Industrial Structure Upgrading, Technological Progress, and Regional Carbon Emission Intensity

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Abstract: At present, China is in a critical period of transformation from high-speed development to high-quality development.Energy conservation and emission reduction conform to the concept of high-quality development in China. The upgrading of industrial structure and technological progress are important factors affecting carbon emission intensity. Based on the provincial panel data from 2010 to 2019, this paper explores the relationship between industrial structure upgrading, technological progress and regional carbon emission intensity from both theoretical and empirical aspects by building a mediation effect model. The results show that the upgrading of industrial structure has a significant inhibitory effect on carbon emission intensity; Technological progress has a significant inhibitory effect on carbon emission intensity; Technological progress plays a part of intermediary effect between industrial structure upgrading and carbon emission intensity.Finally, it puts forward policy suggestions such as reasonably promoting industrial structure adjustment, promoting industrial structure optimization, establishing an effective mechanism to promote technological progress, and tackling environmental pollution from the source.

Keywords: Industrial structure upgrading, Technical progress, Carbon emission intensity.

1. Introduction

Since the reform and opening up, China's economy has developed rapidly. However, with the economic development, the carbon emissions and intensity are also increasing. In 2006, China's total nominal carbon emissions reached 6.099 billion tons, becoming the world's largest carbon emitting country. In 2013, China's per capita carbon emissions reached 7.2 tons, 0.4 tons more than that of the European Union. China is under great pressure to reduce carbon emissions and reduce the intensity of carbon emissions. In 2016, China joined the Paris Climate Agreement and promised to reach carbon peak by 2030 and carbon neutral by 2060. In 2022, the National Two Sessions proposed that "we should do a solid job in carbon peaking, carbon neutralization, optimize the industrial structure and energy structure, and implement the carbon peaking action plan." In this context, it is of great significance to explore ways to reduce carbon emission intensity.

Theory and practice show that the upgrading of industrial structure and technological progress are important factors for the carbon emission intensity of films. On the one hand, the consumption of energy and the degree of dependence of different industries are quite different. The secondary industry is a high energy consumption industry and has a strong dependence on energy. While the secondary industry drives economic growth, it will lead to a lot of carbon dioxide emissions. The tertiary industry is a low energy consumption industry and has a low degree of dependence on energy. Therefore, China's industrial structure needs to be upgraded to reduce energy intensity and carbon emission intensity. On the other hand, technological progress can enable enterprises to use new processes and equipment in the production process, improve the utilization efficiency of fossil energy, and inhibit carbon emission intensity. At present, China is in a critical period of transformation from high-speed development to high-quality development. Promoting energy conservation and emission reduction is in line with the concept of high-quality development in China, while industrial structure upgrading, technological progress and carbon emission intensity are closely related. Therefore, exploring the relationship between the three is of practical significance for promoting carbon emission reduction.

2. Literature References

The research on industrial structure upgrading and carbon emission intensity is relatively rich. Wang Wenju and Xiang Qifeng (2014) found that industrial structure adjustment can effectively reduce carbon emission intensity through research, and its contribution to China's carbon emission reduction goal can reach 60% at most [1]. Wang Shaojian and Huang Yongyuan (2019) put the upgrading of industrial structure into the driving factors of carbon emission intensity. Through research, they found that the upgrading of industrial structure can significantly reduce carbon emission intensity [2]. Some scholars believe that there is a nonlinear relationship between industrial structure upgrading and carbon emissions. He Wenju et al. (2019) empirically studied the relationship between population density, industrial agglomeration and carbon emission intensity based on the perspective of agglomeration economy, crowding effect and spatial effect, and found that the impact of population density, industrial structure and enterprise density on carbon emissions presents a "N" trend [3]. Cheng Yeqing (2013) explored the influencing factors of China's energy consumption carbon emission intensity by using the method of spatial measurement, and found that the industrial structure is an important factor affecting the space-time evolution of China's energy carbon emission intensity [4].

