The costs of “blue sky”: environmental regulation and employee income in China

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Abstract
Strict environmental regulations may change the behavioral decisions of firms. Based on the exogenous impact of the Chinese Central Government’s inclusion of environmental performance in the assessment targets of municipal officials in 2007, this study uses the difference-in-difference method to explore the impact of environmental regulations on employee income. We find that (1) environmental regulations will significantly reduce the average wage level of employees in polluting industries and have no significant impact in nonpolluting industries. (2) This effect is more pronounced in eastern China, where environmental regulations are more stringent, and in areas where political promotion incentives are stronger. (3) Mechanistic analysis finds that environmental regulations will affect employee income by increasing costs and constraining financing. (4) More importantly, we find that the decline in the average wage level of firms is mainly due to the decline in the average wage level of ordinary employees, and the average wage level of management has not decreased significantly, which means that environmental regulations have expanded the functional income distribution. Our findings contribute to a comprehensive understanding of the effectiveness of environmental regulatory policy implementation and associated economic cost issues.

Keywords Environmental regulation · Employee income · Functional income distribution

Introduction
Striking a balance between economic development and environmental protection is a common concern of many countries and governments (Okereke and McDanels 2012; Tang et al. 2020). China, as the world’s largest developing country, is no different. While achieving great economic development, it also faces severe environmental problems (Zhang et al. 2019; Zhou et al. 2020). According to the Bulletin of the State of the Environment of China 2015, 78% of prefecture-level cities across the country have severely exceeded air pollution standards. Every year, 350,000 to 400,000 Chinese minors die from air pollution (World Bank 2007). To strengthen pollution control, the Chinese government has implemented a series of environmental regulatory measures for polluting gas emissions; these measures have played an important role in improving China’s environment (Ren et al. 2018; Li et al. 2017; Fan et al. 2019). However, the implementation of these measures not only will cause changes in pollution levels but also will have a nonnegligible impact on the economic activities of firms. In this regard, a large number of studies have focused on the impact of environmental regulations on firm innovation, investment, productivity, exports, migration, labor demand, and tax avoidance (Bergek and Berggren 2014; Cai et al. 2016; Albrizio et al. 2017; Hering and Poncet 2014; Chen et al. 2018a, b; Liu et al. 2021; Geng et al. 2021; Yu et al. 2021). However, few studies have focused on the impact of environmental regulations on employee income. When a firm is faced with
the negative impacts associated with environmental regulations, it may reduce the wage level of employees in response, which is one of the important behavioral decisions it may make. Surprisingly, very little is known about this behavior at present.

At the same time, the decline in the labor income share is a common problem faced by many countries in the world, including China (Gollin 2002; Karabarbounis and Neiman 2013). The inequality of social income has become one of the biggest challenges affecting global social stability. Since labor income, such as wages, is the main source of income for most people, the existing literature has studied the determinants of firm wages and other labor income from multiple perspectives, such as technological progress (Acemoglu 2003), market monopoly (Berkowitz et al. 2016), urban agglomeration (Chen et al. 2021), industrial structure (Acemoglu and Guerrieri 2008), tax incentives (Suárez Serrato and Zidar 2016; Garrett et al. 2020), minimum wage (Card and Krueger 1994), trade liberalization (Amiti and Cameron 2012), and imports and exports (Autor et al. 2013; Amiti and Davis 2012). These studies did not consider the impact of environmental regulation.

This study attempts to fill this important gap by studying China, the world’s largest pollutant emitter and developing country. In the face of increasingly serious environmental pollution problems, the Chinese central government began including environmental performance in the assessment indicators of municipal officials in 2007 and began appointing government officials in reference to pollution reduction performance. However, due to differences in local government responses, in the following years, only some local governments included environmental target constraints in their government work reports, which were clearly listed as performance targets for the year. As a result, these regions, where objective environmental constraints are written into government work reports, are subject to stricter environmental regulations.

