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

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Abstract
With the rapid development of industrialization and urbanization in China, the ecological environment has been damaged, especially the air quality, which has negatively impacted the productivity and lives of residents. China has taken various measures to improve air quality, and industrial upgrading is one of these measures. This article uses urban and provincial data from 2015 to 2018 and a multilevel growth model to study how industrial upgrading can improve air quality. The following conclusions are drawn through empirical analysis. If industrial upgrading is not considered, with time, air quality will gradually deteriorate. However, once the country adopts strategic measures for industrial upgrading, the combined effect of industrial upgrading and time will improve air quality. Industrial upgrading and industrial restructuring jointly reduce air pollution and have a significant impact on the improvement of air quality. Company goals for economic profit and survival will eventually lead to overall industrial upgrades that have little effect on air improvement. According to the empirical results, this paper puts forward some suggestions to improve the air quality.

Keywords Industrial upgrading · Air quality · Multilevel growth model

Introduction
Reform, opening up, and the implementation of the market system have created opportunities for China’s development and promoted rapid economic growth. However, rapid economic growth has come at the cost of heavy environmental pollution. The ecological environment has been destroyed, and air pollution is particularly serious. China’s air pollution was on the rise before 2013 (Li et al. 2018). It has a great impact on residents’ health and travel (Kenneth and Michael 2003; Zhang et al. 2014; Zhang et al. 2015). To improve air quality, China has adopted a series of measures. At the national level, punishment for polluting companies has increased, outdated production capacity has been eliminated, supervision and rectification of polluting industries have been strengthened, and strategic emerging industries have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 a major problem 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 vary, and the industrialization process is one of its main causes. He (2015) analyzed the causes of haze pollution and found that the overheavy industrial structure was its primary cause and emphasized that air pollution is closely related to industrial development. A high proportion of the 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 and Ye 2011) which will inevitably generate more pollution emissions and affect air quality. The transformation and upgrading of the secondary industry must be guided to gradually reduce the proportion of heavy and chemical industries. Realizing the structural transformation of the regional spatial layout of the secondary industry in China and making the regional layout of various industrial sectors more reasonable must be priorities. 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 industrial upgrading improved air quality? How can the air quality be improved? These questions will help with understanding the contribution of industrial structure adjustment and upgrading to air quality improvement to formulate more targeted air pollution control measures and provide important support for government departments to make decisions to improve air quality. For the purpose of this research, this article uses a 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 have important theoretical and applied value.

**Literature review**

Domestic and foreign studies 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 a 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 and Wang 2017). Green development is the future direction of China's economy, and 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 from industrial upgrading and did not involve air quality impacts. However, with the improvement of China’s overall environmental quality, air pollution will eventually be contained.

Second, industrial upgrading has a direct impact on air quality. One of the most effective ways to reduce carbon emissions in China is to change the extensive economic growth mode and promote industrial upgrading (Li 2021). Structural upgrades through an increase in the proportion of the tertiary industry can keep significant waste gas within limits (Li 2011). In regions with less dependence on natural resources, the emission reduction effect of industrial structure change will be more obvious (Li et al. 2019a, b; Zhou and Luo 2021). Industrial structure upgrading can reduce CO₂ emissions (Dong et al. 2021). The total amount of CO₂ emissions was reduced from 5707.2 million tons to 5452.1 million tons, but the GDP of 825.9 billion RMB was sacrificed (Chang 2015). Scholars then began to focus on the impact of industrial structure upgrading on air quality (Lei 2014; Guo 2016; Feng et al. 2018). They found that industrial structure upgrading has regional heterogeneity in energy conservation and emission reduction, and the effect on energy conservation and emission reduction in the eastern region is more obvious (Xiao and Liu 2014). Therefore, the upgrading of industrial structure and rationalization of industrial structure can significantly restrict PM₂.₅, which is conducive to the improvement of air quality (Guo and Zhu 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 industrial upgrading and industrial structure adjustment data 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, it addresses how to achieve improved air quality through ongoing 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.

**Variable description and research method**

**Variable description**

The explained variable is air quality. Air quality is measured by the air quality index (AQI), which is a nonlinear
dimensionless index for describing 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, PM₂.₅, 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 is, 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 the air quality index to represent air quality. The air quality index is considered urban data.

The core explanatory variables are industrial structure adjustment (Isa) and industrial upgrading (Isu). Referring to the literature of Li et al. (2019a, b) and Luan et al. (2021), this paper uses the proportion of secondary industry (%) to measure industrial structure adjustment. In the secondary industry, many polluting industries produce a large number of pollutants, which impact 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 is, 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 it is to air quality improvement. The 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 to achieve the goal of improving air quality (Li et al. 2020, 2021). 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 from urban data, and the amount of sewage charges and public supervision is from provincial data.

