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The impact of the pilot program on industrial structure upgrading in low-carbon cities

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ABSTRACT

The pilot program of low-carbon cities is of great significance for China's overall economic and social development. The construction of low-carbon cities contributes to adjusting the industrial structure, optimizing the energy structure and accelerating institutional reforms. Using the panel data of 285 prefecture-level cities during 2006–2015, this paper takes the pilot program of low-carbon cities as a quasi-natural experiment to detect the impact of the pilot program on industrial structure upgrading and its possible mechanism. The results reveal that the construction of low-carbon cities displays a positive impact on industrial structure supererogation while it has little effect on industrial structure rationalization. Ventilation coefficient is regarded as an instrumental variable to address endogenous problems. The conclusions are still tenable after a series of robustness tests. Mechanism analysis shows that the pilot program can bolster industrial structure supererogation via technological innovation and the reduction of the proportion of high-carbon industries. The regional heterogeneity analysis indicates that the influence of the pilot program on the industrial structure supererogation in the central and western areas is more positive than that in the eastern area, whereas the impact of the pilot program on the industrial structure rationalization is not significant in the three areas. The heterogeneity analysis of environmental law enforcement indicates that the pilot program can more obviously bump up the industrial structure supererogation in cities with strong law enforcement intensity. The impact on the industrial structure rationalization is not evident in cities with weak law enforcement intensity, but the industrial structure rationalization is significantly improved in cities with strong law enforcement intensity. This paper provides insights for realizing the integrated development of low-carbon cities and industrial structure upgrading.

1. Introduction

Since the reform and opening up, Chinese industry has generated remarkable economic dividends, with the average annual growth rate of industrial added value as high as 11.5%. Although the industrial scale is rapidly expanded, the extensive development model has not fundamentally changed. This model also breeds environmental problems such as air pollution, smog and climate change, which threatens China's sustainable economic development and people's quality of life. These problems has not allowed China to wait for an unknown inflection point in the environmental Kuznets curve. Appropriate intervention is required to achieve a green growth model. To combat climate change, Chinese government has vigorously promoted green low-carbon development and issued the *Notice on Conducting the Pilot Program of Low-Carbon Provinces and Cities* in July 2010. The first pilot areas include five provinces and eight cities. In November 2012, *Notice by government on Launching the Pilot Program of the Second Group of Low-Carbon Provinces and Cities* was announced. It groups 29 provinces and cities.

Environmental regulation is an essential instrument to overcome environmental problems and adjust industrial structure. China's economic development has entered a new era characterized by the fact that the economy has shifted from a stage of rapid growth to a stage of high-quality development. Continuous

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structure adjustment, especially the adjustment of industrial structure, is a prerequisite for China's economic growth and high-quality development. Currently, China is undergoing rapid industrialization and urbanization. High-carbon industries are the leading industries underpinning national economic development. Therefore, it is urgent to adjust and optimize the industrial structure in order to reduce energy consumption in the production or CO_2 emission. As an important policy tool to improve the ecological environment, can the pilot program of low-carbon cities promote the upgrading of industrial structure so as to realize the integrated development of low-carbon cities and industrial structure upgrading?

The public concern is that the government's strict environmental regulation may impede China's economic development and slow down the upgrading of industrial structure. Theoretically, environmental regulation may impose additional costs of emission reduction and pollution control on enterprises, damage their productivity and market competitiveness, thus restraining the transformation and upgrading of industrial structure (Ambec et al., 2013; Guo et al., 2019). However, plenty of scholars are optimistic about stringent environmental regulation. Porter believed that appropriate environmental regulation can produce "innovation compensation" for enterprises, develop green technologies, processes and products, which can partially or completely offset the costs caused by environmental regulation, and then improve technological innovation and competitiveness of enterprises (Porter and van der Linde, 1995; Yang et al., 2019). Based on this logic, the industrial structure is ultimately upgraded (Sun, 2019). Moreover, under the constraints of environmental regulation, the pollution control strategy of enterprises will decrease the investments in energy-intensive and high pollution production, which results in the shift of production resources from high pollution and energy-intensive sectors to low pollution and low-energy sectors (Popp and Newell, 2012; Aghion et al., 2013).

Does China's policy of pilot low-carbon cities improve the environmental quality at the expense of inhibiting industrial structure upgrading? Or realize the double dividend of environment and economy? Furthermore, what mechanisms will the pilot program of low-carbon cities affect the upgrading of industrial structure? A clear understanding of above issues is favorable to clarifying the relationship between environmental policies and industrial structure transformation. The evaluation of the effect of the policy is also of great practical significance to the revision and improvement of China's environmental policies and the transformation of economic growth model. There are two main difficulties in evaluating the impact of environmental regulations on industrial structure upgrading. First, environmental regulations and industrial structure upgrading are endogenous. On one hand, environmental policies implemented in the region and the level of industrial structure are mutually affected. On the other hand, individual unobservable heterogeneity and macroeconomic trends can influence economic performance. These omitted variables will lead to the estimation errors of the model (Cai et al., 2016). second, most of existing studies have used such proxy indicators as pollution emissions, pollution discharge fees, environmental pollution expenditures (Guo and Zhang, 2015; Apte et al., 2018). They are not only related to the environmental regulation intensity, but affected by factors like corporate pollution behaviors, local environmental supervision as well. Consequently, it is difficult to attribute changes in pollution emissions, pollution discharge fees and environmental pollution expenditures to the adjustment of environmental regulation. To tackle the above problems, Hering and Poncet (2014), Greenstone and Hanna (2014), Guo and Zhang (2015) used the natural experiment method to construct the Differences-in-Differences (DID) model to conduct in-depth empirical research on the economic performance caused by environmental regulation. This method is gradually developed into one of the most popular methods in the arena of policy evaluation.

This paper took the first pilot program of low-carbon cities in China as a quasi-natural experiment, and employed DID method to evaluate the impact of the pilot program on the upgrading of China's industrial structure. Among the 285 prefecture-level city samples in this paper, 115 cities have been approved to build low-carbon cities by 2013, which served as a fine quasi-natural experiment. Specifically, in our sample, 115 low-carbon pilot cities constituted the treatment group, and the other 170 prefecture-level cities naturally belonged to the control group. The DID method was adopted to remove the regional unobservable variables that do not change with time (i.e. economic basis, natural conditions, etc.). Meanwhile, the detailed geographic location information in the data was utilized to control a series of macro-economic indicators at the city-year level before and after the pilot, further reducing the estimation errors caused by omitted variables.

