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The Threshold Effect of Rationalization of Industrial Structure on Air Quality in Shanxi Province

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Abstract: Shanxi Province is a typical resource-based region. After years of economic transformation, the air quality has been at a low level for a long time. The rationalization of industrial structure can measure the effect of economic transformation and whether it has an important impact on air quality. Therefore, it is necessary to study the non-linear impact that the rationalization of industrial structure has had on air quality at different stages, which is of positive significance for the continuing transformation and upgrading of resource-based regions. This study constructs a threshold regression model based on the panel data of 11 provincial cities in Shanxi Province from 2004 to 2016. The results show that the rationalization of industrial structure had a double threshold effect on air quality under different threshold variables. On the whole, optimizing the rationalization of industrial structure in Shanxi Province can improve air quality, and the improvement effect dropped first, and then began to rise. As a result, the current energy transformation and upgrading process should focus on the rationalization of industrial structure to solve the conflict between air quality and economic development.

Key words: rationalization of industrial structure; air quality; threshold effect; Shanxi Province

1 Introduction

The influence on air quality of the rapid development of China's economy cannot be ignored (Wang and Liu, 2016). In particular, resource-based provinces have been affected by their endowment of resources and industrial structure. The long-term environmental degradation has imposed a negative impact on the health of local people and sustainable development of the regional economy. As a typical resource-based province in China, Shanxi Province is a good representative and its air quality has been at a low level for a long time. Data from ecological environment notice in Shanxi Province in 2018 showed that Shanxi was the most polluted region and its air remained the dirtiest in China. The air quality of 11 provincial cities was lower than the national second level. The impact on environmental quality has become a severe obstacle to high-quality economic development in Shanxi. Figuring out how to further improve the quality and speed of economic development under the premise of ensuring air quality is an urgent problem to be solved. Many scholars have carried out research on the relationships between air quality and economic and social development, and explored various solutions.

Some scholars study air quality from the perspective of urban development. From the perspectives of urbanization level, industrialization level, industrial agglomeration, technological progress, population structure and environmental regulation, the specific influences and laws of different factors on air quality were verified (Wang, 2017; Zhou, 2017; Xu and Zhang, 2018; Wang et al., 2019). Besides, the manifestations of economic development, such as

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economic development scale, urban expansion and population concentration, affect the atmosphere greatly. It is generally believed that there is a close relationship between economic development and air pollution, but economic development cannot spontaneously solve the problem of air pollution. Different studies have arrived at a variety of conclusions because of the differences in research perspectives, sample selection, index system construction and other key factors (Wu et al., 2018).

There is also a close relationship between industrial structure and air quality (Yang et al., 2018). The upgrading of industrial structure can usually improve the utilization efficiency of social resources, thereby helping to improve air quality. At the same time, industrial structure is the key to promoting the coordinated development between urban development, economic development and air quality (Wang et al., 2016; Zhu et al., 2018). Linear regression models and Environmental Kuznets Curves are often applied in studies on the relationship between industrial structure and air quality (Sun et al., 2016; Li and Wang, 2017; Liu et al., 2017). According to most studies, the environmental quality was improved with the upgrading of industrial structure to a certain extent (Xu and Kong, 2014; Cheng et al., 2019), but it was exacerbated by the development of secondary industries (Leng and Du, 2015; Shao et al., 2016); and some important influencing factors have been identified which affect air quality through industrial structure upgrading (Guo and Guo, 2016; Sun and Zhong, 2017; Li et al., 2017; Feng et al., 2018).

The traditional model has been used by scholars to investigate the link between industrial structure and air quality from different angles, however the problem of structural mutation in the influence variables has been ignored. The influence of industrial structure on air quality can be affected by the different states of control variables, so ignoring them works against refining the problem investigation. At present, this is a deficiency of the studies on the industrial structure and air quality in resource-based regions. Taking Shanxi Province as an example, it has experienced twenty years' development in economic structure transformation, however, the effect is not significant. The air quality has been at a low level for a long time, which has seriously restricted the sustainable development of the regional economy. Considering all these issues, this paper discusses the following questions: Does the industrial structure of Shanxi Province have a threshold effect on air quality? If so, what rules must be followed under different control variables? Can we improve air quality from the perspective of industrial structure? To answer these questions, the threshold regression model is applied for analysis of the nonlinear relationship between industrial structure and air quality under different control variables. Considering that the rationalization of industrial structure (RIS) is an effective indicator for measuring the coordination among various industries, which represents the efficiency of resource utilization, this study uses RIS as a substitute indicator for industrial structure. The conclusions can provide a basis for the energy region represented by Shanxi Province to effectively resolve the contradiction between economic development and air quality.