**Research method**

Referring to the multilevel model coefficient relationship diagram of Kreft and Leeuw (1998), the multilevel growth model of this study is shown in Fig. 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.

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

\[ AQI_{tij} = \beta_{0ij} + \beta_{1ij}T_{tij} + \epsilon_{tij} \]  

(1)
where $AQI$ represents urban air quality. $T$ represents the time variable. $i$ represents different cities in China. $j$ represents different provinces. $\beta_{0ij}, \beta_{1ij}$ represent the regression coefficients. $\epsilon_{0ij}$ represents the random error term. If the time variable in Formula (1) becomes $T^2$, $T^3$, 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 Fig. 1, the form of the city model is as follows:

$$\beta_{0ij} = \gamma_{00j} + \gamma_{01j}Isu_{ij} + \epsilon_{0ij}$$

(2)

$$\beta_{1ij} = \gamma_{00j} + \gamma_{01j}Isa_{ij} + \epsilon_{0ij}$$

(3)

where $Isu$ is industrial structure adjustment; $\gamma_{00j}, \gamma_{01j}, \gamma_{10j}, \gamma_{11j}$ represents the regression coefficient; and $\epsilon_{0ij}, \epsilon_{1ij} \sim N(0, \sigma^2)$ represents 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 Fig. 1, the form of the province model is as follows:

$$\gamma_{00j} = \delta_{000} + \delta_{001}Isa_{ij} + \epsilon_{00j}$$

(4)

$$\gamma_{01j} = \delta_{010} + \delta_{011}Isu_{ij} + \epsilon_{01j}$$

(5)

$$\gamma_{10j} = \delta_{100} + \delta_{101}Isa_{ij} + \epsilon_{10j}$$

(6)

$$\gamma_{11j} = \delta_{110} + \delta_{111}Isu_{ij} + \epsilon_{11j}$$

(7)

where $Isu$ is industrial upgrading. $\delta_{000}, \delta_{010}, \delta_{100}, \delta_{101}, \delta_{110}, \delta_{111} \sim N(0, \sigma^2)$ represents the regression coefficient. $\epsilon_{00j}, \epsilon_{01j}, \epsilon_{10j}, \epsilon_{11j} \sim N(0, \sigma^2)$ represents the random error term.

Formula (4)–(7) is substituted into Formula (1),

$$AQI_{ij} = \alpha_{00} + \alpha_{01}Isa_{ij} + \epsilon_{00j} + \epsilon_{01j} + \epsilon_{10j} + \epsilon_{11j}$$

(8)

Formula (8) has been sorted out,

$$AQI_{ij} = \alpha_{00} + \alpha_{01}Isa_{ij} + \epsilon_{00j} + \epsilon_{01j} + \epsilon_{10j} + \epsilon_{11j}$$

(9)

Substituting the control variables of 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:

$$AQI_{ij} = \alpha_{00} + \alpha_{01}Isu_{ij} + \alpha_{02}Sda_{ij} + \alpha_{03}Pus_{ij} + \epsilon_{00j} + \epsilon_{01j} + \epsilon_{02j} + \epsilon_{03j}$$

(10)

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

**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 the 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 the *China Environmental Yearbook* in 2016–2019. Stata16.0 is used for data analysis.

**Empirical analysis**

**Multilevel structure test—empty model**

To test whether the data have a multilevel structure, we build an empty model with no explanatory variables. The specific form of the empty model is as follows,

$$AQI_{ij} = \beta_{0ij} + \epsilon_{0ij}$$

(11)

$$\beta_{0ij} = \gamma_{00j} + \epsilon_{00j}$$

(12)

where, $\epsilon_{0ij} \sim N(0, \sigma^2), \epsilon_{0ij} \sim N(0, \sigma^2)$, and $\text{cov}(\epsilon_{0ij}, \epsilon_{0ij}) = 0$. $\sigma^2$ represents the within-group variance. $\sigma^2$ represents the between-group variance. Substituting Formula (12) into Formula (11), a variance analysis model with random effects is obtained:

$$AQI_{ij} = \gamma_{00j} + \epsilon_{0ij} + \epsilon_{1ij}$$

(13)

Estimating Formula (13), we get $\sigma^2 = 44.581, \sigma^2 = 365.426$. The intraclass correlation coefficient (ICC) is $CC(\rho) = \frac{\sigma^2}{\sigma^2 + \sigma^2} = 0.8913$. This shows that approximately 89.13% of the total variability is caused by the...
differences between the research cities, so the multilevel model can be used for analysis.