Taking advantage of the exogenous impact of the Chinese central government’s inclusion of environmental performance in the assessment targets of prefecture-level officials in 2007, we compiled the environmental target data disclosed in the government work report of China’s prefecture-level city and constructed a difference-in-difference empirical strategy to explore the impact of environmental regulations on firm employee income. We found that environmental regulations have reduced the average wage level of employees in polluting industries by 3.2%, and this effect exists only in polluting industries, not in nonpolluting industries. This conclusion is established in a series of robustness tests. Heterogeneity analysis finds this effect to be more pronounced in eastern China, where environmental regulations are more stringent, and in areas where political promotion incentives are stronger. Mechanistic analysis shows that the increase in firm costs and the increase in financing constraints are important channels for the decline in firm average wages caused by environmental regulations. Furthermore, we also find that the decline in the average wage level of firms is mainly due to the decline in the average wage level of ordinary employees. The average wage of management has not decreased significantly, and environmental regulations have increased functional income distribution.

Our study contributes to the existing literature in the following three aspects. First, our research attempts, for the first time, to explore the impact of environmental regulation on the income of employees and its internal mechanism. These relationships provide new perspectives and insights. Through the abovementioned literature review, it can be found that the literature on environmental regulation and firm behavior decision-making mainly focuses on innovation, investment, productivity, export, migration, labor demand, and tax avoidance (Berger and Berggren 2014; Cai et al. 2016; Albrizio et al. 2017; Hering and Poncet 2014; Chen et al. 2018a, b; Liu et al. 2021; Geng et al. 2021). The discussion on firm labor income mainly focuses on technological progress, market monopoly, urban agglomeration, industrial structure, tax incentives, minimum wage, trade liberalization, and imports and exports (Acemoglu 2003; Berkowitz et al. 2016; Chen et al. 2021; Acemoglu and Guerrieri 2008; Garrett et al. 2020; Card and Krueger 1994; Amiti and Cameron 2012; Amiti and Davis 2012). The research in this study is an expansion and supplement to the above two aspects of the literature.

Second, our research enriches the discussion about the political economy of centralization and the political economy of pollution. From the perspective of the relationship between the central and local governments and promotion incentives, our study combines environmental policies with government work goals and explores the impact of the internal motivation of local governments in implementing environmental regulations on firm employee income, thereby enriching the political economy of centralization (Blanchard and Shleifer 2001; Xu 2011; Heberer and Senz 2011) and the political economy of pollution (Burgess et al. 2012; Kahn et al. 2015; Lipscomb and Mobarak 2016; He et al. 2020)-related research.

Third, our research supplements the spillover effects of environmental regulations. Specifically, we found that the negative impact of environmental regulations on the average wage level of firm employees exists only in polluting firms, not nonpolluting firms, and the decline in the average wage level of firm employees comes from the decline in the average wage level of ordinary employees. The average wage of management has not decreased, and environmental regulatory measures have increased functional income distribution. This finding enables us to have a more comprehensive
understanding of the negative externalities and economic costs of environmental regulations.

The rest of the study is structured as follows: the “Policy background and theoretical analysis” section briefly explains the institutional background and theoretical analysis of this study; the “Data and empirical strategy” section introduces the data and research design, and the “Empirical results and analyses” section presents the main results, robustness checks, and heterogeneous effects. The “Mechanism analysis” section discusses the internal mechanism of the impact of environmental regulations on employee income. The “Further analysis: who truly bears the costs?” section further analyzes who bears the cost of environmental regulations. The “Conclusions” section presents our conclusions.