2 Model construction and variable description

2.1 Research methods

For a long time, the coal, coke and iron industries have been the pillar industries in Shanxi Province. As a result, pollution discharge or emission has not been effectively controlled, and the ecological environment has been severely degraded. As an important part of the economic structure, the industrial structure has a more far-reaching impact on air quality than the consumption structure, the distribution structure and the exchange structure. The adjustment of the industrial structure in Shanxi Province has lasted for nearly 20 years. The government has introduced a series of policies to promote the transformation and upgrading of the economic structure, but taken as a whole, the air quality is still at a low level. This paper explores ways to improve air quality from the perspective of the industrial structure, and selects important factors as control variables for studying the influence of the industrial structure on air quality in different situations.

Studying the linear relationships can reveal the connections between the industrial structure and air quality, but this kind of research ignores the influence of the structural mutation of the influencing factors, and the degree of refinement of the relationship disclosed is insufficient. Therefore, a linear regression model cannot satisfy the needs of this study.

The threshold regression model can reveal the nonlinear relationships between the explanatory variable and the explained variable (Kremer et al., 2013), and linear regression in stages can obtain a detailed analysis. So, this study selected the threshold regression model as the main research method to reveal the nonlinear influence of industrial structure on air quality.

The general form of the fixed-effect threshold regression model proposed by Hansen (1999) is as shown in equation (1):

$$\begin{aligned} y_{it} &= \alpha_i + \beta_1 x_{it} I(q_{it} \leqslant \gamma) + \beta_2 x_{it} I(q_{it} > \gamma) + \varepsilon_{it} \\ i &= 1, 2, \cdots, n \end{aligned} \tag{1}$$

where y_{it} is the explanatory variable; x_{it} is a vector consisting of exogenous explanatory variables, which is not related to the disturbance term; q_{it} is a threshold variable; and γ is the threshold to be estimated. $I(\cdot)$ is the indicator function, and when the condition of the indicator function is satisfied, the function takes a value of 1, otherwise it takes a value of 0. ε_{it} is a disturbance term of the independent distribution, and $\varepsilon_{it} \sim N(0, \delta^2)$. α and β are parameters of the function. This is a typical nonlinear regression model, usually estimated by nonlinear least squares, which minimizes the residual sum of squares. On the basis of the above, the threshold value can be extended to multiple values. For a threshold variable, assuming there are two thresholds, the threshold regression model is expressed as equation (2):

$$y_{it} = \alpha_i + \beta_1 x_{it} I(q_{it} \leqslant \gamma_1) + \beta_2 x_{it} I(\gamma_1 < q_{it} \leqslant \gamma_2) + \beta_3 x_{it} I(q_{it} \geqslant \gamma_2) + \varepsilon_{it},\ i = 1, 2, \cdots, n \quad (2)$$

2.2 Data description

2.2.1 Data source

The data used in this paper come from 11 cities of Shanxi Province from 2004–2016. The $PM_{2.5}$ data come from the National Aeronautics and Space Administration (NASA), and other basic economic data are all from the Shanxi Statistical Yearbooks from 2004–2016.

2.2.2 Indicator selection and processing

(1) Core explanatory variables

The core explanatory variable is the rationalization of industrial structure (RIS). RIS can measure the upgrading of industrial structure from the integration of various industries, and can reflect the effect of the optimal allocation and utilization of resources. The measure of RIS can be calculated by the Theil index (Gan et al., 2011). The formula for the Theil index is shown in equation (3):

$$TL = \sum_{i=1}^{n} \left[\left(\frac{Y_i}{Y} \right) \ln \left(\frac{Y_i}{L_i} \Big/ \frac{Y}{L} \right) \right] \quad (3)$$

where Y and L represent the total output value and quantity of labor force of each industry; Y_i and L_i represent the output value and quantity of labor force of industry i. Based on the three industrial output values in Shanxi Province, the Theil index values from 2004 to 2016 of the 11 provinces are calculated which can replace the RIS. According to equation (3), when the economy is in equilibrium, TL is zero. That is, the more reasonable the industrial structure, the closer the TL value is to zero. On the contrary, a greater deviation from zero indicates that the industrial structure is less reasonable.

