 has an insignificant impact on air quality. The chi-square statistic of the maximum likelihood ratio test of the linear growth model and the nonlinear growth model is 0.1, and the corresponding P value is 0.753, which is greater than the significance level of 0.05, so the linear growth model should be used. In Figure 2, the linear growth trajectory is represented by red dot and red line, and the curve growth trajectory is represented by green dot and green line. The curve growth trajectory and the linear growth trajectory almost overlap. Once again, Figure 2 shows that linear growth models should be used.

Figure 2 Comparison of fitting results between linear growth model and curve growth model

4.3 Analysis on the improvement of air quality by industrial upgrading

Multilevel structure test and unconditional linear growth model test show that the multi-layer linear growth model can be used to study the improvement of air quality by industrial upgrading. According to formula (10), the multilevel linear growth model is estimated, and the calculation results are shown in Table 2. For comparison, the results of the mixed panel model are added to Table 2.

Table 2 Results of mixed panel model and multilevel linear growth model

AQI	Mixed panel model	Multilevel linear growth model
	Model3	Model4
T	-2.466*** (-4.40)	56.41*** (2.57)
Isa	0.288*** (2.90)	6.836*** (3.57)
Isu	-7.532 (-0.93)	13.271 (0.93)
Isa×Isu		-1.011*** (-3.5)
Isa×T		-0.996* (-1.93)
Isu×T		-8.568***

		(-2.63)
Isa×Isu×T		0.151**
		(1.97)
Sti	-134.654	140.269***
	(-1.12)	(3.19)
Sda	1.156***	-0.222***
	(6.62)	(-3.81)
Pus	0.002	0.003***
	(0.72)	(3.39)
_cons	108.668*	-15.144
	(2.07)	(-0.16)
Observations	1144	1144
AIC	9876.499	7986.026
BIC	9911.795	8056.618

280 Note: t or z statistics are in parentheses, * means significant at the level of 0.1, ** means

281 significant at the level of 0.05,*** means significant at the level of 0.01

282 Model 3 is the regression result of the mixed panel model, and model 4 is the

283 regression result of the multilevel growth linear model.It can be seen from Table 2

284 that the AIC and BIC of model 4 are 7986.026 and 8056.618, which are smaller than

285 the values of AIC and BIC of model 3, indicating that the multilevel linear model is

286 better than the mixed panel model.In Model 3, as time changes, the AQI value of air

287 quality continues to decrease.With the increase of time for one year, the air quality

index decreased by 2.466, and time has a significant impact on air quality. In Model 4, time has a significant impact on air quality, and the air quality index rises by 56.14 for every additional year. From a numerical point of view, the value of Model 4 is much greater than the value of Model 3. This is the actual situation. Time does not improve air quality. Time only reflects a long-term trend. If there is no national environmental pollution control policy, the air quality will only get worse and worse as time changes.

In Model 3, the impact of industrial structure adjustment on air quality is significant. For every 1% increase in the proportion of the secondary industry, the air quality index will increase by 0.288. In model 4, the impact of industrial structure adjustment on air quality is significant. For every 1% increase in the proportion of secondary industry, the air quality index will increase by 6.836. Whether it is a mixed panel model or a multi-level linear growth model, an increase in the proportion of the secondary industry will aggravate air pollution, but there is a certain degree of difference, which is consistent with Li's conclusion (Li, 2015). It can be seen from the numerical value that the coefficient value of Model 3 is much smaller than that of Model 4, which underestimates the influence of the proportion of the secondary industry on air quality. The impact of industrial upgrading on air quality is not significant in model 3 or model 4. Regardless of whether the industrial upgrading is positive or negative, whether the value is large or small, it will not affect the air quality, and the air quality will not improve or deteriorate. If the impact of industrial upgrading on air quality is analyzed separately, air quality will not change much.

Under the pressure of industrial upgrading, industrial restructuring has a

significant impact on air quality. For every increase of 1 unit in the interactive item of industrial restructuring and industrial upgrading, air pollution will drop by 1.011. This dynamic change process can be more intuitively represented by Figure 3. The minimum value of industrial structure adjustment is 13.57%, the maximum value is 72.9%, the minimum value of industrial upgrading is 6.33, and the maximum value is 7.62. Under the pressure of industrial upgrading, industrial restructuring has improved air quality as shown in Figure 3. Under the low level of industrial restructuring, different levels of industrial upgrading are conducive to air quality improvement, but the gap in the improvement level is relatively small. With the increase in the proportion of the secondary industry, the improvement of air quality by different industrial upgrading levels has become more and more obvious, and the gap in the improvement level has become bigger and bigger. In a high level of industrial upgrading, the adjustment of the industrial structure has a greater effect on improving air quality.