Policy background and theoretical analysis

Policy background

To rapidly develop the economy, following the reform and opening up of China, the Chinese government paid great attention to economic performance when promoting local officials and initially adopted a development strategy that relied on heavy industry. This mode of economic development is characterized by high and extensive pollution and so has led to the environmental pollution problem becoming increasingly serious. This typically results in a sharp increase in the discharge of sulfur dioxide (SO2) and other major pollutants, which directly leads to an increase in the frequency and intensity of acid rain. According to Geng et al. (2021), between 1996 and 2000, 72% of cities in China experienced acid rain and 33% of these cities had acid rain frequencies higher than 40%. In response to the need for long-term sustainable economic development, the Chinese government has decided to implement environmental regulations to improve the status quo of environmental pollution. China’s earliest environmental regulation goals began in the 10th Five-Year Plan (2000–2005), but due to the lack of reasonable and effective decomposition and assessment methods for environmental protection-related quantitative indicators, the planning goals lack strong constraints, and emission reduction targets for major pollutants have not been achieved (Shi and Xu 2018). At the beginning of the 11th Five-Year Plan (2006–2010), the central government decided to take stronger measures. Since local officials actually implement the central environmental goals, the central government has decided to include “pollution reduction assessment” as an important factor for officials’ political promotion. In December 2006, the central government issued the “Decision on Implementing the Scientific Outlook on Development and Further Enhancing Environmental Protection,” which clearly stated that the “pollution reduction assessment” should be used as the basis for the political promotion of local officials. Subsequently, the Ministry of Environmental Protection signed the “11th Five-Year Plan Major Pollutant Total Reduction Target Responsibility Letter” (PRTRL) with provinces, municipalities, autonomous regions, and municipalities directly under the Central Government in 2007 and officially began the pollutant emission reduction assessment for local officials.

Under China’s unique model of political centralization and economic decentralization, local governments have tremendous influence and control over the development of the local economy (Jin et al. 2005). Environmental emission reduction targets are incorporated into the assessment method based on economic performance. This change in political assessment methods directly affects the political promotion of local officials and profoundly changes the behavior of local governments. The key to this measure lies in the level-by-level decomposition and assessment of environmental protection goals. The central government signs a PRTRL with provincial governments to decompose and implement the national pollution reduction goals for each province, and then each province decomposes and implements it for each prefecture-level city. The cities are then included with their districts and counties, as well as the polluting firms within their jurisdiction, before finally being checked by the central and provincial governments. The results of the assessment are announced to the public and used as the basis for the political promotion of prefecture-level city officials. This also ensures that local governments are able to implement the environmental regulation policies of the central government. Figure 1 plots the average SO2 emissions of prefecture-level cities in China from 2004 to 2012. After the PRTRL in 2007, SO2 emissions dropped rapidly.
In the government’s daily operation, the government work report, which is an important planning document for prefecture-level city governments, can fully reflect its focus each year. Therefore, the pollution reduction targets disclosed in government work reports will inevitably have an important impact on polluting firms in the jurisdiction. After the central and local governments signed the PRTRL, differences emerged in local government responses to it, and in the following years, only some local governments included environmental target constraints in their government work reports, which were clearly listed as performance targets for the year. This difference in response means regions where pollution reduction targets are written into government work reports are subject to stricter environmental regulations compared to other regions and provides a realistic basis for this study to distinguish between the treatment group and the control group.

**Theoretical analysis**

**Cost of production**

Theoretically, environmental regulations can influence the wages of employees in firms through multiple channels. The first is the firm cost channel. On the one hand, environmental control has increased the production cost of firms by requiring firms to adopt high-cost clean energy, increase pollution control equipment, and upgrade or rectify high-pollution production lines (Jaffe et al. 1995; Berman and Bui 2001; Alpay et al. 2002). On the other hand, the collection of pollution fees, such as pollution discharge fees, pollution rights trading, and payment of guarantee deposits, also increases the environmental costs of firms (He et al. 2020). When firms face the negative impact of increased costs, reducing employee wages is a common way for firms to reduce costs. Lowering wages can save the firm’s cash flow in the short term. For employees, when the firm lowers wages, the choices they face are very limited. Due to the obvious differences between different industries, it is difficult for workers to master the knowledge and skills necessary for other industries in a short period of time. At the same time, prefecture-level city governments are the actual implementers of environmental regulations and policies. Workers can only find jobs in the same industry in other cities, and the cost of changing cities is far greater than the loss of wage decline. Therefore, workers will accept the firm’s lower wage level in the short term. Based on this outcome, this study expects that environmental regulations will reduce the wages of employees in firms. At the same time, the relevant research on the negative impact of firms and the income of employees also provides support for the theoretical logic of this study. For example, the study by Dauth et al. (2014) in Germany found that the increase in costs brought about by import competition significantly reduced the average wage level of firms. Felix and Hines (2009) and Fuest et al. (2018) found that when faced with rising costs caused by rising income tax rates, firms will pass on the tax burden by directly reducing wages. All these evidence show that reducing the wage level of employees is indeed a common method for firms to resist external uncertainties and possible negative shocks. Therefore, environmental regulations will cause a decline in the wages of employees in firms.