The research on technological progress on carbon emission intensity mainly focuses on three aspects. Some scholars believe that technological progress can reduce carbon emission intensity;Yin Yinggang and Chang Xiangdong (2021) found through theoretical and empirical analysis that progress can reduce carbon emission intensity by promoting industrial structure upgrading [5]. Cheng Yu et al. taking 118 countries around the world as the research object, the analysis of the relationship between technological progress and carbon emission rate shows that scientific and technological innovation can promote the optimization of industrial structure through technological integration, product innovation and other paths, so as to achieve the effect of energy conservation and emission reduction[6].Other scholars believe that technological progress can promote the upgrading of industrial structure and thus contribute to economic development. However, with the improvement of economic development level, the social consumption of energy will increase, which will promote the improvement of carbon emission intensity, namely the "rebound effect" (Jin Peizhen et al., 2014) [7]. Some scholars believe that the relationship between the two is uncertain. Fisher Vanden (2006) believed that due to the "rebound effect", the relationship between technological progress and carbon emission intensity was uncertain [8].

Based on the above literature analysis, most scholars focus on the impact of industrial structure upgrading and carbon emission intensity, as well as the impact of technological progress on carbon emission intensity. Few scholars study industrial structure upgrading, technological progress and carbon emission intensity in the same analytical framework. Industrial structure upgrading and technological progress are closely related, and both will have an impact on carbon emission intensity, Therefore, this paper puts the three into the same analytical framework to explore the relationship between them.

3. Theoretical Mechanism and Hypothesis

3.1. Impact of Industrial Structure Upgrading on Carbon Emission Intensity

The upgrading of industrial structure refers to the process in which the industrial focus gradually shifts from the primary and secondary industries to the tertiary industry. The upgrading of industrial structure is a long and dynamic process. Although the industrialization process of our country has promoted the rapid development of our economy, the secondary industry has a strong dependence on energy, so while the industry is developing rapidly, the carbon dioxide emissions and emission intensity are also increasing. The upgrading of industrial structure can mainly affect the carbon emission intensity in three ways. First, for enterprises, energy, as an important factor of production, can be gradually matched with other factors of production to achieve the best in the process of adjusting the production scale of enterprises, so as to improve the overall synergistic economic benefits, thereby increasing the output of unit energy consumption, improving energy efficiency and reducing the carbon emission intensity. Between different industries, the upgrading of industrial structure will lead to the change of scale proportion. When the industrial structure is transferred from agriculture to industry and service industry, from high energy consumption and low efficiency to low energy consumption and high efficiency, the carbon emission intensity will also change accordingly [9]. Secondly, the upgrading of industrial structure can also be considered as the flow process of different elements within and among different industries in the industrial economy composed of various departments. With the continuous upgrading of the industrial structure, the flow of energy elements from low efficiency sectors to high efficiency sectors has accelerated, thus inhibiting the increase of carbon emission intensity. Thirdly, the upgrading of industrial structure can reduce the dependence of the secondary industry on energy by improving quality and efficiency and reducing costs, thus hindering the improvement of carbon emission intensity. Based on the above analysis, hypothesis 1 is proposed:

Hypothesis 1: Industrial structure upgrading can inhibit the increase of carbon emission intensity in a region.

3.2. Impact of Technological Progress on Carbon Emission Intensity

Technological progress can mainly affect carbon emission intensity through the following two ways. First, from a micro perspective, technological progress can have an impact on carbon emission intensity by improving enterprise productivity and reducing enterprise production costs [10]. For productive enterprises, with the continuous improvement of their technological level, the utilization efficiency of their production factors will be improved, so the amount of factors consumed in the production of a unit product will be reduced, thus inhibiting the increase of carbon emission intensity. On the other hand, the production cost of enterprises will continue to decrease with the improvement of their technological level, which makes it possible for enterprises to develop and utilize clean energy [11], This will help reduce the intensity of carbon emissions. Secondly, from a meso and macro perspective, technological progress can change the supply and demand structure and employment structure of production factors to a certain extent [12], so that labor can be transferred between different industries, improve the spatial fitness of labor, and improve the quality and allocation efficiency of factors, thus promoting the transformation of the driving force of economic development from factor driven to innovation driven. Based on the above analysis, hypothesis 2 is proposed:

Hypothesis 2: Technological progress can inhibit the increase of regional carbon emission intensity.