2. Literature review and policy background

2.1. Literature review

The upgrading of industrial structure is a dynamic process in which the internal resource allocation of industrial structure is continuously reasonable and the industrial efficiency is continuously improved that is coordinated with the internal and external environments of industrial development based on the characteristics of regional resource endowment (Chen et al, 2016). The industrial structure upgrading is the result of economic development to a certain stage. Extant literature has divided the evolution of China's industrial structure upgrading into three stages, namely, the priority development stage of heavy industry driven by material factors from 1949 to 1977, the coordinated development stage of industrial structure driven by material factors from 1978 to 2010, and the transformation and upgrading stage of industrial structure driven by innovation after 2010 (Sun, 2019). The factors such as the society's demand (Krammer, 2015), technological innovation (Kraftova et al., 2016; Kergroach, 2019), trade openness (Chen et al, 2016) and institutional reform (Han et al., 2017) can affect the industrial structure upgrading.

There were few studies on the impact of environmental regulations on the upgrading of industrial structure. But there were mainly two types of literature closely related to it. The first stream of literature which was the theoretical basis of the relationship between environmental regulation and industrial structure upgrading mainly focuses on the relationship between environmental regulations and economic performance. The first view was that environmental regulation hindered economic development, i.e. "the theory of compliance cost", which insisted that environmental regulation would increase the cost of pollution control and crowd out the investments used for production or technological innovation, thus causing the decline of corporate performance and hampering technological innovation (Yang et al., 2011). Therefore, the government's environmental regulation policies would bring down productivity and economic growth (Ambec et al., 2013). On the basis of this theory, Guo et al. (2019) find out that there was a conflict between environmental regulations and the development of pollution-intensive industries. Several scholars held the opposite view that environmental regulation stimulated economic development, namely "Porter hypothesis". Porter and van der Linde (1995) conducted case analysis and found that appropriate environmental regulation could generate "innovation compensation" for enterprises, such as green technologies, process and products, which might enhance economic performance and corporate competitiveness (Lanoie et al., 2008; Yang et al., 2011; Popp and Newell, 2012; Aghion et al.,2013). Arik (2009), and Suphi (2015) used the data from developed countries including the United States, Germany and concluded that environmental regulations have promoted the upgrading of industrial structure.

Additionally, there was a stream of literature aiming to evaluate the efficacy of the policy of low-carbon cities. Low-carbon technologies played an increasingly prominent role in economic development. The developed cities in the globe regarded building low-carbon cities as an vital way to strengthen the competitiveness of cities and even countries (Hamamoto, 2006). Low-carbon construction was a common and important measure to check air pollution and improve residents' well-being. The literature investigating a low-carbon city was largely based on the background of developed countries (Ellison et al., 2013; Wolff, 2014; Gehrsitz, 2017). Wolff (2014) and Gehrsitz (2017) used economic empirical methods to examine the effect of low-carbon city policy after solving endogenous problems. Wolff (2014) adopted the DID method to evaluate the impact of low-carbon zone policies implemented in Europe in recent years on regional air quality. Gehrsitz (2017) also utilized the DID to explore the impacts of German low-carbon policy on air quality and infant mortality. The above studies found that the low-carbon policy has significantly improved local air quality and reduced infant mortality in Europe. It is noted that the pilot program of low-carbon cities has been implemented in China for many years. A few studies focus on the relationship between this policy and environmental treatment. Lin et al. (2014) and Chay et al. (2016) examined the environmental performance of low-carbon cities from the aspects of carbon emission level and carbon emission intensity. Cheng et al. (2019) proved that low-carbon pilot cities significantly increased green total factor productivity by using the prefecture-level panel data in 2007–2016. The pilot program of low-carbon cities is not only a major strategy for China's socioeconomic development, but also a great opportunity to speed up the transformation of the economic development model and the adjustment of economic structure. However, at present, there is scanty literature examining the impact of this policy on the upgrading of industrial structure.

2.2. Policy background

Carbon emissions from human activities are the main cause of climate change. The economic growth of China's cities is accompanied by increasing energy consumption and greenhouse gas emissions. In 2009, China's urban energy consumption accounted for more than 60% of the national total. To address climate change, all mankind must shoulder the shared responsibility of reducing carbon emissions. Chinese government, actively involved in global climate governance, has proposed a binding emission reduction target: China's carbon emissions fall by 40–45% by 2020 compared with 2005 and by 60–65% by 2030. Subsequently, the local governments have taken the initiative to implement the central government's decisions. In 2010, the central government announced the *Notice on Conducting the Pilot Program of Low-Carbon Provinces and Cities* (abbreviated as "Notice"), and launched two groups of pilot provinces and cities. The first group was initiated in 2010, including 5 provinces and 8 other cities (in total of 82 cities). The second group was launched in 2013, including Hainan province and 28 other cities (in total of 33 cities). Fig. 1 plots the distribution of pilot regions. In 2010, pilot low-carbon cities accounted for about 54.16% of the country's total carbon emissions. During the 12th Five-Year Plan period, the pilot program of low-carbon cities was designed to reduce greenhouse gas emissions by 17% from 2010 level (Martin et al., 2013). The Notice expects all pilot areas to explore a low-carbon and green development model suitable for their region's natural conditions, resource endowment and economic foundation.

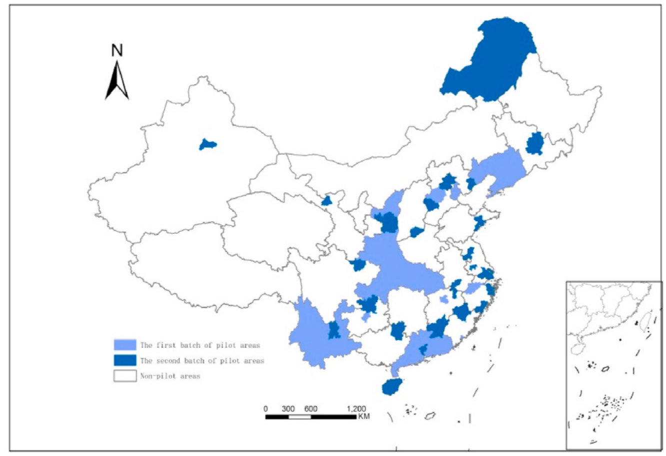

Fig. 1. Geographic distribution of pilot and non-pilot areas.