RIS values are shown in Table 1 below. The RIS of each secondary city in Shanxi Province had changed greatly during the sample period, and presented a state of continuous optimization as a whole. There was a peak in 2008 and almost a trough in 2009, which was mainly due to the impact of the economic crisis. The secondary industry was severely hit by the economic crisis, and the industrial structure in Shanxi province was forced to adjust. As a result, RIS suddenly became much better than before with the overall economic weakness in 2009.

The RIS of Linfen City had long been at the lowest level in Shanxi Province, which was consistent with the lowest air quality. The optimization speed of RIS of Yuncheng was the fastest, and it remained at a high level for Shanxi Province. The RIS of Yangquan City was stable and high, and the layout of the industrial structure was the most reasonable in Shanxi Province, which was consistent with its overall air quality.

(2) Control variables

Taking the influence of other factors into consideration, this study incorporates four types of control variables into the model: sophistication of industrial structure (SIS), economic development scale (ES), urbanization level and infrastructure construction. SIS represents the upgrading of industrial structure, which imposes direct and indirect effects on air quality. There is a nonlinear relationship between economic development and air quality (Guo et al., 2017), and ES is one of the important variables affecting air quality. Air quality is seriously influenced by urbanization, and the urbanization rate is generally believed to have a negative impact on air quality (Liang et al., 2017). The urbanization

Table 1 The RIS value of 11 provincial cities in Shanxi Province from 2004 to 2016

Year	Linfen	Lvliang	Datong	Taiyuan	Xinzhou	Jinzhong	Jincheng	Shuozhou	Yuncheng	Changzhi	Yangquan
2004	0.212	0.289	0.167	0.068	0.264	0.315	0.168	0.220	0.346	0.314	0.036
2005	0.140	0.137	0.050	0.035	0.087	0.144	0.071	0.170	0.263	0.134	0.007
2006	0.119	0.102	0.048	0.005	0.076	0.112	0.100	0.207	0.189	0.108	0.010
2007	0.132	0.101	0.030	0.007	0.063	0.082	0.092	0.164	0.125	0.085	0.009
2008	0.264	0.243	0.183	0.086	0.217	0.233	0.232	0.225	0.293	0.196	0.034
2009	0.121	0.074	0.014	0.027	0.004	0.100	0.066	0.015	0.122	0.113	0.001
2010	0.099	0.092	0.012	0.017	0.018	0.100	0.067	0.020	0.135	0.024	0.001
2011	0.133	0.113	0.013	0.026	0.035	0.102	0.084	0.029	0.129	0.133	0.005
2012	0.141	0.110	0.019	0.028	0.035	0.114	0.101	0.017	0.072	0.195	0.011
2013	0.187	0.182	0.022	0.077	0.051	0.140	0.108	0.037	0.040	0.210	0.043
2014	0.188	0.155	0.026	0.067	0.064	0.068	0.080	0.036	0.028	0.158	0.035
2015	0.199	0.120	0.037	0.089	0.069	0.059	0.067	0.025	0.021	0.109	0.028
2016	0.204	0.144	0.039	0.131	0.085	0.068	0.058	0.032	0.031	0.102	0.029

level in this study is measured by urban-rural population ratio (PR) and per capita electricity consumption (PEC). The level of urban environmental construction has a direct impact on air quality and it is measured by the per capita green coverage (PIC).

(3) Threshold variables

The threshold variables include rationalization of industrial structure (RIS), sophistication of industrial structure (SIS), economic development scale (ES) and urban-rural population ratio (PR). Based on threshold variables set from multiple angles, this study analyzes the impact of RIS on air quality from multiple perspectives.

3 The empirical analysis

3.1 Stationarity test

In order to avoid spurious regression, the stationarity test of data is necessary. The Levin, Lin & Chu test, ADF test and PP test were adopted to test the stationarity of variables, and the results were judged by these three tests. Table 2 shows that the sequence after the first-order difference is stable.

