Study on the effect of income distribution on NOx emission reduction in China's industry: based on threshold regression

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Abstract. This paper uses panel data of 30 provinces in China to study the emission reduction effect of different factors on NOx under different income levels, and focuses on the test of threshold characteristics of each influencing factor based on per capita GDP. The research shows that, on the whole, GDP per capita, population size, energy intensity, industrial structure and environmental regulation intensity have threshold characteristics for NOx emission intensity based on GDP per capita. Therefore, in order to improve NOx emission reduction effectiveness, the government should adopt different regional governance strategies based on the income characteristics of different regions.

1. Introduction

NOx is not only the main substance to form acid rain, but also an important substance to form photochemical smog in the atmosphere. It has great harm to human health and ecological environment. During the 12th Five Year Plan period, environmental protection work focuses on the total amount control and emission reduction of NOx. The 13th Five Year Plan for ecological environment protection further points out that the total emission of NOx will be controlled within 15.74 million tons by 2020, 15% lower than that in 2015. Governments at all levels have increased efforts to control environmental pollution, but affected by the level of economic development, population distribution and other factors, there are great differences in resource utilization rate and NOx pollution contribution among regions [1]. Any unscientific governance pattern will inevitably lead to inefficient governance and repeated governance, and ultimately reduce the effectiveness of environmental protection.

The research on NOx emission is mainly reflected in the following aspects: using emission factors to calculate emission inventory; simulating the spatial distribution of emissions; analyzing the influence of various factors; using remote sensing technology; spatiotemporal analysis is applied to the research; using various indexes to analyze the spatial and temporal distribution characteristics; using LMDI method to decompose the factors [3-6]. The above studies rarely use relevant indicators to quantify the regional differences of NOx, and lack of research on NOx emission reduction effect and regional governance strategy from the perspective of income division. Based on EKC theory, this paper considers the population, energy, industrial structure and policy factors. According to the regional income level, the non-linear adjustment threshold characteristics of NOx emission intensity in high-income areas and low-income areas under different income levels are discussed. Finally, according to the effect of emission reduction in different income regions, combined with the income threshold pattern, the macro and micro countermeasures are given for the implementation of industrial NOx emission reduction measures in eastern, central and western regions and different provinces.
2. Influencing factors analysis and model construction of NOx emission

Based on EKC theory and considering population, energy, industrial structure and policy factors, this paper constructs the determination equation of industrial NOx emission [7-12]:

\[
\ln(n_{o\times i,t}) = \beta_0 + \beta_1 p_{s,t} + \beta_2 e_{i,t} + \beta_3 p_{gdp,t} + \\
\beta_4 (p_{gdp,t})^2 + \beta_5 e_{i,t} + \beta_6 i_{n,d,t} + \epsilon_{i,t}
\]  

(1)

Where: i represents the province, t represents the year; nox is the intensity of NOx emission, and the natural logarithm is taken in the model. In the actual estimation model, ln(nox) and ln(noxp) are used to represent the industrial added value and per capita emission intensity respectively. ps is the population size; ei is the energy intensity; pgdp is the per capita GDP; er is the intensity of environmental regulation; ind is the industrial structure.

This paper empirically tests 30 provinces in China from 2006 to 2015 (considering the continuity and comparability of data, excluding Tibet). Considering that the traditional division of East, middle and West is not completely based on the income level, in order to test the difference of pollution emissions in different income regions, the existing provinces are divided into high-income group and low-income group according to the average ranking of pgdp.

3. Test of NOx emission threshold characteristics based on per capita income

With the reform of economic system and the upgrading of economic structure, the adjustment of many economic variables is gradually changing, which intuitively shows the characteristics of non-linear adjustment, Hansen's threshold regression model is used to judge and identify the threshold characteristics of non-linear adjustment of NOx emission intensity by various factors at different income levels [13]. This paper sets per capita GDP (pgdp) as the threshold variable, and tests the threshold characteristics of industrial structure (ind), environmental regulation (er), population scale (ps) and energy intensity (ei) on industrial added value and per capita NOx emission intensity respectively.