**Financing constraints**

In addition to the firm cost mechanism, environmental regulations may also affect the wages of firm employees through financing restraint mechanisms. After the signing of the PRTRL in 2007, The People’s Bank of China, the China Banking Regulatory Commission, and other relevant departments issued a number of documents to restrict banks and other financial institutions from lending to firms in high-energy-consuming and high-polluting industries, such as the “Notice on Earnestly Implementing National Macro-Control Policies and Strictly Preventing Banking Risks” and the “Notice on Deeply Implementing National Macro-Control Measures and Effectively Strengthening Credit Management.” In addition, the China Banking Regulatory Commission organized a special inspection and notification meeting on loans to polluting firms, requesting the recovery of loans to firms that did not meet the standards for energy consumption and pollution. The implementation of these measures has further deteriorated the financing environment of polluting firms and increased the financing constraints faced by firms. Existing studies have also confirmed that polluting firms do have higher financing constraints than nonpolluting firms (Hong and Kacperczyk 2009), and environmental regulations will increase the financing constraints faced by polluting firms by sending signals to the capital market (Geng et al. 2021). According to financing theory, the preferred choice for firms is to use their own funds first and then use debt financing (Myers and Majluf 1984). When a firm’s external financing is blocked, it can rely only on internal financing to provide financial support. As one of the important means of a firm’s internal financing, reducing the wages of firm employees can ease financing constraints by increasing the firm’s cash flow. Therefore, environmental regulations will also reduce the wage level of firm employees by increasing financing constraints.

**Data and empirical strategy**

**Data**

The data we use are the environmental regulation target data of China’s 225 prefecture-level cities and the data of A-share listed firms from 2004 to 2014. The reason for selecting the
sample interval from 2004 to 2014 is that they are located at the ends of China’s 10th Five-Year Plan and 12th Five-Year Plan, and they happen to include the year (2007) when the PRTRL was signed. The government environmental regulation target data come from the government work reports of each prefecture-level city over the years, collected from the official website of the local prefecture-level city government, and manually sorted by the environmental regulation targets of the local government. In the process of collection and sorting, we deleted the prefecture-level cities in the two special provinces of Xinjiang and Tibet. We deleted the prefecture-level cities with more serious deficiencies in government work reports. In the end, we collected environmental regulation target data for 225 (77%) prefecture-level cities in China.

The data of A-share listed firms come from the China Stock Market & Accounting Research Database (CSMAR). This database is one of the most authoritative corporate databases in China and provides very detailed corporate financial data. In the process of data sorting, we screened and processed the original data as follows: First, we excluded financial industry firms such as banks and insurance firms and firms with severely missing values for key variables. ST/PT firms are also excluded because their financial conditions are abnormal.\(^1\) Second, to prevent the influence of outliers, we carried out [1%, 99%] tailing treatment for the main financial variables. After the above treatment, a total of 2387 A-share listed firms were obtained. Finally, after matching the two datasets, our sample contains 17,850 observations from 2387 listed firms in 225 cities in China from 2004 to 2014.

### Models

The signing of the PRTRL in 2007 provided a quasi-natural experimental environment for investigating the impact of environmental regulations. We use the difference-in-difference model to identify the impact of environmental regulations. We use the cash paid to and for employees divided by the number of employees in the firm.\(^3\)

The control variables in this study are variables that affect the wages of employees at the firm level, including (1) firm age. The survival time of a firm in the market will affect the wages of employees at the firm level, including wages paid to employees, bonuses, allowances and subsidies, pension insurance, unemployment insurance, supplementary pension insurance, housing provident funds and payments to employees, and housing difficulties subsidies. We use the cash paid to and for employees divided by the number of employees in the firm.\(^3\)

\(^1\) According the Chinese Company Law, listed firms that have reported losses (negative net earnings) for two consecutive years are categorized as “special treatment” (ST), whereas companies that have reported losses for three consecutive years are to be put into “particular treatment” (PT) status and are suspended from the exchanges. ST firms are limited to 5% share-price movements up or down daily. PT firms are given a maximum one-year grace period to return to profitability, failing which they will be permanently delisted from the stock exchange. There are no ST/PT firms in our sample.