Figure 3 Industrial upgrading improves air quality

The interaction term between industrial structure adjustment and time has a

significant impact on air quality. Each increase of 1 unit will reduce air pollution by
 0.996 units. The interaction term between industrial upgrading and time has a
 significant impact on air quality. Each increase of 1 unit will reduce air pollution by
 8.568 units. With the change of time, the improvement of air quality by industrial
 upgrading is more obvious. This change process can be shown in Figure 4. It can be
 seen from Figure 4 that when the proportion of the secondary industry is small, the
 slope of the change over time is relatively gentle. When the proportion of the
 secondary industry is relatively large, its slope will become steeper with time. It shows
 that if the country increases the proportion of the secondary industry, it should also
 take reducing air pollution as the constraint. Industrial upgrading will promote the
 improvement of air quality, whether it is high or low, and the improvement range will
 be bigger and bigger with the development of time. From the change trend of the
 graph, industrial upgrading is more conducive to the improvement of air quality with
 the change of time.

Figure 4 Industrial structure adjustment and industrial upgrading improve air quality over time

Under the pressure of industrial upgrading, the adjustment of industrial structure has a significant impact on air quality over time. For every increase of 1 unit in the interaction terms of industrial structure adjustment, industrial upgrading and time, air pollution will increase by 0.151 unit. The impact is positive, which is not conducive to the improvement of air quality. It shows that the environmental regulation policy is not strict enough, and the interactive items of industrial structure adjustment and industrial upgrading are not conducive to the improvement of air quality relative to the time trend.

4.4 Robustness test

In order to ensure the reliability of the research results, a robustness test is now carried out. In this paper, the dependent variable is changed to $pm_{2.5}$, and a multilevel linear growth model is used for estimation. The results are shown in Table 3. It can be seen from Table 3 that the sign directions of the estimation results are basically the same for Model 5 and Model 3, Model 6 and Model 4.

Table 3 Robustness test results

$Pm_{2.5}$	Mixed panel model	Multilevel linear growth model
	Model5	Model6
T	-2.818*** (-5.87)	52.715*** (2.69)
Isa	0.191*** (2.63)	5.679*** (3.37)

Isu	-10.454	13.723
	(-1.56)	(1.10)
Isa×Isu		-0.387***
		(-3.29)
Isa×T		-0.902*
		(-1.96)
Isu×T		-8.109***
		(-2.79)
Isa×Isu×T		0.134*
		(1.96)
Sti	-7.922	98.213**
	(-0.09)	(2.51)
Sda	0.785***	-0.164***
	(5.48)	(-3.16)
Pus	0.007***	0.002**
	(3.36)	(2.51)
_cons	102.903**	-45.434
	(2.39)	(-0.55)
Observations	1144	1144
AIC	9219.526	7689.093
BIC	9254.822	7759.685

Note: t or z statistics are in parentheses, * means significant at the level of 0.1, ** means

significant at the level of 0.05, *** means significant at the level of 0.01

5 Research conclusions and countermeasures

5.1 Research conclusions

According to the empirical results, this paper draws three conclusions.

The first is that industrial upgrading itself has no significant impact on air quality. If industrial upgrading is embodied in the replacement of leading industries, although these replacements have considered environmental pollution, they are all based on the game between the government and enterprises under government environmental supervision. When it comes to specific enterprises, their goals are economic profit and enterprise survival, which ultimately leads to the overall industrial upgrading that has little effect on air improvement.

The second is that industrial upgrading and industrial structure adjustment together can reduce air pollution, which has a significant impact on air quality improvement. If industrial upgrading is embodied in the substitution of advanced technologies for traditional technologies, industrial upgrading will have an effect on the adjustment of industrial structure. These will promote the expansion of the proportion of knowledge- and technology-intensive industries, and be conducive to energy conservation and emission reduction.

The third is that industrial upgrading and time have a significant impact on air quality. The construction of ecological civilization is the millennium plan for the sustainable development of the Chinese nation. The central government's assessment

of the political achievements of local governments at all levels has been transformed into the assessment of the construction of ecological civilization. Industrial upgrading under the influence of time will inevitably reduce the impact on environmental pollution, which is conducive to the improvement of air quality.