The pilot program of low-carbon cities has a bearing on economic and social advancement. Curbing greenhouse gas emissions is a major strategy for China's economic growth as well as a great opportunity to readjust economic development model and upgrade economic structure. The main functions of low-carbon cities are to adjust the industrial structure, alter the energy structure to save energy and increase efficiency, increase carbon sequestration, etc. China strives for the formation of a new pattern of green and low-carbon development and ecological civilization, which requires not only to control carbon emissions but also to build low-carbon cities from the dimensions of industrial structure, spatial form, consumption pattern and daily operation. Low-carbon industries is gradually developed by upgrading technologies, encouraging circular economy, optimizing industrial structure, transforming urban functions from industrial functions to service trade functions, advocating green travel and green consumption.

The pilot program of low-carbon cities affects the upgrading of industrial structure mainly via following ways. First, the pilot program requires improving the development quality of high-carbon industries. It calls for economic restructuring, the elimination of polluting processes, equipment and enterprises, strict emission standards for all companies and raised entry criteria for heavy-polluting industries like the iron and steel, non-ferrous, traditional construction, and electric power industries. That is, it is necessary to guarantee that the overall city planning accords with the principle of sustainable development at the decision-making stage, and push ahead with the low-carbon cities program at the planning stage. Second, given local industrial characteristics and development strategies, pilot areas ought to accelerate low-carbon technological innovation, promote low-carbon exploitation and industrialization, and utilize low-carbon technologies to upgrade traditional industries (Yang et al., 2019). Meanwhile, pilot areas have to popularize low-carbon buildings and low-carbon transportation, develop emerging high-tech industries such as the environmentally friendly and new energy industries, and closely follow the latest technological development that can be applied to the low-carbon industries (Yang et al., 2019).

3. Data sources and econometric model

3.1. Data sources

This paper adopts the data of 285 cities in China from 2006 to 2015 to investigate the impact of the pilot program of low-carbon cities on the upgrading of industrial structure. The list of the 115 low-carbon cities comes from the Notice. The economic data of the prefecture-level cities are from China City Statistical Yearbook, including GDP per capita, the informatization level, the human capital level, the urbanization degree, the opening degree, etc. In this paper, all the value variables are uniformly calculated into the constant price with a base period of 2006. Some missing data are filled by consulting the statistical yearbooks of provinces or by interpolation method. Additionally, this paper selects the data at the city level for channel analysis. The data on patent application is collected manually through Baiteng Patent Retrieval system. The data on the proportion of city's heavy industries and the proportion of high-carbon industries is collated based on the systematic processing of the micro-database of Chinese companies during 2006–2013.

3.2. Econometric model

This paper employs the DID method to evaluate the impact of the pilot program of low-carbon cities on industrial structure upgrading. The first layer of difference comes from the city level, and the second layer is from the year level. In practice, there are two batches of pilot cities. The first batch was initiated in 2010, including 82 cities. The second batch was launched in 2013, including 33 cities. We set the experimental group–dummy variable treat –according to whether it is affected by the policy when using the DID method. 115 low-carbon pilot cities are regarded as the experimental group with a value of 1, and other cities as the control group with a value of 0. We set the experimental period–dummy variable period based on the time of policy implementation. The period for the year of policy implementation and later is assigned a value of 1 and the period before policy implementation is assigned a value of 0. Therefore, the DID method of this article compares the differences of industrial structure upgrading between pilot cities and non-pilot cities before and after policy implementation. However, considering that some city characteristics that change with time may be related to the outcome variables and regression factors at the same time, a two-way fixed effects model is constructed for DID estimation. The model is set as below:

$$\mathrm{upgrading}_{i,t} = \alpha_0 + \alpha_1 \mathrm{treat}_i \times \mathrm{period}_t + \gamma X_{i,t} + \mu_t + \phi_i + \varepsilon_{i,t} \quad (1)$$

In equation (1), $upgrading_{i,t}$ is the explanatory variable, which represents the level of industrial structure upgrading of the city i in year t. It is measured by two dimensions, i.e. industrial structure supererogation *ais* and industrial structure rationalization *theil*. $treat_i = 1$ means that city i is the low-carbon city in the year of t. $treat_i = 0$ means that city i is not the low-carbon city in the year of t. $period = 0$ means before the program is implemented. $period = 1$ means the year or after the program is implemented. $X_{i,t}$ stands for a range of control variables at the city-year level, including the economic development level, informatization level, human capital level, urbanization degree, and opening degree. ϕ_i represents the fixed effect of the city, which controls factors that do not change with time, such as geographical location. μ_t denotes the fixed effect of time, which controls the characteristics that do not change with regional changes, such as the changes of the macroeconomic situation. In the above estimation formula, the coefficient concerned in this article is α_1. If the estimated value $\alpha_1 > 0$ is obtained, it indicates that compared with non-pilot cities, the pilot program is conducive to the upgrading of industrial structure; otherwise, there is a inhibiting effect.

3.3. Variable description

3.3.1. Dependent variable

The dependent variable is the industrial structure upgrading, which is decomposed into two dimensions, i.e. the industrial structure supererogation and the industrial structure rationalization (Sun, 2019). The rationalization of industrial structure is a dynamic process where the industrial coordination ability is continuously strengthened, which is a proxy of the coupling degree of factor input allocation and output allocation (Sun, 2019). Some scholars have used the structure deviation degree to measure the industrial structure rationalization (Sartzetakis and Constantatos, 2005). Nevertheless, this measure ignores the relative importance of industries and incorporates absolute values into the calculation. The Theil index can surmount the deficiency of structure deviation to maintain its theoretical basis and economic implication (Lichter et al., 2017). Thus, the Theil index is selected as a proxy of the industrial structure rationalization of prefecture-level cities. The equation is expressed as:

$$\mathrm{theil}_{i,t} = \sum_{m=1}^{3} y_{i,m,t} \ln\left(y_{i,m,t} \big/ l_{i,m,t}\right), m = 1, 2, 3 \quad (2)$$

In equation (2), $y_{i,m,t}$ is the proportion of the industry m in region i in the year of t. $l_{i,m,t}$ represents the proportion of employees in the m industry in region i in the year of t. The *theil* index of industrial structure indicates the production structure and employment structure of the three main industries in China. If the value equals 0, it means that the industrial structure is at an equilibrium level. If not, it demonstrates that the industrial structure deviates from equilibrium. Under this condition, the industrial structure is unreasonable.