3.3. Industrial Structure Upgrading, Technological Progress, and Carbon Emission Intensity

The impact of industrial structure upgrading on technological progress can be analyzed from the micro, meso and macro perspectives. From a micro perspective, the upgrading of industrial structure will promote the development of domestic and foreign markets, and enterprises will carry out technological innovation in order to seize market share, thus forming a competitive advantage [13]; From a medium perspective, the upgrading of industrial structure will inevitably lead to inter industry replacement, the traditional industries will change to the advanced direction, emerging industries and high-tech industries will become leading industries, and social investment will also flow to high-tech industries, thus promoting scientific and technological innovation and achievements transformation [14]; From a macro perspective, the upgrading of industrial structure can improve the quality of economic development. In order to promote the upgrading of industrial structure and improve industrial competitiveness, the government will encourage enterprises to carry out independent innovation by formulating industrial policies to create a good environment for technological innovation. Comprehensive reference to

Hypothesis 2 can clarify the relationship between industrial structure upgrading, technological progress and carbon emission intensity. In order to achieve the goal of energy conservation and emission reduction, the industrial structure needs to evolve to an advanced direction, optimize resource allocation, and drive cooperation and competition between regions. This process is bound to be accompanied by the inclination of the flow of innovative resources [15], which is conducive to the improvement of technology level. The driving effect of technological innovation is an important means to transform various strategic resources into productivity in the process of upgrading and changing the industrial structure. It is the endogenous power of the evolution of advanced industrial structure. By promoting the improvement of productivity and product competition, it lays the foundation for opening up new markets and expanding the development of higher level industries, and promotes the formation of a coordinated innovation and development mechanism among regions, so as to truly achieve carbon emission reduction from the source. Based on the above analysis, hypothesis 3 is proposed:

Hypothesis 3: Technological innovation plays a mediating role between industrial structure upgrading and regional carbon emission intensity.

4. Variable Selection and Model Setting

4.1. Indicator Selection and Data Source

4.1.1. Explained variable: carbon emission intensity(CEI)

As for the calculation of carbon emissions, many scholars use energy consumption to indirectly calculate the total carbon emissions. This paper calculates carbon dioxide consumption based on the consumption of coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, and natural gas. The formula is shown in Formula 1. The carbon emission intensity is expressed by the proportion of regional carbon emissions and GDP, as shown in Formula 2.

$$C = \sum_{i=1}^{8} E_i \times SSC_i \times CEC_i \times \frac{44}{12} \quad (1)$$

$$CEI = \frac{C}{GDP} \quad (2)$$

Wherein, C refers to the total carbon dioxide emissions, andE_i, SSC_i,and CEC_i respectively refer to the consumption of energy, conversion coefficient of standard coal and carbon emission coefficient

4.1.2. Core explanatory variable: industrial structure upgrading(IU)

The upgrading of industrial structure refers to the long-term dynamic process in which the industrial structure gradually transits from the primary and secondary industries to the tertiary industry, which is reflected in the increasing proportion of the tertiary industry in the national economy. The upgrading of industrial structure is a long-term dynamic evolution process. In order to comprehensively reflect the upgrading of industrial structure, this paper, referring to Xu Deyun's [16] (2008) practice, assigns different weights to the primary, secondary and tertiary industries respectively, and then calculates the industrial structure upgrading index. The higher the value, the higher the degree of industrial structure upgrading. The specific calculation formula is as follows:

$$IU = I_1 \times 1 + I_2 \times 2 + I_3 \times 3 \quad (3)$$

Among them, IU is the industrial structure upgrading index.I_1, I_2, and I_3 are the proportion of the output value of the first, second, and third industries in the GDP.

4.1.3. Intermediary variable: technological progress(TL)

This paper uses the ratio of internal expenditure of research and experimental development (R&D) funds to regional gross output value to measure technological progress. The higher the index value, the higher the technical level.