3.2 Threshold effect test

Explained variables, core explanatory variables and threshold variables are taken into account in the threshold regression models. The threshold regression models of the impacts of RIS on air quality are constructed with different thresholds from multiple angles. The specific expression is as follows:

$$PM_{2.5it} = \alpha + \beta_1 RIS_{it} I(RIS \leqslant \gamma) + \beta_2 RIS_{it} I(RIS > \gamma) + \lambda_1 PR_{it} + \lambda_2 PEC_{it} + \lambda_3 PIC_{it} + \lambda_4 SIS_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

The threshold variable in equation (4) is RIS, and a single panel threshold regression model of RIS on air quality is constructed, where α is the constant term of the model, $I(\cdot)$ is the indicator function, β is the coefficient of core explanatory variable, and $\mu_i + \varepsilon_{it}$ is the compound disturbance term. The model constructed with SIS, ES and PR as threshold variables is similar to equation (4).

To verify the rationality and significance of the threshold model, and to determine the number of thresholds accurately, the threshold regression model needs to be tested. During modeling, bootstrapping is adopted to calculate the P value and the F-statistic of the threshold, and the sampling count is 1000. Table 3 shows the results of the threshold effect test.

According to Table 3, the double threshold effect of all variables has passed the significance test, indicating that the impact of RIS on air quality is affected by each threshold variable. Therefore, the double threshold model should be constructed separately.

The stepwise regression is used, and the threshold which has the minimum residual sum of squares is regarded as the estimated value of the threshold. The statistic is constructed by the maximum likelihood method to test the authenticity of the threshold estimates. The test results are shown in Table 4.

According to Table 4, the estimated values of the threshold variables selected in this study have passed the authenticity test under the confidence level of 5%. That is, the estimated value of the threshold is equal to the actual value under the confidence level of 5%. Therefore, the threshold significance and authenticity tests are both passed, and the threshold model can be constructed for further analysis.

Table 2 The results of stationary test

Variable	Levin, Lin & Chu test	ADF test	PP test	Result
Log($PM_{2.5}$)	1.115(0.868)	31.021*(0.096)	32.028*(0.077)	partially stable
Log(SIS)	0.177(0.570)	10.926(0.976)	6.793(0.999)	unstable
Log(RIS)	–5.846***(0.000)	54.754***(0.000)	63.129***(0.000)	stable
Log(ES)	–5.039***(0.000)	22.553(0.191)	46.760***(0.002)	partially stable
Log(PR)	–0.582(0.280)	12.998(0.933)	12.425(0.948)	unstable
Log(PEC)	–3.201***(0.001)	15.001(0.862)	29.269(0.137)	partially stable
Log(PIC)	–2.657***(0.004)	33.833*(0.051)	59.631***(0.000)	stable
Δ Log($PM_{2.5}$)	–12.383***(0.000)	141.249***(0.000)	142.305**(0.000)	stable
Δ Log(SIS)	–10.393***(0.000)	76.653***(0.000)	107.207***(0.000)	stable
Δ Log(RIS)	–14.077***(0.000)	114.197***(0.000)	175.535***(0.000)	stable
Δ Log(ES)	–6.445***(0.000)	45.882***(0.002)	15.155***(0.003)	stable
Δ Log(PR)	–26.177***(0.000)	112.683***(0.000)	115.295***(0.000)	stable
Δ Log(PEC)	–8.339***(0.000)	70.591***(0.000)	79.752***(0.000)	stable
Δ Log(PIC)	–33.544***(0.000)	141.090***(0.000)	140.354***(0.000)	stable

Note: *, **, *** indicate the test is passed at the confidence levels of 10%, 5%, and 1%, respectively.

Table 3 The results of the threshold effect test

Threshold effect	Type of threshold test	Null hypothesis	F-statistic	Prob.	Critical value		
					1%	5%	10%
RIS	Single threshold	linear regression	8.041***	0.002	5.863	3.589	2.537
	Double threshold	Single threshold	3.242*	0.082	6.671	4.022	2.823
SIS (for RIS)	Single threshold	linear regression	8.152***	0.007	7.614	4.121	2.695
	Double threshold	Single threshold	3.959**	0.037	6.779	3.183	2.023
SE (for RIS)	Single threshold	linear regression	7.751***	0.003	6.409	3.841	3.029
	Double threshold	Single threshold	2.916*	0.084	7.732	3.906	2.662
PE (for RIS)	Single threshold	linear regression	5.967**	0.017	6.478	3.714	2.541
	Double threshold	Single threshold	9.051***	0.004	7.543	4.296	2.995

Note: *, **, *** indicate the test is passed at the confidence levels of 10%, 5%, and 1%, respectively. Most triple threshold tests are not significant, and the results are not listed here.