\(^2\) In this study, only if the city where a company is clearly located puts forward the value of the decline in pollutant emissions is the company recognized as part of the treatment group. For example, in the 2008 government work report of Guangzhou City, “chemical oxygen demand and SO2 emissions decreased by 0.9% and 10.4%, respectively.” The authors believe that the enterprises in Guangzhou’s jurisdiction were subject to strict environmental regulations that year.

\(^3\) China’s wage system is usually a basic wage plus welfare. Welfare usually includes bonuses, endowment insurance, medical insurance, unemployment insurance, work injury insurance and maternity insurance, housing provident funds, and so on. The cash paid to and for employees includes wages, bonuses, allowances and subsidies paid to employees, pension insurance, unemployment insurance, supplementary pension insurance, housing provident funds, and housing difficulties subsidies paid to employees. Therefore, it is appropriate for us to use cash paid to and for employees to measure employees’ actual wages from the firm.
study uses the natural logarithm of the difference between the current year and the year when the firm opened. (2) Firm debt ratio. The level of debt ratio of the firm will affect the wage income of firm employees by affecting the labor cost (Chemmanur et al. 2013). This study uses the ratio of the total debt to the total assets of the firm to express the debt ratio. (3) Firm scale. Generally, the larger the size of a firm is, the stronger its market competitiveness and its ability to increase employees’ wages (Brown and Medoff 1989; Fujiwara-Greve and Greve 2004). This study uses the natural logarithm of the firm’s total assets to measure the scale. (4) Profitability. An increase in firm profits will increase the wages of firm employees through profit sharing between employers and employees (Holmlund 1990; Arai and Heyman 2009). This study uses the firm’s return on assets to measure profitability. (5) Capital intensity. Arai (2003) used Swedish data and found that there is a significant positive correlation between capital intensity and employee wages. This variable is measured by the logarithm of the ratio of the annual average balance of net fixed assets to the annual average number of employees. (6) Firm asset structure. Under China’s imperfect financial and labor markets, there is a close relationship between wage payments and fixed assets (Gu 2021). This variable is expressed by dividing the sum of net fixed assets and inventories by total assets. (7) Number of employees in the firm. The number of employees in a firm is an important factor affecting the average wage of a firm. This study controls this to ensure that changes in the firm’s wage are indeed brought about by environmental regulations, rather than changes in the number of employees in the firm or other factors that may affect the number of employees in the firm. We use the natural logarithm of the number of employees in the firm. Table 1 shows the summary statistics for the main variables.

### Empirical results and analyses

#### Baseline results

Table 2 shows the baseline results of the impact of environmental regulations on the income of employees. Column (1) is the regression result of the full sample, in which the control variables, firm fixed effects, and year fixed effects are controlled. The results show that the coefficient of the environmental regulation variable (ER × Post) is −0.017, which is significant at the 5% level, and which means that compared to the control group, environmental regulation reduces the average wage of the employees in the treatment group by 1.7%. According to the previous analysis, those that are truly affected by environmental regulations should be polluting industry firms in prefecture-level cities that set clear pollution reduction targets, and nonpolluting industry firms will hardly be affected. To this end, according to the “Announcement on the Implementation of Special Emission Limits for Air Pollution” issued by the Ministry of Ecology and Environment of the People’s Republic of China and the study of He et al. (2020), we divided the full sample into polluting industry firms and nonpolluting industry firms (see Table 11) to further explore the impact of environmental regulations on the income of employees. The results are shown in columns (2) and (3) in Table 2. Environmental regulations have significantly reduced the average wage of polluting firms, and they have no significant impact on non-polluting firms. Compared with firms in the polluting industry in the control group, environmental regulations have reduced the average wage of firms in the polluting industry in the treatment group by 3.2%.