Firstly, the number of thresholds is determined, and then the estimation is carried out under the conditions that there is no threshold, one threshold and two thresholds. After inspection, only the high-income group's impact on per capita emission intensity (ln(noxp)) of population size (ps) passes the nonlinear test, while the high-income group's impact on per capita emission intensity (ln(noxp)) of environmental regulation (er) does not pass the nonlinear test. In the above cases, there is no threshold characteristic based on per capita GDP, so it is not listed. The models in columns (1) to (8) of Table 1 accept the original assumption as a single threshold model, but reject the original assumption as a double threshold model.

| variable | high-income group | low-income group | high-income group | low-income group | high-income group |
|----------|-------------------|------------------|-------------------|------------------|-------------------|
|          | (1) ln(nox) | (2) ln(noxp) | (3) ln(nox) | (4) ln(noxp) | (5) ln(nox) | (6) ln(nox) | (7) ln(noxp) | (8) ln(noxp) |
| ind_1   | 1.5828* | 1.1087** | -2.6849 | -0.4561* | -0.1606** | \(0.0920**\) | 0.1606** | \(-0.7916**\) |
|         | (-2.45) | (2.50) | (-1.40) | (-1.79) | (-3.22) | (-2.84) | (-3.22) | (-2.84) |
| ind_2   | 1.343** | 1.6384** | -3.0849 | -0.9998 | -0.0849** | \(-0.7916**\) | -3.0849** | \(-0.7916**\) |
|         | (-2.86) | (3.79) | (-2.43) | (-0.80) | (-2.43) | (-0.80) | (-2.43) | (-0.80) |
| er_1    | 0.1606** | \(-0.7916**\) | \(-0.7916**\) | \(-0.7916**\) | \(-0.7916**\) | \(-0.7916**\) | \(-0.7916**\) | \(-0.7916**\) |

Table 1. Industrial structure, environmental regulation and population size of the threshold regression results of NOx emissions.
|       | er_2  | ps_1  | ps_2  | pgdp  | (pgdp)^2 | ps   | ei    | er    | ind   | constant term |
|-------|-------|-------|-------|-------|----------|-------|-------|-------|-------|--------------|
|       |       |       |       | 1.0650**  | 2.5184**  | -0.0883 (-1.37) | 0.4334 (1.05) | 2.3248** (5.94) | 0.4634** (7.53) | 6.6664* (11.67) |
|       |       |       |       | 0.4865** (2.46) | 0.4573** (-4.86) | -0.0020 (-0.45) | -0.1578 (-1.32) | 0.446** (-5.08) | -0.0291** (-7.25) | 3.9228** (7.72) |
|       |       |       |       | -0.1614* (-2.24) | -0.2683* (-2.85) | -0.2272 (-0.47) | -0.3120 (-0.66) | -0.3399** (-3.34) | -0.4419 (-0.93) | 4.9739** (2.35) |
|       |       |       |       | 0.345** (-3.34) | 0.3281** (-3.50) | -0.2079 (-1.44) | -0.4133** (-2.19) | -1.5457** (-3.49) | -2.9779** (-2.40) | 6.0900** (11.02) |
|       |       |       |       | 0.5934** (3.49) | 0.7852** (3.00) | 0.6707** (2.67) | 0.8659** (5.06) | 0.8205** (3.26) | 0.7110** (2.86) | 6.5513** (3.11) |
|       |       |       |       | 0.6162* ** (3.49) | 0.7852** (3.00) | 0.5934** (3.49) | 0.7110** (2.86) | 0.8205** (3.26) | 0.7110** (2.86) | 6.5513** (3.11) |
|       | 0.0356** (-6.99) | 0.4655** (7.72) | 0.354** (-6.61) | 0.3454** (-7.38) | 0.3454** (-7.38) | 0.3454** (-7.38) | 0.3454** (-7.38) | 0.3454** (-7.38) | 0.3454** (-7.38) | 0.3454** (-7.38) |
|       | 0.0454 (0.20) | 0.0454 (0.20) | 0.0454 (0.20) | 0.0454 (0.20) | 0.0454 (0.20) | 0.0454 (0.20) | 0.0454 (0.20) | 0.0454 (0.20) | 0.0454 (0.20) | 0.0454 (0.20) |
|       | -0.0394 (-1.6) | -0.0394 (-1.6) | -0.0394 (-1.6) | -0.0394 (-1.6) | -0.0394 (-1.6) | -0.0394 (-1.6) | -0.0394 (-1.6) | -0.0394 (-1.6) | -0.0394 (-1.6) | -0.0394 (-1.6) |
|       | 0.4266** (-7.10) | 0.4266** (-7.10) | 0.4266** (-7.10) | 0.4266** (-7.10) | 0.4266** (-7.10) | 0.4266** (-7.10) | 0.4266** (-7.10) | 0.4266** (-7.10) | 0.4266** (-7.10) | 0.4266** (-7.10) |
|       | 0.3275** (-2.70) | 0.3275** (-2.70) | 0.3275** (-2.70) | 0.3275** (-2.70) | 0.3275** (-2.70) | 0.3275** (-2.70) | 0.3275** (-2.70) | 0.3275** (-2.70) | 0.3275** (-2.70) | 0.3275** (-2.70) |
|       | 0.3520** (-3.76) | 0.3520** (-3.76) | 0.3520** (-3.76) | 0.3520** (-3.76) | 0.3520** (-3.76) | 0.3520** (-3.76) | 0.3520** (-3.76) | 0.3520** (-3.76) | 0.3520** (-3.76) | 0.3520** (-3.76) |