The industrial structure supererogation refers to the process of industrial structure evolving from a low level to a high level according to the history and logical sequence of economic development (Barros and Managi, 2016). Generally, according to Clark's law, the industrial structure supererogation can be defined as the raise in the ratio of non-agricultural industries, which can be measured by the hierarchical coefficient of industrial structure, the change index of Moore structure, the proportion of high-tech industries and so on (Achyuta et al., 2014; Akpalu and Ametefee, 2017). The hierarchical coefficient of industrial structure is used to quantitatively describe the evolution process of the three major industries from the relative changes in the proportion. The equation is as below:

$$\mathrm{ais}_{i,t} = \sum_{m=1}^{3} y_{i,m,t} \times m, m = 1, 2, 3 \quad (3)$$

In equation (3), $y_{i,m,t}$ stands for the proportion of m industry in regional GDP in region i in the year of t. *ais* index denotes that the dominant industry in China has gradually shifted from the primary industry to the secondary and tertiary industries, which is the connotation of the industrial structure supererogation.

3.3.2. Independent variables

The key independent variable is the dummy variable *treat*. According to the list of low-carbon cities in the *Notice on Conducting the Pilot Program of Low-Carbon Provinces and Cities* and the time of establishment, we get the key independent variable *treat*period*.

3.3.3. Control variables

Drawing on the previous literature, control variables mainly include: (1) the economic development level (Pergdp), which is measured by the per capita GDP. A region with a higher level of economic development has more advantages in human resources, natural resources, and degree of opening, which provides a better foundation for industrial structure upgrading; (2) the informatization level (Inform), which is calculated by the ratio of the total amount of post and telecommunications business per capita to GDP per capita. Information technology is a kind of high-tech form with digitization, networking, intelligence, personalization, multimedia, and sharing, which can stimulate technological change and industrial structure upgrading; (3) the level of human capital (Human), which is measured by the ratio of the number of students with general higher education to the region population. The upgrading of industrial structure largely relies on the technological development degree and the quality of workforce. The education attainment not only reflects the structure of the labor force, but measures the potential of technological development as well; (4) the urbanization degree (Urban), which is measured by the proportion of urban residents in the area to the total population. The urbanization process helps to increase the industrial production efficiency, promote the development of the vast rural areas, and propel the overall development of the region. It thus has promoted the transformation of industrial structure; (5) the trade openness (Open), which is measured by the ratio of the amount of actual used foreign capital to GDP of the region. The trade openness can affect economic growth through multiple channels such as output effects, technology spillover effects, and investment growth effects, and then affect the upgrading of industrial structure. The descriptive statistics of the variables are reported in Table 1.

4. Empirical analysis

4.1. Baseline regression

In Table 2, Columns 1–2 present the results of the benchmark regression on the impact of the pilot program of low-carbon cities on the industrial structure supererogation. Model 2 adds the region-year cross-fixed effect based on Model 1. The results turn out that the coefficient of *Treat*×*period* is 0.019, significant at 1% level, which proves that the pilot program of low-carbon cities significantly promotes the industrial structure supererogation, indicating that the pilot program of low-carbon cities has quickened up the evolution of the leading industry shifting from agriculture to industry and services. On the one hand, to construct low-carbon cities, more efforts should be put to eliminate polluting processes, equipment and enterprises, and raise entry standards for industries such as iron and steel, non-ferrous materials, building materials, chemical industry, power and light industries. This move can help root out traditional heavy enterprises with low-end technologies. On the other hand, low-carbon cities encourage the development of strategic emerging industries, thereby enhancing local industrial structure supererogation.

Columns 3–4 of Table 2 report the benchmark regression results

Table 1
Descriptive statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Theil	2850	0.319	0.255	0.001	1.964
Ais	2850	2.154	0.160	1.162	2.866
Pergdp	2850	0.386	0.317	0.082	5.332
Inform	2850	0.302	0.416	0.003	6.025
Human	2850	0.152	0.212	0.002	1.856
Urban	2850	0.361	0.165	0.075	1.000
Open	2850	0.037	0.061	0.000	0.825

of the influence of pilot program on industrial structure rationalization. Model 4 adds the region-year cross-fixed effect based on Model 3. The results show that the coefficient of *Treat*×*period* is negative, but not statistically significant, that is, the pilot program of low-carbon cities cannot propel the industrial structure rationalization. The explanation is that the pilot program does not take geographical advantages and industrial development goals into account, resulting in irrational allocation of resources and weak association between industries. It adversely affects local industrial structure rationalization. As a result, the pilot program' influence on the industrial structure rationalization is insignificant.

4.2. Parallel trend test

The DID should satisfy the parallel trend assumption. If the pilot program is not launched, the trend of industrial structure upgrading in low-carbon and non-low-carbon cities should be parallel. In order to identify the impact of the pilot program of low-carbon cities, this paper tests the parallel trend existing in the experimental group and the control group. Furthermore, policies often take a long time to take effect. The formulation, adjustment and implementation of policies are not accomplished overnight. Policy makers need a certain period of time to properly convey their intentions. People also need to gradually adapt to accurately understand policy information and make reasonable responses (Lu and Yu, 2015). For example, when enterprises realize that the local government intends to improve the environmental quality by more stringent environmental supervision, enterprises need a period of time to adjust their output plans, production technologies, etc. Following Jacobson et al. (1993), the event analysis method is used to test the parallel trend and lag phase. The equation is expressed as:

$$\mathrm{upindustry}_{i,t} = \alpha_0 + \sum_{k=-4}^{k=6} \alpha_k \times \mathrm{treat}_i \times \mathrm{period}_k + \gamma X_{i,t} + \mu_t + \phi_i + \varepsilon_{i,t} \tag{4}$$

In equation (4), $period_k$ is the dummy variable of low-carbon city construction year. k represents the k-th year after the implementation of the pilot program. Since the pilot program of low-carbon cities is not put in practice in all regions at the same time, $period_k$ represents different years for different regions. The coefficient α_k stands for the difference of industrial structure upgrading between experimental and control groups in the k-th year that is the beginning of the pilot program. If the trend of α_k is relatively flat during the period of $k < 0$, it conforms to the parallel trend hypothesis. Conversely, if the trend of α_k is significantly increased or decreased during the period of $k < 0$, it shows that the experimental and control groups are disparate before the start of policy, which is not in line with the parallel trend hypothesis. The results are presented in Fig. 2. Two dependent variables are displayed in Fig. 2-A and 2-B respectively: industrial structure supererogation and industrial structure rationalization. It can be found that the estimation coefficients of dummy variables in the years before the construction of low-carbon cities fail to pass the significance test of 5% level. This verifies that the treatment group and the control group meet the parallel trend assumption. However, in Fig. 2-B, α_k began to be significantly positive and gradually increased from 2011, demonstrating that the impact of the pilot program on the industrial structure supererogation has been overt since the lag of one year, and the impact has become increasingly significant. In Fig.2-B, the pilot program insignificantly impacts the industrial structure rationalization.