4.1.4. Control variables

Energy consumption structure(COV):This paper uses the ratio of coal consumption to total energy consumption to measure the energy consumption structure. The smaller the index is, the higher the coal proportion is, that is, the more reasonable the energy consumption structure is. Coal is a non clean energy. Compared with other energy resources, the utilization efficiency of coal is low, which will bring a lot of carbon dioxide emissions in the process of using coal. Therefore, excessive reliance on coal will promote the increase of carbon emission intensity.

Opening up(ET):This paper uses the proportion of FDI (foreign direct investment) in GDP to measure the degree of opening up. This indicator is a positive indicator. Foreign direct investment can not only increase capital accumulation, contribute to the continuity of production process, but also bring relatively mature production experience and management experience to enterprises or regions, and help promote the improvement of production technology of enterprises or regions. Therefore, making good use of foreign direct investment is conducive to the improvement and innovation of production technology, which is conducive to the adjustment of industrial structure, and thus plays a role in carbon emission intensity.

Degree of government intervention(GOV):This paper uses the proportion of the government's general public budget expenditure in the total regional output value to measure the degree of government intervention. The higher the index value, the stronger the government intervention. The general public budget expenditure of the government includes three costs of science and technology, that is, the cost subsidized by the state to support the development of science and technology. The government can make up for the failure of the science and technology market to a certain extent through intervention. The more funds the government invests in science and technology, the more conducive to the innovation of science and technology, thus affecting the carbon emission intensity.

Human capital(HUM):Following the practice of previous literature, this paper sets the educational years of primary education, junior high education, senior high education and general higher education as 6, 9, 12 and 16 years respectively, and then calculates the average educational years of the labor force by weighting. The level of human capital can improve people's comprehensive quality and make people more aware of energy conservation and emission reduction. People will be more inclined to buy clean products, thus helping to curb the increase of carbon emission intensity.

Table 1. Variable Description

Variable Type	Variable code	computing method
Interpreted variable	CEI	Calculated according to Formula (1) and (2)
Core explanatory variables	IU	Calculated according to formula (3)
Intermediary variable	TL	Internal expenditure of R&D funds/GDP
control variable	COV	Coal consumption/total energy consumption
	ET	FDI/GDP
	GOV	Government general public budget expenditure/GDP
	HUM	Average years of education

4.1.5. Data source

This paper uses panel data from 30 provinces from 2010 to 2019 for modeling analysis (Hong Kong, Macao, Taiwan and Tibet are partially missing, and will be excluded). All data in this paper are from China Statistical Yearbook, China Energy Statistical Yearbook, China Economic Network database and WIND database. In order to eliminate the influence of heteroscedasticity, all variables are treated logarithmically.

4.2. Model Settings

Firstly, a benchmark regression model is built to test the effect and extent of industrial structure upgrading, technological progress and other control variables on carbon emission intensity. The model is shown in model(4).

In order to test whether there is intermediary effect of technological progress in the process of industrial structure upgrading affecting carbon emission intensity, this paper uses the research of Wen Zhonglin (2006) for reference to build an intermediary effect model[17]. As shown in Equations 5 to 7, $\alpha_1, \alpha_2,$ and α_3 are constant terms; Control indicates the control variable; γ_j are the coefficient of each control variable. $e_1, e_2,$ and e_3 are residual;The coefficient β_1 of Formula 5 is the total effect of industrial structure upgrading on carbon emission intensity; The coefficient β_2 of Formula 6 shows the effect of industrial structure upgrading on technological progress of intermediary variable; The coefficient β_3 of Formula 7 represents the direct effect of the upgrading of the independent variable industrial structure on the carbon emission intensity after controlling the influence of the intermediary variable technological progress; The coefficient β_4 represents the effect of intermediate variable technological progress on carbon emission intensity after controlling independent variable industrial structure upgrading; The mediation effect is the product of β_2 and β_4.