Table 4 Test results of threshold estimates

Threshold variable	Threshold estimates	95% confidence interval
RIS	–0.894	(–2.134,–0.580)
	–0.659	(–0.737,–0.580)
SIS (for RIS)	–0.308	(–0.447,0.258)
	–0.296	(–0.390,–0.214)
ES (for RIS)	1.059	(0.852,1.072)
	1.267	(0.779,1.383)
PR (for RIS)	–0.048	(–0.117,–0.038)
	–0.227	(–0.247,–0.217)

3.3 Results and analysis

This study sets different threshold variables to determine the impact of RIS on air quality. Through the Hausman test and comparison of parameter estimates, the fixed-effect panel threshold regression is selected for empirical analysis. The empirical results are shown in Table 5.

(1) Regression results with RIS as the threshold variable

Taking RIS as the threshold variable, a double-threshold regression model was constructed. The empirical results show that RIS has a negative impact on air quality under the 10% confidence level when the first threshold of RIS is –0.894; and when the threshold is greater, this negative impact is diminished. When achieving the second threshold of –0.659, the impact of RIS on air quality increases. According to the above analysis, the smaller the value of RIS, the higher the degree of rationalization. Therefore, the empirical results indicate that the higher the RIS, the more obvious the improvement of air quality. On the contrary, the worse RIS, the worse the air quality.

According to the threshold, RIS is divided into three phases: the advanced phase (the threshold is less than –0.894), the intermediate phase (the threshold is located between –0.894 and –0.659) and the lower phase (the threshold is greater than –0.659). When RIS is at the lower phase, it imposes a significant improvement on environmental quality. Specifically, when RIS increases by one percentage point, the air quality increases by 0.079 percentage points. When RIS is at the intermediate phase, RIS promotes the improvement of air quality non-significantly. When RIS is at the advanced phase, the RIS improves air quality significantly. As a threshold variable, RIS has a double threshold effect. With the upgrading of industrial structure of Shanxi Province, the RIS will gradually increase, leading to a significant improvement in air quality.

(2) Regression results with SIS as the threshold variable

A double threshold model was constructed with SIS as the threshold variable. When SIS is small (less than –0.308), RIS will have a significant negative impact on air quality, under the 1% confidence level. When RIS increases by one percentage point, the air quality will be improved by 0.119 percentage points. When SIS is between –0.308 and –0.296 (the second threshold), the improvement of air quality caused by RIS will be reduced. When SIS exceeds –0.296, the improvement degree will increase significantly. These trends indicate that with the improvement of SIS, the improvement of air quality caused by RIS is significant, and the improvement effect goes up after initially dropping.

(3) Regression results with ES as the threshold variable

A double threshold model was constructed with ES as the threshold variable. The empirical results in Table 5 show that during the three phases of economic development (threshold values are 1.059 and 1.267, respectively), the impact of RIS on air quality has a significant threshold effect. At this time, the elastic coefficients of the impact of RIS on air quality are –0.086, –0.044, and –0.079 in the three phases, respectively, which indicates a significant improvement on air quality (under a confidence level of 1%). This shows that with the strengthening of economic development in Shanxi Province, the RIS has a continuous significant impact on the improvement on air quality.

(4) Regression results with PR as the threshold variable

A double threshold model was constructed by taking urban-rural population ratio in the urbanization level (PR) as