Table 2
Impact of low-carbon city pilot policy on the industrial structure upgrade.

Variable	AIS	AIS	THEIL	THEIL
Model	(1)	(2)	(3)	(4)
Treat × period	0.028** (0.013)	0.019*** (0.004)	−0.047 (0.114)	−0.051 (0.197)
Control	Y	Y	Y	Y
City-fixed effect	Y	Y	Y	Y
Year-fixed effect	Y	Y	Y	Y
City-year-fixed effect	N	Y	N	Y
Observations	2850	2850	2850	2850
R-squared	0.276	0.411	0.231	0.260

Note: For all regressions, robust standard errors, clustered at the city level are in parentheses.***p < 0.01, **p < 0.05, *p < 0.1.

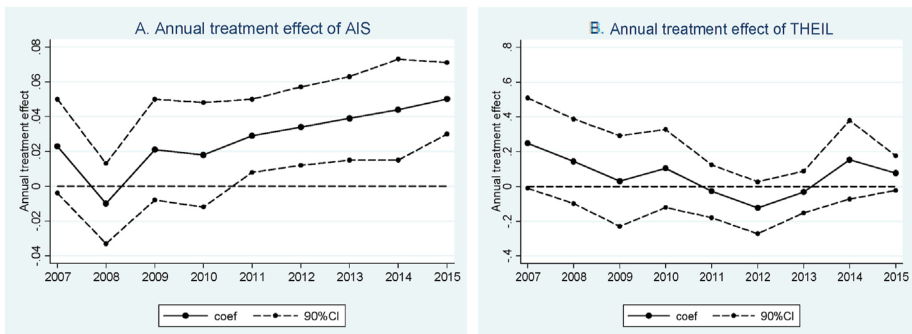

Fig. 2. Annual treatment effect.
Note: AIS represents industrial structure supererogation, THEIL represents industrial structure rationalization.

4.3. Robustness test

4.3.1. Placebo test

Each city has its unique characteristics. Although the unchanged city characteristics are controlled by adding city fixed effects, city characteristics that change with time may exercise influence over the experimental group and the control group, thus disturbing the hypothesis. These influences are beyond the control of the model in this paper. In this regard, the indirect placebo test is utilized following Chetty et al. (2009) and La Ferrara et al. (2012). Our sample consists of 115 low-carbon pilot cities out of a total of 285 cities. At the beginning, we randomly choose 115 cities from a total of 285 cities. They are assigned as low-carbon pilot cities, the rest as non-low-carbon pilot cities. To eradicate the influence of any rare event, we repeat 500 random sampling. Then based on the grouping of random selection, we carry out 500 benchmark regressions to get the regression coefficients and P values. Fig. 3 reports the distribution of regression coefficients. It can be observed that the coefficients estimated based on random samples are distributed near 0 and obey the normal distribution, which accords with the expectation of placebo test. The coefficient (0.19) of the benchmark regression estimation[1] is almost independent of the coefficient distribution. These results manifest that our estimation will not be seriously biased by any missing variables.

4.3.2. Instrument variable

The endogenous problem in this paper mainly derives from the non-random selection of low-carbon pilot cities. Local governments apply for the pilot program. The NDRC decides whether to ratify their applications according to the work basis of each region and the representativeness of the pilot layout. What we are concerned about is whether the cities involved in the pilot program belong to the regions with severe carbon emissions. The industrial structure in these regions may be dominated by heavy industries. This will engender differences in the trend of industrial structure upgrading between pilot cities and non-pilot cities. To get rid of the potential endogenous problem, this paper further uses the instrumental

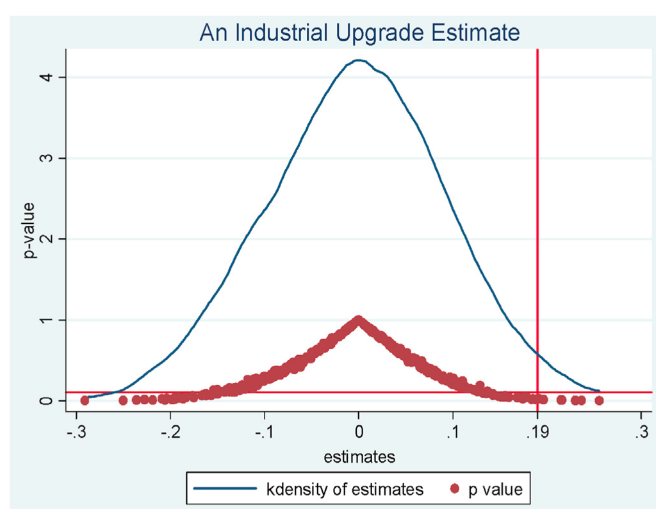

Fig. 3. Kernel density distribution.
Note: The X-axis represents the estimated coefficients from 500 randomly assigned *Treat × period*. The blue curve is the estimated kernel density distribution. The red dot is p-value. The red line is the true estimated value for the column 2 of Table 1.

[1] In order to better describe the P-value of the coefficient, the coefficient is magnified 10 times. The estimated coefficient distribution map of placebo test is drawn.

variable to consolidate the results. In light of Hering and Poncet (2014), we select the ventilation coefficient as the instrumental variable of low-carbon cities state. The ventilation coefficient is the product of the wind speed and the height of the mixed layer. The wind speed influences the horizontal diffusion of pollutants, and the height of the boundary layer affects the vertical diffusion. A higher value means that the pollutant diffusion is faster. Logically, the ventilation coefficient has the peculiarities of instrumental variables. First, the larger the ventilation coefficient is, the more favorable the pollutants are to spreading. The lower the pollution concentration in the area, the lower the probability that it will be selected as a low-carbon construction city. So the instrumental variables are negatively correlated with endogenous variables. Second, as a natural meteorological condition, it is exogenous.