$$\mathrm{LNCEI}_{it} = \delta_0 + \delta_1 \mathrm{LNIU}_{it} + \delta_2 \mathrm{LNTL}_{it} + \sum_j \gamma_j \,\mathrm{Control} + \varepsilon_{it} \quad (4)$$

$$\mathrm{LNCEI}_{it} = \alpha_1 + \beta_1 \mathrm{LNIU}_{it} + \sum_j \gamma_j \,\mathrm{Control} + e_1 \quad (5)$$

$$\mathrm{LNTL}_{it} = \alpha_2 + \beta_2 \mathrm{LNIU}_{it} + \sum_j \gamma_j \,\mathrm{Control} + e_2 \quad (6)$$

$$\mathrm{LNCEI}_{it} = \alpha_3 + \beta_3 \mathrm{LNIU}_{it} + \beta_4 \mathrm{LNTL}_{it} + \sum_j \gamma_j \,\mathrm{Control} + e_3 \quad (7)$$

Where: i represents the time, and t represents the individual province; Represents the random disturbance term, and the meaning of other variables is described above.

5. Empirical Analysis

5.1. Descriptive statistics

Table 2 shows the descriptive statistical results of each variable. It can be seen from Table 2 that the maximum value of China's carbon emission intensity is 2.015, the minimum value is -0.945, and the standard deviation is 0.633. This shows that there is a large gap in carbon emission intensity in different regions of China, which may be related to the industrial structure, energy consumption structure and other factors in each region. The maximum value of China's industrial structure upgrading is 1.043, the minimum value is 0.758, and the standard deviation is 0.051. It can be seen that there are differences in industrial structure upgrading in different regions of China, but the differences are small. The maximum value of China's technological progres is -2.765, and the minimum value is -5.684. The standard deviation is 0.589. It can be seen that there are large differences in the level of technological progress in different regions of China.

Table 2. Descriptive Statistical Results of Variables

variable	Observations	average value	standard deviation	minimum value	Maximum
LNCEI	300	0.659	0.633	-0.945	2.015
LNIU	300	0.865	0.051	0.758	1.043
LNTL	300	-4.272	0.589	-5.684	-2.765
LNCOV	300	-0.359	0.098	1.911	2.548
LNET	300	-4.325	1.101	-9.181	-2.531
LNGOV	300	-1.479	0.379	-2.246	-0.465
LNHUM	300	2.201	0.098	1.912	2.548

5.2. Multicollinearity test

In order to avoid the impact of multicollinearity on the regression results, this paper first conducts a correlation test on each explanatory variable. The results show that the correlation coefficient between the explanatory variables is below 0.6, indicating that the correlation between the explanatory variables is not very strong. Then calculate the variance expansion factor of each explanatory variable, as shown in Table 3, the variance expansion factor of each explanatory variable is less than 10, indicating that there is no multicollinearity.

Table 3. Variance Expansion Factor

variable VIF	**LNTL**	**LNIU**	**LNHUM**
	4.29	3.48	2.72
	LNGOV	**LNCOV**	**LNET**
	2.50	1.96	1.94

5.3. Benchmark regression

First, this paper estimates the relationship between the variables of the benchmark model and carbon emission intensity using the panel model, as shown in Table 4 and 5. Model I is a fixed effect model, and model II is a random effect model. According to the Hausman test, this paper finally chooses a fixed effect model. According to the regression results of the fixed effect model, the upgrading of the industrial structure can significantly curb the intensity of carbon emissions. This is because with the continuous upgrading of the industrial structure, the proportion of the tertiary industry in the national economy is gradually increasing. The tertiary industry has the characteristics of low energy consumption and high added value. It consumes less energy and emits less carbon dioxide per unit output; In addition, with the continuous upgrading of the industry, energy resources gradually flow to efficient and low energy consumption production departments, reducing energy consumption and carbon dioxide emissions. Therefore, the upgrading of the industrial structure can significantly curb the intensity of carbon emissions.