**Unconditional linear growth model test**

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

\[ \beta_{0ij} = \gamma_{0i} + \varepsilon_{0ij} \]  
(14)

\[ \beta_{1ij} = \gamma_{1i} + \varepsilon_{1ij} \]  
(15)

The curve growth model is as follows,

\[ AQI_{ij} = \beta_{0ij} + \beta_{1ij}T_{ij} + \beta_{2ij}T_{ij}^2 + u_{ij} \]  
(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),

\[ \beta_{2ij} = \gamma_{2i} + \varepsilon_{2ij} \]  
(17)

The unconditional growth model is tested to judge whether to use the linear growth model or curve growth model. According to Formula (1) and Formulas (14) - (17), the calculation results are shown in Table 1.

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 decreases and air quality gradually improves. 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 Fig. 2, the linear growth trajectory is represented by red dots and red lines, and the curve growth trajectory is represented by green dots and green lines. The curve growth trajectory and the linear growth trajectory almost overlap. Once again, Fig. 2 shows that linear growth models should be used.

|                | Linear growth model | Curve growth model |
|----------------|---------------------|--------------------|
| Model          | Model1              | Model2             |
| \( T \)        | -2.649***           | -2.382***          |
|                | (-17.47)            | (-2.77)            |
| \( T^2 \)      | -0.053              |                     |
|                | (-0.31)             |                    |
| cons           | 81.937***           | 81.67***           |
|                | (67.80)             | (55.33)            |
| Wald statistics| 305.16              | 305.3              |
| Observations   | 1144                | 1144               |

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

**Fig. 2** Comparison of fitting results between the linear growth model and curve growth model
Analysis of the improvement of air quality by industrial upgrading

Multilevel structure tests and unconditional linear growth model tests show that the multilayer 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.

Model 3 is the regression result of the mixed panel model, and Model 4 is the regression result of the multilevel growth linear model. Table 2 shows that the AIC and BIC of Model 4 are 7986.026 and 8056.618, respectively, which are smaller than the AIC and BIC values of Model 3, indicating that the multilevel linear model is better than the mixed panel model. In Model 3, as time changes, the AQI value of air quality continues to decrease. With the increase in time by one year, the air quality index decreased by 2.466, and time had a significant impact on air quality. In Model 4, time has a significant impact on air quality, and the air quality index rises by 56.41 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 worsen over time.

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 multilevel linear growth model, an increase in the proportion of the secondary industry will aggravate air pollution (Li 2015; Zhu et al. 2019; Zhang et al. 2020; Xin et al. 2021), but there is a certain degree of differences. 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, or whether the value is large or small, the air quality will not be affected; it will not improve or deteriorate. If the impact of industrial upgrading on air quality is analyzed separately, air quality will not change much.

Pressured by 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 Fig. 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 Fig. 3. Under a 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 increasingly obvious, and the gap in the improvement level has become increasingly larger. At a high level of industrial upgrading, the adjustment of the industrial structure has a greater effect on improving air quality.

The interaction term between industrial structure adjustment and time has a significant impact on air quality. Each

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

|     | 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 |
|     |                   | Isa×Isu -1.011*** (3.5) |
|     |                   | Isa×T -0.996* (1.93) |
|     |                   | Isu×T -8.568*** (3.63) |
|     |                   | Isa×Isu×T 0.151** (1.97) |
|     |                   | Sti -134.654 (-1.12) 140.269*** (3.19) |
|     |                   | Sda 1.156*** (6.62) -0.222*** (3.81) |
|     |                   | Pus 0.002 (0.72) 0.003*** (3.39) |
|     |                   | _cons 108.668* (2.07) -15.144 (-0.16) |
|     |                   | Observations 1144 1144 |
|     |                   | AIC 9876.499 7986.026 BIC 9911.795 8056.618 |

1 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
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 Fig. 4. Figure 4 shows 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. This shows that if the country increases the proportion of the secondary industry, it should also use 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 increasingly larger with the development of time. From the change trend

Fig. 3  Industrial upgrading improves air quality

Fig. 4  Industrial structure adjustment and industrial upgrading improve air quality over time
of the graph, industrial upgrading is more conducive to the improvement of air quality with the change of 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 units. The impact is positive, which is not conducive to the improvement of air quality. This 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.