5.2 Countermeasures and suggestions

Based on the above conclusions, this article puts forward the following countermeasures and suggestions.

First, strengthening the degree of environmental regulation in various regions and restricting the newly replaced leading industries. The impact of industrial upgrading on eco-efficiency will vary with the intensity of environmental regulations. Most of the environmental regulations implemented in various parts regions of China are relatively loose (Han et al., 2016). The newly established leading industries will not take the improvement of social responsibility and the improvement of air quality as one of the main objectives. Only by strengthening the degree of environmental regulation in various regions and implementing strict environmental protection laws and regulations will it have a shocking effect on enterprises. Especially for the newly replaced leading industries, restraining economic behavior and increasing social responsibility, involving undesirable intangible output, should be considered into the impact on the ecological environment.

Second, persisting in green innovation and promoting the industrial sector to move towards the global mid-to-high-end value chain. In the process of industrialization in western developed countries, they have experienced the

development path of first pollution and then treatment, and now they attach great importance to the protection of the ecological environment. The new materials, new technologies, new methods, and new thinking in China's innovation must be based on the concept of green. All industries in China should use green technologies and green production methods to improve energy efficiency and reduce pollutant emissions. In this way, in the process of transformation of the global value chain, the Chinese industrial sector can gradually shift from the low-end position to the mid-to-high end position.

Third, improving the mechanism of sharing by the whole people and driving high-quality economic development. Industrial upgrading under the influence of time has a significant effect on the improvement of air quality, indicating that time reflects a long-term trend. If the long-term trend aims at improving and perfecting the sharing mechanism for the whole people, it will help eliminate the dual structure of urban and rural areas, improve the level of human capital, and improve the quality of the whole people. When the whole people at a higher level no longer pay attention to food and clothing issues, but pay attention to the quality of life, it will lead to high-quality economic development. High-quality economic development will put environmental protection in a more important position, and the air quality closely related to residents will be greatly improved.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Consent to Participate

Not applicable.

Consent to Publish

All authors have approved the manuscript and agree with submission to Environmental Science and Pollution Research.

Author Contributions

Zining Li and Congxin Li are the co-first authors, Congxin Li is the corresponding author, and all authors contributed equally to this work.

Funding

This research was supported by Chinese National Funding of Social Sciences (No.18BJY081).

Declaration of Interest statement

All authors declare that there is no competing interests in this paper.

Availability of data and materials

The raw data used to support the findings of this study. The raw data comes from National Bureau of Statistics of China.

References

Chang N.,2015.Changing industrial structure to reduce carbon dioxide emissions:

A Chinese application. Journal of Cleaner Production, 103: 40-48.

<https://doi.10.1016/j.jclepro.2014.03.003>

Cole M.A.,2000. Air Pollution and Dirty Industries:How and Why Does the

Composition of Manufacturing Output Change with Economic Development?

446 Environmental and Resource Economics,17: 109-123.
 447 <https://doi.10.1023/A:1008388221831>
 448 Dong J.J., Dou Y., Jiang Q.Z.,et al.,2021. How Does Industrial Structure Upgrading
 449 Affect the Global Greenhouse Effect? Evidence From RCEP and Non-RCEP
 450 Countries.Frontiers in Energy Research, 9:683166.
 451 <https://doi.10.3389/fenrg.2021.683166>
 452 Du K.R.,Cheng Y.Y.,Yao X.,2021. Environmental regulation, green technology
 453 innovation, and industrial structure upgrading: The road to the green
 454 transformation of Chinese cities. Energy Economics,98:105247.
 455 <https://doi.10.1016/j.eneco.2021.105247>.
 456 Feng Y.X., Shi L., Ling H.C.,2018.Fiscal Decentralization,Industrial Structure and
 457 Environmental Pollution.Soft Science,32(11):25-28.
 458 Fu L.H.,2010.An Empirical Research on Industry Structure and Economic Growth
 459 Statistical Research. Statistical Research,28(8):79-81.
 460 <https://doi.10.3969/j.issn.1002-4565.2010.08.011>
 461 Guo A.,2016. Panel Data Analysis of the Relationship Between Air Pollutant
 462 Emissions,Economics,and Industrial Structure of China.Emerging Markets
 463 Finance and Trade,52(6):1315-1324.
 464 <https://doi.10.1080/1540496X.2016.1152792>
 465 Guo Q., Zhu M.F.,2021.The nonlinear effect of industrial structure upgrading on air
 466 quality in Shanxi province.Future and Development,4:99-105.
 467 <https://doi.10.3969/j.issn.1003-0166.2021.04.017>