Table 5 The results of threshold regressions using different threshold variables

Independent variable	Model 1	Model 2	Model 3	Model 4
	Threshold variable-RIS	Threshold variable-SIS	Threshold variable-ES	Threshold variable-PR
SIS	–0.249***(–4.128)	–0.060(–0.789)	–0.188***(–2.962)	–0.258***(–4.313)
ES	0.079(1.577)	0.097*(1.911)	0.252***(3.399)	0.044(0.875)
PR	–0.062(–0.502)	–0.013(–0.102)	–0.044(–0.357)	0.212(1.553)
PEC	–0.077**(–2.064)	–0.111***(–2.956)	–0.097**(–2.594)	–0.085**(–2.271)
PIC	–0.035(–1.111)	–0.003(–0.093)	–0.024(–0.772)	–0.016(–0.513)
RIS_1	–0.039**(–2.418)	–0.119***(–5.366)	–0.086***(–5.438)	–0.159***(–5.5030
RIS_2	–0.007(–0.244)	–0.080***(–5.079)	–0.044***(–2.889)	–0.094***(–5.841)
RIS_3	–0.079*(1.764)	–0.146***(–3.119)	–0.079(–0.834)	–0.154***(–3.671)
R^2	0.660	0.453	0.552	0.574
F-stat	42.25***	48.96***	58.62***	39.28***

Note: *, **, *** indicate the test is passed under the confidence levels of 10%, 5%, and 1%, respectively; The numbers in parentheses indicate t-statistics.

the threshold variable. At the three stages of urbanization level (the threshold values are –0.048 and –0.227, respectively), the impact of the RIS in Shanxi Province on air quality has a significant threshold effect. Increasing RIS will lead to an improvement in air quality, and the improvement decreased at first, and then increased. This indicates that in different stages the RIS will promote the improvement of air quality with the advancement of urbanization in Shanxi Province.

4 Conclusions and discussion

Constrained by the layout of long-term economic development, the ecological environment of resource-based regions has been at a low level for a long time, especially the air quality. Taking Shanxi Province as an example, years of economic transformation and upgrading have improved air quality to some extent, but taken as a whole, air quality has not reached the desired state. Therefore, from the perspective of coordinated development, the economic transformation of Shanxi Province cannot be considered a success. In recent years, poor air quality not only affects the health of residents, but also greatly affects the sustainable development of this resource-rich region. The RIS can not only measure the degree of industrial structure upgrade, but also has an important impact on air quality. Therefore, this study focuses on the RIS and discusses its non-linear influence on air quality. Based on the threshold regression model, the influences of RIS on air quality in different stages are calculated under different control factors. The main conclusions of this analysis are as follows:

(1) The RIS has a double threshold effect on air quality, and the inhibiting effect is affected by its own threshold. After the first threshold, the elasticity coefficient decreases from –0.039 to –0.007, and air quality continues to improve. With the development of RIS, the suppression will continue to improve. The elasticity coefficient of this stage is 0.079, that is, the higher the degree of development of the rationalization of industrial structure, the more obvious the promoting effect on air quality.

(2) Both the SIS and PR have double threshold effects. With the improvement of SIS and PR, RIS will continue to improve the air quality. The empirical results show that the development of SIS and PR can promote the improvement of air quality. Therefore, the promotion of the SIS and PR of Shanxi Province are important ways to improve air quality.

(3) The ES has a double threshold effect. With the expansion of the economic development scale in Shanxi Province, RIS improves air quality. However, there are significant differences in the intensity of the improvement effect at different stages. Therefore, Shanxi Province should reduce the energy consumption per unit of output and promote the high-quality economic development to enhance the improvement of air quality by RIS.

For a long time, the development of industrial structure in Shanxi Province has been unbalanced, which has exerted negative effects on air quality. According to the empirical analysis results, Shanxi Province should promote RIS to resolve the conflict between economic development and environmental quality.

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山西省产业结构合理化对空气质量的门限效应研究

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摘　要： 山西省属于典型的资源型省份，历经多年的经济转型发展，空气质量仍长期处于全国较低水平。产业结构合理化能够对经济转型的效果进行测度，且对空气质量产生重要影响，因此有必要研究不同阶段产业结构合理化对空气质量的非线性影响，这对资源型区域转型升级具有积极意义。本文利用 2004–2016 年山西省 11 个省辖市的面板数据构建门限回归模型展开研究。结果显示，不同的门限变量下，产业结构合理化对空气质量均具有双重门限效应，整体上看山西省产业结构合理化程度的提升能够促进空气质量的改善，改善的效果呈现先降后升的趋势。因此目前的能源转型升级过程中应着重提升产业结构合理化程度以解决空气质量与经济发展之间的矛盾。

关键词： 产业结构合理化；空气质量；门限效应；山西省