For every 1 unit increase in science and technology investment, the air quality index increases by 140.269, and the impact is significant. This shows that the output effect of China’s science and technology input only brings about economic growth but does not reduce air pollution. Each increase of 1 unit in the collection of sewage charges will reduce the air quality index by 0.222, and the impact will be significant. This shows that the levy of sewage charges increases the cost of enterprises and makes most enterprises consider the impact on the environment. For every additional unit of public supervision, the air quality index rises by 0.003, and the impact is significant. This shows that the positive effect of public supervision in China has not been brought into play.

**Robustness test**

To ensure the reliability of the research results, a robustness test is now carried out. The dependent variable is changed to \( \text{PM}_{2.5} \), and a multilevel linear growth model is used for estimation. The results are shown in Table 3. From the comparison of Table 3 and Table 2, it can be seen 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**

|          | Mixed panel model | Multilevel linear growth model |
|----------|-------------------|--------------------------------|
|          | Model 5           | Model 6                        |
| \( T \)  | -2.818***         | 52.715***                      |
|          | (-5.87)           | (2.69)                         |
| \( \text{Isa} \) | 0.191***         | 5.679***                      |
|          | (2.63)            | (3.37)                         |
| \( \text{Isu} \) | -10.454          | 13.723                        |
|          | (-1.56)           | (1.10)                         |
| \( \text{Isa} \times \text{Isu} \) | -0.387***       |                                |
|          | (-3.29)           |                                |
| \( \text{Isa} \times T \) | -0.902*         |                                |
|          | (-1.96)           |                                |
| \( \text{Isu} \times T \) | -8.109***       |                                |
|          | (-2.79)           |                                |
| \( \text{Isa} \times \text{Isu} \times T \) | 0.134*          |                                |
|          | (1.96)            |                                |
| \( \text{Sti} \) | -7.922           | 98.213*                       |
|          | (-0.09)           | (2.51)                         |
| \( \text{Sda} \) | 0.785***         | -0.164***                     |
|          | (5.48)            | (-3.16)                        |
| \( \text{Pus} \) | 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                       |

\( t \) or \( z \) statistics are in parentheses, * means significant at the 0.1 level, * * means significant at the 0.05 level, *** means significant at the 0.01 level.

**Research conclusions and countermeasures**

**Research conclusions**

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

The first is that if industrial upgrading is not considered, time will have a significant impact on air quality. This shows that without any measures, the air quality will only worsen over time. However, once the country takes strategic measures of industrial upgrading, industrial upgrading and time will have a significant impact on air quality. This shows that the construction of an 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 over time will inevitably reduce the impact on environmental pollution, which is conducive to air quality improvement.

The second is that the adjustment of industrial structure has a significant impact on air quality. This shows that if the adjustment of the industrial structure only aims at increasing the proportion of the secondary industry, the air quality will worsen. 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 factors will promote the expansion of the proportion
of knowledge- and technology-intensive industries and will be conducive to energy conservation and emission reduction. The third is that industrial upgrading itself has no significant impact on air quality. Even if industrial upgrading is embodied in the replacement of leading industries, and even though these replacements consider environmental pollution, they are all still part of the game between the government and enterprises under government environmental supervision. In regard to specific enterprises, their goals are economic profit and enterprise survival, which ultimately leads to overall industrial upgrading that has little effect on air improvement.

**Countermeasures and suggestions**

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

First, improving the mechanism of sharing for the whole population drives high-quality economic development. Industrial upgrading over 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 population, 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 population. When all people at a higher level no longer pay attention to food and clothing issues but pay attention to quality of life, a high-quality economic develops. High-quality economic development will put environmental protection in a more important position, and the air quality close to residents will be greatly improved.

Second, persisting in green innovation and promotion encourages the industrial sector to move toward the global mid-to-high-end value chain. In the process of industrialization in Western developed countries, the development path of first pollution and then treatment has occurred, and now great importance is attached 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 green concepts. 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, the degree of environmental regulation in various regions should be strengthened, and newly replaced leading industries should be restricted. 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 of China are relatively loose (Han and Huang 2016). The newly established leading industries will not accept social responsibility for the improvement of air quality as a main objective. Only strengthening the degree of environmental regulation in various regions and implementing strict environmental protection laws and regulations will cause a shocking effect on enterprises. The impact on the ecological environment should be considered, especially for newly replaced leading industries, for which restraining economic behavior and increasing social responsibility involve undesirable intangible outputs.

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

**Declarations**

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**Consent to participate** Not applicable.

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**Conflict of interest** The authors declare no competing interests.

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