We utilize the wind speed information of 10 m height and boundary layer height (as a proxy for the mixed layer height of 75*75 grids) obtained from the ERA-interim database to match the latitude and longitude of prefecture-level cities announced by the National Geomatics Center of China to extract the annual ventilation coefficient of the prefecture-level city. The results on the second stage of the instrumental variable are displayed in columns 1–2 of Table 3. The results of the first stage are presented in column 3 of Table 3. We still observe that the impact of the pilot program on the industrial structure supererogation is significantly positive. Its estimation coefficient is even larger. The impact on the industrial structure rationalization is not statistically significant, proving the robustness of the benchmark regression results.

4.3.3. Reselected experimental group and control group

Similar to most of DID research frameworks, this paper analyzes all samples in China, with all cities except pilot areas as the control group. The difference of regional industrial structure upgrading may be caused by not only the pilot program, but also the differences in resource endowment, economic development, etc. Therefore, based on the RD method, this paper selects more similar experimental group and control group, thereby reducing the influence of irrelevant factors, especially unobservable factors. The low-carbon pilot cities are conducted in two groups. The first group has been initiated in 82 cities since 2010, and the second group has been launched in 33 cities since 2013. The characteristics of the two groups are almost similar. Hence, 82 cities launched in 2010 are regarded as the experimental group. 33 cities launched in 2013 are seen as the control group. The samples from 2006 to 2012 are used for regression. In Table 4, the regression results are presented in columns 1–2 respectively. The impact of the pilot program on the industrial structure supererogation is significantly positive. The impact on the industrial structure rationalization is not obvious. It demonstrates that estimated results are not affected by the regional selection of the control group.

4.3.4. Impacts of other policy

We probe into the effect of the pilot program of low-carbon cities on the industrial structure upgrading from 2006 to 2015. However, in the same period, industrial structure upgrading may also be influenced by other policies. Two policies implemented during this research window are worthy of our attention: Ambient Air Quality Standards (2012) and innovative city pilot projects. First, on February 29, 2012, the Ministry of Environmental Protection and AQSIQ jointly issued the new Ambient Air Quality Standards. On May 21, the Ministry of environmental protection further released the *Implementation Plan for Phase I Monitoring of the New Air Quality Standard*, which stipulates that by the end of October 2012, all national network monitoring sites in the first implementation cities (74 pilot cities, including key regions like Beijing-Tianjin-Hebei region, municipalities and provincial capital cities) should complete equipment installation and put into trial operation, and monitoring should be carried out in terms of the new *Ambient Air Quality Standards* before the end of December. Second, the Chinese government successively approved the establishment of innovative pilot cities in 57 cities that contain Shenzhen, Dalian, Qingdao, Xiamen, etc. during 2008–2013. Innovative cities refer to cities mainly depending on technologies, knowledge, manpower, culture and other innovative factors to drive development. They have high-end radiation and leading impacts on other areas. To eliminate the disturbance of above two pilot policies, we add the interaction terms of the dummy variables of the relevant policies and the linear trend of time in the regression equation. Columns 3–4 and Columns 5–6 of Table 4 report the results, respectively. The coefficient of $Treat \times period$ is similar to the results of the baseline regression in Table 1. The coefficient of the interaction terms are small and statistically insignificant, which shows that regional-based policies do not cause the biased error of the estimation results.

4.4. Heterogeneity analysis

4.4.1. Regional heterogeneity

For China with a vast territory, there is an imbalance in the distribution of industries between regions. It can be seen from the distribution characteristics that in the central and western regions, the average percentage of total output of pollution-intensive industries in the total output of clean industries is markedly greater when compared with the eastern region. Existing studies find that the industry pollution attribute is an important factor impacting the efficacy of environmental regulation (Deschênes et al., 2017). Is there also a discrepancy in the impacts of the pilot program of low-carbon cities on the industrial structure upgrading in different regions? To figure out the regional heterogeneity of the impacts of the pilot program on industrial structure upgrading, this paper divides 285 prefecture-level cities into 98 developed cities (Eastcity) and

Table 3
Instrument variable.

Model	AIS	THEIL	IV first stage
	(1)	(2)	(3)
Treat × period	0.033** (0.016)	0.042 (0.039)	
Treat (tf) × period			−0.001*** (0.000)
Control	Y	Y	Y
City-fixed effect	Y	Y	Y
Year-fixed effect	Y	Y	YY
Observations	2850	2850	2850
R-squared	0.184	0.266	0.375
F-test excluded instrument			11.832
Weak identification			11.756

Note: For all regressions, robust standard errors, clustered at the city level are in parentheses.***p < 0.01, **p < 0.05, *p < 0.1.

Table 4
Robustness test.

Variable	Reselect the experimental group and the control group		Control the impact of other policies			
	AIS	THEIL	AIS	THEIL	AIS	THEIL
Model	(1)	(2)	(3)	(4)	(5)	(6)
Treat × period	0.039*** (0.007)	−0.051 (0.128)	0.024*** (0.004)	−0.034 (0.214)	0.039*** (0.012)	−0.027 (0.052)
Ambient Air Quality Standard			Y	Y		
Innovative city program					Y	Y
Control	Y	Y	Y	Y	Y	Y
City-fixed effect	Y	Y	Y	Y	Y	Y
Year-fixed effect	Y	Y	Y	Y	Y	Y
Observations	805	805	2850	2850	2850	2850
R-squared	0.138	0.146	0.155	0.254	0.316	0.155

Note: For all regressions, robust standard errors, clustered at the city level are in parentheses.***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

187 undeveloped cities (Mid-westcity). The developed cities are in the eastern region. The undeveloped cities belong to the central and western regions. Columns 1–4 in Table 5 exhibit the regression results.

With respect to the industrial structure supererogation, the pilot program of low-carbon cities produces a significantly positive impact in the cities belonging to three regions. The positive effect in the central and western cities is more obvious than that in the eastern cities. The possible reason is that the central and western regions are suffused with more pollution-intensive industries than the eastern region. The pilot program of low-carbon cities that can foster low-carbon technologies, new energy technologies and new processes will notably propel the industrial structure supererogation in regions like the central and western regions. In the relatively underdeveloped areas, the pilot program provides timely help, which plays a greater role in driving and radiating the local economic development, while in the developed areas, it is just icing on the cake so that its marginal effect is smaller. In terms of the industrial structure rationalization, the positive effect of the pilot program of low-carbon cities is not statistically significant in the eastern, central and western cities.