Technological progress can significantly inhibit the intensity of carbon emissions. Economic growth depends on continuous innovation of technology, and economic growth will further lead to an increase in total energy consumption. The increase in total energy consumption needs the allocation of market mechanisms, so that energy flows between different economic entities. If energy flows from low technology production sectors to high-tech production sectors, it will inhibit the intensity of carbon emissions [18].

In terms of control variables, the energy consumption structure can significantly promote the enhancement of carbon emission intensity. The energy consumption structure is measured by the proportion of coal consumption in the total energy consumption. Coal is a non clean energy, which will produce a lot of carbon dioxide emissions in the process of coal consumption. The average value of China's energy consumption structure is 0.728, and the maximum value is 0.941, which shows that China's coal consumption accounts for a large proportion, Economic growth depends on coal consumption to a certain extent, so the energy consumption structure can promote carbon emission intensity. The degree of opening up has significantly promoted the increase of carbon emission intensity, which may be because the increase of opening up has made some foreign highly polluting enterprises transfer to regions with weak environmental regulation intensity in China, or foreign capital mainly flows to some high energy consumption and high pollution enterprises in China, thus significantly promoting the carbon emission intensity. From the regression results, human capital can significantly inhibit the increase of carbon emission intensity. On the one hand, the improvement of human capital can promote energy conservation and emission reduction from the micro level by improving people's comprehensive quality and enhancing people's awareness of energy conservation and emission reduction and environmental protection; On the other hand, the rapid accumulation of human capital is conducive to promoting regional technological innovation. Through scientific and technological innovation and achievement transformation, the enterprise's production cost is reduced and the efficiency of green economy development is comprehensively improved, which helps to curb the increase of carbon emission intensity.

Table 4. Benchmark Regression Results(fixed effect)

Explanatory variable	**Model I (fixed effect)**	
	Coef.	**St.Err**
LNIU	-4.665***	0.807
LNTL	-0.292**	0.112
LNCOV	0.311***	0.055
LNET	0.049*	0.025
LNGOV	0.071	0.145
LNHUM	-0.790**	0.337
Constant	5.613***	1.302
N	300	
R^2	0.740	

Table 5. Benchmark Regression Results(random effects)

Explanatory variable	**Model II (random effects)**	
	Coef.	**St.Err**
LNIU	-4.684***	0.799
LNTL	-0.291***	0.107
LNCOV	0.308***	0.056
LNET	0.048**	0.024
LNGOV	0.081	0.123
LNHUM	-0.705**	0.322
Constant	5.457***	1.279
N	300	
R^2	0.740	

5.4. intermediary effect test

In this paper, formula(5)□(6)□(7)are tested step by step. The specific test steps are as follows: Step 1: Check whether the coefficient is significant. If it is significant, there may be a mediation effect, and the upgrading of industrial structure has an impact on carbon emission intensity. The second step is to test the coefficients and, if they both are significant, there is a significant intermediary effect, that is, the upgrading of industrial structure can reduce the carbon emission intensity by promoting technological progress. The third step is to test the coefficient. If it is significant, the direct effect is significant. If it is not significant, there is only part of the intermediary effect.

The table 6 reports the regression results of the intermediary effect of industrial structure upgrading on carbon emission intensity. The results of model (1) show that the estimated coefficient in equation (5) is -5.392, which is significant at the 1% confidence level, indicating that the upgrading of industrial results can significantly reduce the intensity of carbon emissions. Hypothesis 1 is verified. This is because, with the upgrading of the industrial structure, energy efficiency gradually flows to the production sector with high energy consumption and low efficiency to the production sector with low energy consumption and high efficiency, reducing the intensity of energy consumption, thereby inhibiting the increase of carbon emission intensity.