468 Han Y.H.,Huang L.X.,2016.Does Industrial Structure Upgrading Improve
 469 Eco-Efficiency?The Journal of Quantitative Technical Economics,4:40-59.
 470 <https://doi.10.13653/j.cnki.jqte.2016.04.003>
 471 Han Y.H.,Zhang F.,Huang L.X.,et al.,2021. Does industrial upgrading promote
 472 eco-efficiency? —A panel space estimation based on Chinese evidence. Energy
 473 Policy,154:112286. <https://doi.org/10.1016/j.enpol.2021.112286>
 474 He X.G.,2015.Structural Transformation and Interregional Coordination: Economic
 475 Observation of the Cause of the Haze.Reform,5:33-42.
 476 Hu W.Q, Tian J.P., Chen L.J.,2020.An industrial structure adjustment model to
 477 facilitate high-quality development of an eco-industrial park. Science of The
 478 Total Environment ,766:142502 <https://doi.10.1016/j.scitotenv.2020.142502>
 479 Jian X.Y., Ye L.,2011.An Empirical Analysis of the Evolution and Optimization of
 480 China's Industrial Structure Since the Reform and Opening Up.Contemporary
 481 Finance & Economics,1:93-102. <https://doi.cnki:sun:ddcj.0.2011-01-018>
 482 Kenneth Y. C., Michael G.,2003.The Impact of Air Pollution on Infant Mortality:
 483 Evidence from Geographic Variation in Pollution Shocks Induced by a
 484 Recession.The Quarterly Journal of Economics,118(3):1121–1167.
 485 <https://doi.org/10.1162/00335530360698513>
 486 Kreft I.,Leeuw J.,1998. Introduction multilevel modeling. Journal of the American
 487 Statistical Association.94(447):985-986. <https://doi.10.2307/2670020>
 488 Lei C.,2014. Spatial econometric analysis of regional economic structure and air
 489 quality.International Conference on Information Management,9:416-419.

490 <https://doi.10.1109/ICIII.2013.6703175>

491 Li CX, Li GZ. (2020). Does environmental regulation reduce China's haze pollution?

492 An empirical analysis based on panel quantile regression. PLoS ONE,

493 15(10):e0240723. <https://doi.org/10.1371/journal.pone.0240723>

494 Li CX, Li GZ. (2020). Impact of China's water pollution on agricultural economic

495 growth: an empirical analysis based on a dynamic spatial panel lag model.

496 Environmental Science and Pollution Research, 28(6):6956-6965.

497 <https://doi.org/10.1007/s11356-020-11079-2>

498 Li CX, Li GZ, Li ZN. The threshold effect of the efficiency of science and

499 technological services on regional environmental governance in China. Growth

500 and Change.2019;50(6):1026-1042. <https://doi.org/10.1111/grow.12314>

501 Li CX, Jia Q, Li GZ (2020) China's energy consumption and green economy

502 efficiency: an empirical research based on the threshold effect.

503 Environmental Science and Pollution Research, 27(29):36621-36629

504 <https://doi.org/10.1007/s11356-020-09536-z>

505 Li G.Q., Qin J.H.,He J.W.,2018.Spatial-Temporal Evolution and Influencing Factors

506 of China's PM2.5 Pollution.Economic Geography, 38(8):11-18.

507 <https://doi.10.15957/j.cnki.jjdl.2018.08.003>

508 Li K.F.,Wang J.,2017.Financial Agglomeration,Industrial Structure and

509 Environmental Pollution—Spatial Econometric Analysis Based on China's

510 Provinces.Journal of Industrial Technology Economy,36(3):3-12.

511 <https://doi.10.3969/j.issn.1004-910X.2017.03.001>

512 Li P.,2015.Has the adjustment of industrial structure worsened our country's
513 environmental pollution?Inquiry into Economic Issues,6:150-156.
514 <https://doi.CNKI:SUN:JJWS.0.2015-06-024>

515 Li S.,2021.The Impact of Industrial Structure Upgrading on My Country's Carbon
516 Emission Reduction from the Perspective of High-Quality Development.
517 Sustainable Development,11(1):149-159.
518 <https://doi.10.12677/SD.2021.111018>

519 Li S.,2011.Urbanization, industrial structure adjustment and environmental pollution.
520 Research on Financial and Economic Issues,6:38-43.