4.4.2. Environmental law enforcement heterogeneity

Environmental regulation relies on the formulation of environmental laws and regulations. The efficacy of the pilot program of low-carbon cities also leans on the stringency of law enforcement. The higher the violation cost in areas with strong law enforcement intensity, the higher the possibility of complying with environmental regulations. At present, regional heterogeneity in environmental law enforcement is still obvious. The differences between the central and western regions are marked. The environmental law enforcement in the Pearl River Delta and the Yangtze River Delta is significantly stronger than other regions. To examine the impact of regional law enforcement intensity on the pilot program's influence on industrial structure upgrading, we use the average payment of pollutant discharge fees by enterprises in each province to measure the regional law enforcement intensity, and group 31 provinces and areas according to the median of law enforcement intensity. The areas where the law enforcement intensity is greater than the median are the areas with strong law enforcement intensity; otherwise they are the areas with weak law enforcement intensity. The samples after grouping are estimated respectively. Columns 5–8 of Table 5 report the results.

In terms of the industrial structure supererogation, the pilot program of low-carbon cities can significantly promote it in areas with high and low law enforcement intensity. The pilot program in cities with higher law enforcement intensity plays a stronger positive role. As for the industrial structure rationalization, the pilot program has no effect on it in cities with weak law enforcement intensity, but the program can significantly enhance it in cities with strong law enforcement intensity. On the whole, the pilot program in cities with strong law enforcement intensity plays a greater role in propelling the transformation of industrial structure. To undertake environmental governance, the core of environmental protection, environmental administrative law enforcement is the main tool. However, there are myriads of problems in the process of China's environmental administrative law enforcement, such as lax examination and approval, the insufficient law enforcement intensity, the ineffective supervision, the evasion and perfunctory treatment of illegal acts, which makes environmental policies ineffective. In China, where the institutional environment is relatively weak, this conclusion has important implications for the improvement and implementation of environmental policies.

4.5. Channel analysis

The aforementioned results indicate that the pilot program of low-carbon cities has significantly promoted the industrial

Table 5
Heterogeneity analysis.

Variable	Eastcity		Mid-westcity		High Enforce		low Enforce	
	AIS	THEIL	AIS	THEIL	AIS	THEIL	AIS	THEIL
Modle	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treat × period	0.014** (0.006)	0.231 (0.105)	0.038*** (0.004)	−0.549 (0.197)	0.034*** (0.010)	0.654* (0.378)	0.018** (0.011)	−0.204 (1.762)
Control	Y	Y	Y	Y	Y	Y	Y	Y
City-fixed effect	Y	Y	Y	Y	Y	Y	Y	Y
Year-fixed effect	Y	Y	Y	Y	Y	Y	Y	Y
Observations	980	980	1870	1870	1310	1310	1540	1540
R-squared	0.329	0.405	0.176	0.303	0.266	0.140	0.371	0.325

Note: For all regressions, robust standard errors, clustered at the city level are in parentheses.***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

structure supererogation, so what is the underlying mechanism? In other words, what key variables does the government's pilot program affect to alter the industrial structure supererogation? Deduced from the above analysis, the pilot program of low-carbon cities can improve the industrial structure supererogation from two channels: inducing technological innovation and reducing the proportion of high-carbon industries.

First, the pilot program may improve the industrial structure supererogation through technological innovation. The pilot program transforms and upgrades traditional industries by low-carbon technologies R&D, demonstration, and industrialization, and encourages the development of strategic emerging industries concerning environmental protection and energy conservation. To testify this mechanism, city's patent applications is regarded as a proxy of technological innovation. The number of city's environmental patent applications is applied to the robustness test. In Table 6, columns 1–2 present the results on the channel analysis. We find that the low-carbon city policy has significantly increased the number of (environmental) patent applications. More importantly, this result is consistent with the intention of low-carbon city: to promote the upgrading of city industrial structure through low-carbon technologies, thus achieving the win-win goal of pollution prevention as well as high-quality economic development.

Second, the pilot program may cut down the proportion of high-carbon industries to strengthen the industrial structure supererogation. In the planning of low-carbon city, efforts ought to be made to eliminate pollution processes, equipment and enterprises, formulate emission standards, and raise entry criteria for industries like the iron and steel, non-ferrous industries to suppress high-carbon industries. To verify this mechanism, this paper collects the data on the proportion of city high-carbon industries from the survey data of industrial enterprises in 2006–2013. The proportion of heavy industrial enterprises is used for a robustness test. In Table 6, the corresponding results are described in columns 3–4, which show that the policy of low-carbon cities has significantly reduced the proportion of high-carbon industries and the proportion of heavy industrial enterprises, attesting that the pilot program can reinforce the industrial structure supererogation by reducing the proportion of high-carbon industries.

5. Discussion

5.1. Theoretical contributions

The paper makes contributions to knowledge in the following three aspects. First, the extant literature on the relationship between environmental regulation and industrial structure upgrading is mainly carried out in the U.S, Germany, Japan and other developed countries (Hamamoto, 2006; Arik, 2009; Suphi, 2015). The research scenarios in developing countries are rare. Different from developed countries such as the U.S., region-based environmental policies are often fraught with greater difficulties in the implementation process in that the laws and institutions in developing countries are relatively insufficient (Greenstone and Hanna, 2014; Li et al., 2016). Therefore, a systematic and reasonable test of the influence of China's pilot program of low-carbon cities has both academic value and practical significance. Second, voluminous studies focus on the influence of environmental policy on the industrial structure supererogation. Few studies have examined the effect of environmental regulation on the industrial structure rationalization. The industrial structure supererogation depicts the proportion of production scale and the coordination of resource input and output among different industries. The industrial structure rationalization mirrors changes in the industrial structure ratio and labor productivity (Han et al., 2017). This paper comprehensively investigates the impacts of environmental regulation on both the industrial structure rationalization and supererogation. Third, this paper probes into the channel of the pilot program of low-carbon cities affecting the industrial structure upgrading. The pilot program is discovered to facilitate the industrial structure upgrading through low-carbon technologies to upgrade traditional industries and the reduction of the proportion of high-carbon industries. The channel analysis deepens the research on the relationship between the pilot program of low-carbon cities and the industrial structure upgrading.