Model (2) and model (3) respectively verified the coefficient sum in equation (6) and equation (7), and the result shows that the estimated value is 2.493, which is significant at the 5% confidence level, indicating that the upgrading of industrial structure can significantly promote technological progress. The estimated value is -4.665, which is significant at the 1% confidence level. Both and significantly indicate that the intermediary effect is significant, that is, the upgrading of industrial structure reduces the intensity of carbon emissions by promoting technological progress, which verifies Hypothesis 2 and Hypothesis 3. The estimated value of is -4.665, which is significant at the 1% confidence level, indicating that the direct effect of industrial structure upgrading on carbon emission intensity is significant, and technological progress partially mediates the impact of industrial structure upgrading on carbon emission intensity. According to the regression results, the total effect of industrial structure upgrading on carbon emission intensity is -5.392, the direct effect is -4.665, the intermediary effect is -0.728, and the amount of intermediary effect is 13.5%.

Table 6. Mediation effect test

Explanatory variable	(1)	(2)	(3)
	LNECI	LNTL	LNECI
LNIU	-5.392*** (-7.35)	2.493** (3.39)	-4.665*** (-5.78)
LNTL			-0.292* (-2.60)
LNCOV	0.292*** (4.58)	0.0646 (1.32)	0.311*** (5.62)
LNET	0.0325* (2.01)	0.0561* (2.27)	0.0489* (1.99)
LNGOV	0.0833 (0.53)	-0.0410 (-0.28)	0.0713 (0.49)
LNHUM	-1.245** (-3.35)	1.558*** (5.06)	-0.790** (-3.42)
Constant	8.431*** (7.24)	-9.653*** (-11.84)	5.613*** (4.31)
N	300	300	300
F	39.21***	16.34***	41.97***
R^2	0.7152	0.4149	0.7404

6. Conclusion and Policy Suggestions

Based on the analysis of the impact mechanism of industrial structure upgrading and technological progress on carbon emission intensity, this paper uses the provincial panel data from 2010 to 2019 to build a mediation effect model, and empirically tests the impact of industrial structure upgrading and technological progress on carbon emission intensity. The research finds that: (1) industrial structure upgrading has a significant inhibitory effect on carbon emission intensity; (2) Technological progress has a significant inhibitory effect on carbon emission intensity; (3) Technological progress plays a part of intermediary role in the process of industrial structure upgrading affecting carbon emission intensity. The intermediary effect is 13.5%, indicating that industrial structure upgrading can have a positive impact on carbon emission reduction by promoting technological progress. Based on the above conclusions, this paper proposes the following policy recommendations:

Firstly,reasonably promote the adjustment of industrial structure and promote the optimization of industrial structure. In terms of the extent of industrial structure adjustment, we should gradually adjust the industrial industries with more serious pollution, and gradually increase the proportion of the tertiary industry with less energy consumption. In terms of the quality of industrial structure adjustment, it is necessary to accelerate the transformation of industrial structure, promote the continuous aggregation of resource elements to high productivity industries with high added value and low energy consumption, and contribute to high-quality economic development. In addition, the application of clean energy should cover industries with high pollution and high energy consumption. At the same time, the government should encourage enterprises to vigorously develop clean energy, gradually get rid of dependence on non clean energy, and reduce carbon emission intensity.

Secondly,establish an effective mechanism to promote technological progress and tackle environmental pollution from the source. The government should increase policy preference and support for scientific and technological innovation, encourage and advocate enterprises to increase investment in research and development, improve the transformation efficiency of scientific and technological innovation achievements, pay attention to the use value of scientific and technological research and development achievements, and give consideration to environmental protection, green and commercial values. Technological progress can solve the problem of environmental pollution from the source. In order to improve the efficiency of technological innovation, we should strengthen the introduction of cutting-edge technology and talents, and form a long-term mechanism of technology driven development.

Thirdly, form an effective path for technological progress to promote the upgrading of industrial structure and thus reduce carbon emission intensity. Technological progress can reduce carbon emission intensity by promoting industrial structure upgrading. All regions should try their best to develop high-tech industries, or transform the energy consumption structure of the secondary industry through technological innovation, which will play a positive role in promoting the upgrading of the industrial structure, thus promoting carbon emission reduction.

The manuscript should include a conclusion. In this section, summarize what was described in your paper. Future directions may also be included in this section. Authors are strongly encouraged not to reference multiple figures or tables in the conclusion; these should be referenced in the body of the paper.