#### Robustness checks

To ensure the robustness of the benchmark regression results, we conducted a series of tests. The first is the test of parallel trend assumption. An important assumption for the difference-in-difference estimation is that if there is no environmental regulation, the average wages of employees in the treatment group and the control group have a strict common trend. To verify the common trend of the treatment group and the control group, we extend Model (1) to the following event study equation for testing:

\[
\ln wage_{it} = a + \beta_k \sum_{k=-3}^{5} D_{t_0}^k + \xi X_{it} + \eta_i + \gamma_t + \epsilon_{it} \tag{2}
\]

where \( \ln wage_{it} \) is the dependent variable, which represents the employee’s income of firm \( i \) in year \( t \). \( D_{t_0}^k \) is a series of “event-time” dummies that equal one when the environmental regulations are \( k \) years away in a firm. \( t_0 \) represents the year when firm \( i \) began to be affected by environmental regulations.

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Table 1 Summary statistics

| Variable | Obs | Mean | S.D | Min | Max |
|----------|-----|------|-----|-----|-----|
| lnwage   | 17,850 | 11.073 | 0.729 | 9.296 | 13.523 |
| ER × Post | 17,850 | 0.263 | 0.440 | 0 | 1 |
| lnage    | 17,850 | 2.645 | 0.477 | 0.693 | 3.258 |
| lev      | 17,850 | 0.454 | 0.213 | 0.045 | 0.908 |
| size     | 17,850 | 21.666 | 1.273 | 14.937 | 28.509 |
| roa      | 17,850 | 0.039 | 0.056 | −0.194 | 0.204 |
| Incapital | 17,850 | 12.434 | 1.150 | 9.539 | 15.855 |
| lnL      | 17,850 | 7.454 | 1.330 | 3.664 | 10.902 |
| tang     | 17,850 | 0.418 | 0.185 | 0.033 | 0.833 |

All monetary values are in real terms. For definitions of these variables, see Table 10 in the Appendix.
regulations, and $k$ is the difference between the current year and $t_{0}$. During the operation, we merge all periods of more than 4 years before the implementation of environmental regulations into the 4th year before implementation. All periods of more than 5 years after the implementation of environmental regulations are merged into the 5th year after implementation. The 4th year before implementation was selected as the base period. Therefore, $D_{t-k}$ is a series of dummies indicating whether $t - t_{0} = k$, with $k = -3, -2, -1, 0, 1, 2, 3, 4, 5$. By focusing on the year dummies leading up to the environmental regulation, this specification provides us with an opportunity to check whether there is any evidence of preexisting trends, which in turn serves as an effective way to verify whether our main results suffer from selection bias. In addition, the year dummies after the environmental regulation identify dynamics in the reform’s effect. $X$ is the control variable in this study, which is mainly an index that can affect the income level of employees at the firm level. $\gamma_{i}$ is a fixed effect at the firm level. $\eta_{t}$ is a time fixed effect. $\epsilon_{it}$ is an error term. In the regressions, the standard errors are clustered by firm.

The estimated results are shown in Fig. 2. The $x$-axis label $-3$ represents the third year before the implementation of environmental regulations, and the rest can be deduced by analogy. The red dashed line represents the 95% confidence interval. From the results, before the implementation of environmental regulations, the change trends of the treatment group and the control group are the same, there is no significant trend difference, and the parallel trend assumption is satisfied. After the implementation of environmental regulations, environmental regulations have a significant negative impact on the average wage of employees in polluting industries, while firms in nonpolluting industries have not been affected by environmental regulations, and this effect has a certain degree of sustainability in the short term.

Second, we ruled out the impact of some policies in the same period. Specifically, before the signing of the PRTRL, in 1998, the Chinese government began to implement the Two Control Zone (TCZ) policy for acid rain and SO2 to reduce the trend of aggravating air pollution. However, the actual implementation of the TCZ policy had its intended effect only after 2005 (Chen et al. 2018a, b). To eliminate the impact of the TCZ policy, in panel A in Table 3, we control for the interaction of the year dummy variable before and after the TCZ policy and the firm dummy variables for whether the firm is located in the TCZ areas. Second, to address environmental pollution, the Chinese government issued and implemented the Air Pollution Prevention and Control Action Plan (APPCAP) in 2013. For this reason, in panel B of Table 3, we have deleted the samples of 2013 and 2014. Finally, in 2011, the Chinese government began to try to use the market mechanism represented by the carbon emissions trading (CET) policy to promote environmental protection in seven provinces and cities. In panel C in Table 3, we control for the interaction of the year dummy variable before and after the CET policy and the firm dummy variables for whether the firm is located in the CET areas. All the results show that the environmental policies of the same period will not affect our estimates, and our conclusions are still valid.