Columns (1) and (3) are the threshold regression results of industrial structure's influence on NOx emission intensity of industrial added value. In the low-income group, the segmented results of industrial structure's influence on emission intensity show that the single threshold value of per capita GDP is 1.185 (ten thousand yuan), which basically proves that the influence effect of industrial structure on emission intensity will change with the change of per capita GDP. However, it failed to pass the 10%
significance level test, so it was impossible to determine the direction and size of the influence within this level; When \( pgdp > 1.185 \), the impact coefficient of industrial structure is \(-3.0849\), which is statistically significant.

Therefore, the sample data of the low-income group can only prove that when the per capita GDP is greater than 1.185, the industrial structure has a significant negative impact on the emission intensity of industrial added value. In the high-income group, the segmented results of the impact of industrial structure on the emission intensity show that the single threshold value of per capita GDP is 4.769 (ten thousand yuan). It is basically proved that the effect of industrial structure on emission intensity will change with the change of per capita GDP. When \( pgdp < 4.769 \), the impact coefficient of industrial structure is \(-1.5828\); When \( pgdp > 4.769 \), the impact coefficient of industrial structure is \(-1.3432\). The coefficients are significant at the level of 5%. Considering different income groups, all provinces in the low-income group have crossed the threshold value of 1.185 at the present stage, so the impact of industrial structure on emission reduction gradually decreases with the increase of per capita GDP, that is, the effect of industrial scale economy shows a decreasing trend.

Columns (2) and (4) are the threshold regression results of industrial structure affecting per capita NOx emission intensity. In the low-income group, the segmented results show that the single threshold value of per capita GDP is 1.145 (ten thousand yuan). When \( pgdp < 1.145 \), the industrial structure has a significant impact on the emission intensity. The effect is negative; When \( pgdp > 1.145 \), the impact coefficient of industrial structure is positive but not significant. Therefore, the sample data of low-income group can only prove that when the per capita GDP is less than 1.145, industrial agglomeration has a significant negative impact on the emission intensity of industrial added value. However, at present, all provinces in the low-income group cross the threshold of 1.145, so it is impossible to determine the direction and size of the impact of industrial structure on the per capita emission intensity of the low-income group. In the high-income group, the segmented results show that the single threshold of per capita GDP is 7.833 (ten thousand yuan), and when \( pgdp < 7.833 \), the impact coefficient of industrial structure is 1.1087, when \( pgdp > 7.833 \), the influence coefficient of industrial structure increases to 1.6384. The coefficients are significant at the level of 5%. It also fully reflects the characteristics that the speed of economic agglomeration is far ahead of the speed of population agglomeration.

Columns (5) and (6) are the threshold regression results of the impact of environmental regulation intensity on the NOx emission intensity of industrial added value. In the low-income group, the single threshold value of per capita GDP is 1.766 (ten thousand yuan). When \( pgdp < 1.766 \), the impact coefficient of environmental regulation intensity is \(-0.0920\), which is statistically significant, Therefore, the sample data of the low-income group can only prove that when the per capita GDP is small. However, at the present stage, all provinces in the low-income group (except Guizhou) have crossed the threshold of 1.766, so it is impossible to determine the direction and size of the impact of environmental regulation intensity on the per capita emission intensity of the low-income group (except Guizhou). When \( pgdp < 5.718 \), the impact coefficient of environmental regulation intensity is \(-0.1606\); When \( pgdp > 5.718 \), the impact coefficient decreases to \(-0.4266\). The coefficients are significant at the level of 1%. In the low-income group, the segmented results show that the single threshold value of per capita GDP is 2.301 (ten thousand yuan). When \( pgdp < 2.301 \), the impact coefficient of environmental regulation intensity is \(-0.7916\), and it is statistically significant. When \( pgdp > 2.301 \), the impact coefficient of environmental regulation intensity is positive, but it is not statistically significant. Therefore, the sample data of low-income group can only prove that when the per capita GDP is less than 2.301, the environmental regulation intensity has a significant negative impact on the industrial added value emission intensity Therefore, it is impossible to determine the direction and magnitude of the impact of environmental regulation intensity on the per capita emission intensity of most provinces in the low-income group at this stage.