521 Liu H.W.,liu C., Zheng S.L.,2020.The Effect of New Ambient Air Quality Standards
522 on the High-quality Development of Chinese Enterprises.China Soft Science,
523 10:45-55.

524 Li Z, Shao S, Shi X P, et al., 2019. Structural transformation of manufacturing,
525 natural resource dependence, and carbon emissions reduction: Evidence of a
526 threshold effect from China. Journal of Cleaner Production, 206: 920-927.
527 <https://doi.10.1016/j.jclepro.2018.09.241>

528 Luan B.j.,Zou H.,Chen S.X,et al.,2021. The effect of industrial structure adjustment
529 on China's energy intensity: Evidence from linear and nonlinear analysis.
530 Energy,218:119517. <https://doi.10.1016/j.energy.2020.119517>.

531 Luan B.J., Zou H., Chen S.X.,et al.,2021.The effect of industrial structure adjustment
532 on China's energy intensity: Evidence from linear and nonlinear analysis.Energy,
533 218:119517. <https://doi.10.1016/j.energy.2020.119517>

534 Shen Y.J., Yu S.L.,Jiang D.Q.,2019.Does the Improvement of Air Quality Decrease
 535 Firm Labor Cost? Management World,6:161-178.
 536 <https://doi.10.19744/j.cnki.11-1235/f.2019.0086>
 537 Xiao T.,Liu H.,2014.An Empirical Study on the Adjustment of Industrial Structure
 538 and Energy Conservation and Emission Reduction. Economist,9:58-68.
 539 <https://doi.CNKI:SUN:JJXJ.0.2014-09-008>
 540 Wang F., Dong S.C. Mao Q.L.,2014.Evolution of China's industrial structure and
 541 spatial-temporal differentiation in environmental effect.Geographical
 542 Research,33(10):1793-1806. <https://doi.10.11821/dlyj201410001>
 543 Wendling Z. A.,EmersonN J. W., Desherbinina, e t a l., 2020. Environmental
 544 Performance Index[R]. New Haven, CT:Yale Center for Environmental Law &
 545 Policy, Yale University.48-55.
 546 <https://epi.yale.edu/downloads/epipolicymakerssummaryr11.pdf>
 547 Zhang A., Zhong L., Yong X.,et al.,2015.Tourists' Perception of Haze Pollution and
 548 the Potential Impacts on Travel: Reshaping the Features of Tourism Seasonality
 549 in Beijing, China. Sustainability,7:2397-2414. <https://doi.10.3390/su7032397>
 550 Zhang Q.,Zheng Y.,Kong D.M.,2019.Local Environmental Governance Pressure,
 551 Executive's Working Experience and Enterprise Investment in Environmental
 552 Protection:A Quasi-natural Experiment Based on China's "Ambient Air Quality
 553 Standards 2012".Economic Research Journal,6:183-198.
 554 <https://doi.CNKI:SUN:JJYJ.0.2019-06-013>

555 Zhang Y.Y., Liu X.J., Zhang L.,et al.,2021.Evolution of secondary inorganic aerosols
 556 amidst improving PM_{2.5} air quality in the North China plain.Environmental
 557 Pollution,281(15): 117027 . <https://doi.10.1016/j.envpol.2021.117027>
 558 Zhang Z.L.,Wang J.,Chen L.H.,2014.Impact of haze and air pollution-related hazards
 559 on hospital admissions in Guangzhou, China. Environmental Science and
 560 Pollution Research ,21:4236–4244. <https://doi.10.1007/s11356-013-2374-6>
 561 Zheng Y.,Xiao JZ.,Cheng J.H.,2020. Industrial Structure Adjustment and Regional
 562 Green Development from the Perspective of Mineral Resource Security.
 563 International journal of environmental research and public health,17(19):1-18.
 564 <https://doi.10.3390/ijerph17196978>.
 565 Zhou D., Luo D. Q.,2021. Green taxation, industrial structure transformation and
 566 carbon emissions reduction. Resources Science,43(4): 693- 709.
 567 <https://doi.10.18402/resci.2021.04.05>