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References

[1] Wang Wenju, Xiang Qifeng. Evaluation of China's Industrial Restructuring and Energy Saving and Emission Reduction Potential [J]. China Industrial Economy, 2014 (01): 44-56

[2] Wang Shaojian, Huang Yongyuan. Spatial spillover effect and driving factors of China's urban carbon emission intensity [J]. Journal of Geography, 2019, 74 (06): 1131-1148.

[3] He Wenju, Zhang Huafeng, Chen Xiongchao, Yan Jianjun Empirical Study on China's Provincial Population Density, Industrial Agglomeration and Carbon Emission -- From the Perspective of Agglomeration Economy, Congestion Effect and Spatial Effect [J]. Nankai Economic Research, 2019 (02): 207-225

[4] Cheng Yeqing, Wang Zheye, Zhang Shouzhi, Ye Xinyue, Jiang Huiming. Spatial measurement of carbon emission intensity of China's energy consumption and its influencing factors [J]. Journal of Geography, 2013, 68 (10): 1418-1431.

[5] Yin Yinggang always faces east Scientific and technological innovation, industrial structure upgrading and regional carbon emission intensity - empirical analysis based on spatial econometric model [J]. Finance and Economy, 2021 (12): 40-51

[6] Cheng Yu, Sun Yixuan, Wang Xinjing, Yin Jianzhong. Research on the impact of global scientific and technological innovation on carbon productivity and countermeasures [J].

China's Population, Resources and Environment, 2019, 29 (09): 30-40

[7] Jin Peizhen, Zhang Yabin, Peng Xing The double-edged effect of technological progress in carbon dioxide emission reduction -- based on empirical evidence from 35 Chinese industries [J]. Science of Science Research, 2014, 32 (05): 706-716

[8] FISHER-VANDEN K，EFFERSON G H，JINGKU M，et al.Technology development and energy productivity in China. Energy economics, 2006, 28 (5-6): 690-705.

[9] Yu Zhiwei, Fan Yaping, Luo Hao. Research on the Impact of China's Advanced Industrial Structure on Carbon Emission Intensity [J]. East China Economic Management, 2022,36 (01): 78-87

[10] Yin Yinggang always faces east Scientific and technological innovation, industrial structure upgrading and regional carbon emission intensity - empirical analysis based on spatial econometric model [J]. Finance and Economy, 2021 (12): 40-51

[11] Zhong Maochu, Zhao Tianshuang. Carbon productivity and industrial structure adjustment from the perspective of dual carbon goals [J]. Nankai Journal (Philosophy and Social Sciences Edition), 2021 (05): 97-109

[12] Sun Liwen, Li Yifan, Ren Xiangwei. Industrial structure upgrading, technological innovation and carbon emissions - a regulated intermediary model [J]. Technical Economy, 2020, 39 (06): 1-9

[13] Li Jing, Li Xiaoping, Hao Liangfeng. The impact of dual environmental regulation on carbon emission intensity under the constraint of technological innovation [J]. China's Population, Resources and Environment, 2021,31 (09): 34-44

[14] Zhong Maochu, Zhao Tianshuang. Carbon productivity and industrial structure adjustment from the perspective of dual carbon goals [J]. Nankai Journal (Philosophy and Social Sciences Edition), 2021 (05): 97-109

[15] Zhao Fan, Luo Liangwen. The impact of industrial agglomeration in the Yangtze River Economic Belt on urban carbon emissions: heterogeneity and mechanism [J]. Reform, 2022 (01): 68-84

[16] Xu Deyun. A theoretical explanation and verification of the determination and measurement of industrial structure upgrading form [J]. Financial Research, 2008 (01): 46-49

[17] Wen Zhonglin, Zhang Lei, Hou Jietai. Mediated regulatory variable and regulated intermediary variable [J]. Journal of Psychology, 2006 (03): 448-452

[18] Pan Xiongfeng, Peng Xiaoxue, Li Bin. Market distortion, technological progress and energy efficiency: policy options based on provincial heterogeneity [J]. World Economy, 2017, 40 (01): 91-115.