5.2. Policy implications

To win the battle against climate change and achieve the goal of temperature control, reducing carbon emissions is a shared responsibility of all humankind. In the context of China's rapid urbanization, whether low-carbon cities can be built from the dimensions of industrial structure, spatial patterns, consumption patterns and daily operations is the key for China to seize the opportunity of low-carbon development and combat global climate change. This paper finds that the impact of the pilot program of low-carbon cities on the industrial structure upgrading is complicated, which confronts China's industrial structure adjustment and high-quality development with severe challenges. To reinforce the positive role of the pilot program in the transformation and upgrading of industrial structure, this paper puts forward the following suggestions.

(1) The empirical results of this paper indicate that the construction of low-carbon cities significantly boosts the industrial structure upgrading, and the effect on the industrial structure rationalization is contingent on the intensity of regional environmental law enforcement. In the past 20 years, low-carbon technologies have played an increasingly significant role in catalyzing economic and social changes. Developed cities around the world have taken the construction of low-carbon cities as a vital measure to enhance the competitiveness of cities and even countries. The

Table 6
Channel analysis.

Modle	Patent	Environmental patent	The proportion of high-carbon industrial	The proportion of heavy industrial
	(1)	(2)	(3)	(4)
Treat × period	0.145** (0.068)	0.329* (0.189)	−0.030* (0.114)	−0.063*** (0.197)
Control	Y	Y	Y	Y
City-fixed effect	Y	Y	Y	Y
Year-fixed effect	Y	Y	YY	Y
Observations	2850	2850	2280	2280
R-squared	0.276	0.411	0.231	0.260

Note: For all regressions, robust standard errors, clustered at the city level are in parentheses.***p < 0.01, **p < 0.05, *p < 0.1.

economic, cultural and institutional foundations of developing countries are disparate from developed countries. Region-based environmental policies tend to face greater difficulties in implementation. The results of this paper show that the construction of low-carbon cities, a region-based environmental policy in the largest developing country, China, does not sacrifice economic performance for environmental performance, but spurs the industrial structure upgrading and improves environmental quality, which realizes the double dividend of environment and economy. Therefore, it can be considered as an effective tool of pollution control in the context of economic structural transformation.

(2) The construction of low-carbon cities props up the transformation and upgrading of industrial structure through technological innovation and the reduction of the proportion of high-carbon industries. This signifies that the government can increase the efficiency of structural transformation and upgrading of low-carbon cities by increasing investment in technological innovation and strictly curbing high-carbon industries. For enterprises, they should be encouraged to invest in technological innovation, shift from “end-of-pipe treatment” to “source treatment”, increase investment in cleaner production technologies and environmental protection technologies, and improve the transformation ability of scientific and technological achievements. The government ought to attract high-quality talents, create good working conditions, hardware and software environments, and strictly formulate and implement environmental regulations to ensure the effective construction of low-carbon cities. Besides, on the basis of the issued industrial phase-out catalog, the government shall lay down plans to gradually eliminate backward production capacities, production equipment and processes, industrial enterprises with low operational efficiency, high energy consumption per unit, high carbon emission intensity, etc. This is beneficial to the improvement of the elimination mechanism. The enterprises with backward production capacities will also be shepherded to integrate with emerging industries and characteristic industries.

(3) The results of heterogeneity analysis uncover that the effect of low-carbon city construction on the transformation of industrial structure in the central and western regions is more apparent than that in the eastern region. Due to the differences in environment, resources, technological level, industrial policies, etc., there have been regional discrepancies between the eastern, central and western regions along with China’s economic development. The findings of this paper mean that cities in different regions of China should adopt low-carbon policies according to local conditions. For the central and western regions dominated by pollution-intensive industries, the industrial structure adjustment should underscore the upgrading and transformation of traditional industries with high carbon emissions. A circular industrial chain should be formed in the industrial agglomeration area. In the context of China’s efforts to foster strategic emerging industries, the local governments should plan, guide and support the development of strategic emerging industries in line with the characteristics of city development, so as to form efficient, energy-saving and environmentally friendly equipment and products. In particular, they should also further the development of high value-added emerging industries, regard knowledge- and technology-intensive industries as new economic growth points, and gradually reduce the proportion of high-carbon emission industries in the economic system.

6. Conclusions

To explore how to develop economy and conquer climate change in the rapid development stage of industrialization and urbanization, China has determined to make the low-carbon development path a great move for socioeconomic development. In this paper, the quasi-natural experiment of the pilot low-carbon cities in many areas of China is used to evaluate the impact of the pilot program of low-carbon cities on the city industrial structure upgrading. This paper draws the following conclusions. ①The pilot program has significantly improved the industrial structure supererogation, whereas it exerts insignificant influence on the industrial structure rationalization. It indicates that the construction of low-carbon cities in China is conducive to the economic performance. ②Channel analysis reveals that the pilot program propels the industrial structure supererogation via technological innovation and the reduction of the proportion of high-carbon industries, which shows that the construction of low-carbon cities has reached the goals of reducing carbon emissions to a certain extent. ③The analysis of regional heterogeneity indicates that regional differences reside in the impact of the pilot program on the industrial structure supererogation, but not for the industrial structure rationalization. Specifically, the impact of pilot low-carbon cities on the industrial structure supererogation in the central and western cities is more positive than that in the eastern cities, while the impact’s on the industrial structure rationalization is not obvious in the cities of three regions. ④Regarding the heterogeneity analysis of environmental law enforcement, it manifests that the pilot program in cities with strong law enforcement intensity has a more positive impact on the industrial structure supererogation. Moreover, the pilot program can significantly stimulate the industrial structure rationalization in cities with strong law enforcement intensity, rather than cities with weak law enforcement intensity.

CRediT authorship contribution statement

Jingjing Zheng: contributions to the paper, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. **Xuefeng Shao:** contributions to the paper, Formal analysis, Investigation, Writing - review & editing. **Wei Liu:** contributions to the paper, Software, Data curation, Investigation, Writing - review & editing. **Jie Kong:** contributions to the paper: Polished the Language, Formal analysis, Investigation. **Gaoshan Zuo:** contributions to the paper, Conceptualization, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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