Column (8) is the threshold regression result of population size affecting the per capita NOx emission intensity of high-income group. The segmented result shows that the single threshold value of per capita GDP is 5.869 (ten thousand yuan). When \( pgdp < 5.869 \), the impact coefficient of population size is \(-0.3275\); When \( pgdp > 5.869 \), the influence coefficient of industrial structure is \(-0.3520\). The coefficients
are all significant at the level of 1%. In conclusion, the emission reduction effect of population size on per capita emission intensity increases with the increase of per capita GDP, especially in the provinces with per capita income of 5.869 (Shanghai, Tianjin, Beijing, Jiangsu, Zhejiang, Inner Mongolia, etc.) The improvement of population concentration in Guangdong Province is greatly conducive to the improvement of pollution control level.

Table 2. The threshold regression results of the influence of energy intensity on NOX emission intensity. All models accept the original assumption as a single threshold model, but reject the original assumption as a double threshold model. In the low-income group, the single threshold value of per capita GDP is 1.766 (ten thousand yuan), and the influence coefficient of energy intensity increases with the growth of per capita GDP. In the high-income group, the single threshold value of per capita GDP is 4.769 (ten thousand yuan), and the influence coefficient of energy intensity on industrial added value emission intensity increases with the growth of per capita GDP. At present, all provinces in the low-income group (except Guizhou) cross the threshold value of 1.766. The positive effect of energy intensity in low-income group is greater than that in high-income group.

| Explained variable | ei_1         | ei_2         | Threshold type | F value  | Threshold value |
|-------------------|--------------|--------------|----------------|----------|-----------------|
| ln(nox)           | 0.7034***    | 0.8547***    | single threshold | 9.314**  | 4.769           |
|                   | (2.82)       | (4.97)       | double threshold |         |                 |
| ln(nox)           | 0.8112***    | 1.017***     | single threshold | 16.934** | 1.766           |
|                   | (4.04)       | (4.12)       | double threshold |         |                 |
| ln(noxp)          | 0.6657***    | 0.8627***    | single threshold | 15.793*  | 1.766           |
|                   | (3.92)       | (3.55)       |                |          |                 |

Table 2 shows the threshold regression results of the impact of energy intensity on NOX emission intensity. All models accept the original assumption as a single threshold model, but reject the original assumption as a double threshold model. In the low-income group, the single threshold value of per capita GDP is 1.766 (ten thousand yuan), and the influence coefficient of energy intensity increases with the growth of per capita GDP. In the high-income group, the single threshold value of per capita GDP is 4.769 (ten thousand yuan), and the influence coefficient of energy intensity on industrial added value emission intensity increases with the growth of per capita GDP. At present, all provinces in the low-income group (except Guizhou) cross the threshold value of 1.766. The positive effect of energy intensity in low-income group is greater than that in high-income group.

4. Conclusion
On the whole, the population size, energy intensity, industrial structure and environmental regulation intensity of the income group show threshold characteristics based on per capita GDP for NOx emission intensity. At present, for industrial value-added NOx emission intensity, with the growth of income, the emission reduction effect shows a downward trend, only Guizhou is still in the rigid rising period. The emission reduction effect of environmental regulation is not significant in low-income group. For high-income areas, the emission reduction effect of environmental regulation intensity is significant, especially for Shanghai, Tianjin, Beijing, Jiangsu, Zhejiang, Inner Mongolia and Guangdong. The emission reduction effect of industrial structure is significant, especially in low-income areas. The emission reduction effect of population size is significant, especially in high-income areas. Based on the analysis of NOx emission intensity per capita, Shanghai, Tianjin, Beijing, Jiangsu, Zhejiang, Inner Mongolia and Guangdong, whose per capita income exceeds the threshold of (5.869 ten thousand yuan), improving the degree of population agglomeration and expanding the scale of cities are conducive to pollution control, exerting the scale effect and reducing pollution emissions.

Acknowledgement
This paper is one of the phased achievements of the introduction of talents research start-up fund project of Shenyang Aerospace University: The impact of economic agglomeration on energy consumption and environmental development in Liaoning Province (21YB10).

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