Third, the impact of the financial crisis was considered. In the sample interval of this study, the outbreak of the global financial crisis in 2008–2009 had a large impact on the production and operation of firms. To cope with the impact of the financial crisis, firms were very likely to reduce costs by reducing the average wage of employees, which leads to the findings of this study not being entirely based on environmental regulations. After the financial crisis, firms also needed a long time to recover. Taking into account the long-term impact of the economic crisis, we removed all samples from 2008 and after and re-examined the impact

| Dependent variable | lnwage | Polluting industries | Nonpolluting industries |
|--------------------|--------|----------------------|-------------------------|
|                    |        | (1)                  | (2)                     | (3)                     |
| ER × Post          | $-0.017^{**}$ | $-0.032^{**}$ | $-0.012$               |                        |
|                    | (0.008) | (0.014)              | (0.009)                 |                         |
| Image              | $0.164^{***}$ | $0.265^{***}$ | $0.138^{***}$           |                        |
|                    | (0.034) | (0.065)              | (0.039)                 |                         |
| lev                | $0.039$ | $-0.198^{**}$ | $0.125^{**}$            |                        |
|                    | (0.049) | (0.095)              | (0.056)                 |                         |
| size               | $0.302^{***}$ | $0.230^{***}$ | $0.314^{***}$           |                        |
|                    | (0.018) | (0.035)              | (0.021)                 |                         |
| roa                | $0.464^{***}$ | $0.515^{***}$ | $0.427^{***}$           |                        |
|                    | (0.091) | (0.163)              | (0.110)                 |                         |
| Incapital          | $0.108^{***}$ | $0.114^{***}$ | $0.113^{***}$           |                        |
|                    | (0.011) | (0.029)              | (0.012)                 |                         |
| lnL                | $-0.494^{***}$ | $-0.435^{***}$ | $-0.504^{***}$          |                        |
|                    | (0.017) | (0.036)              | (0.019)                 |                         |
| tang               | $-0.082$ | $-0.054$             | $-0.116^{*}$            |                        |
|                    | (0.051) | (0.085)              | (0.059)                 |                         |
| Firm fixed effects | Y      | Y                    | Y                       |                         |
| Year fixed effects | Y      | Y                    | Y                       |                         |
| Observations       | 17,850 | 4338                 | 13,512                  |                         |
| $R$-squared        | 0.699  | 0.728                | 0.693                   |                         |

Standard errors are clustered at the firm level.

*Indicates a significance level of 10%

**Indicates a significance level of 5%

***Indicates a significance level of 1%
Fig. 2 Testing for the parallel trend assumption: (A) polluting industries and (B) nonpolluting industries. Standard errors are clustered at the firm level.

Table 3 Testing for concurrent policies

| Dependent variable | Polluting industries | Nonpolluting industries |
|-------------------|----------------------|-------------------------|
| lnwage            | (1)                  | (2)                     |

Panel A: “Two Control Zone” policy
- \( \text{ER} \times \text{Post} \)  
  \(-0.031^{**} \)  
  \(-0.011 \)  
  \(0.014\)  
  \(0.009\)
- \( \text{TCZ} \times \text{Post2005} \)  
  \(-0.058 \)  
  \(-0.068^* \)  
  \(0.051\)  
  \(0.038\)
- Observations  
  4338  
  13,512
- \( R \)-squared  
  0.728  
  0.693

Panel B: Air Pollution Prevention and Control Action Plan
- \( \text{ER} \times \text{Post} \)  
  \(-0.038^{**} \)  
  \(0.002 \)  
  \(0.017\)  
  \(0.010\)
- Observations  
  3271  
  9951
- \( R \)-squared  
  0.709  
  0.665

Panel C: Carbon Emissions Trading policy
- \( \text{ER} \times \text{Post} \)  
  \(-0.026^* \)  
  \(-0.010 \)  
  \(0.014\)  
  \(0.009\)
- \( \text{CET} \times \text{Post2011} \)  
  \(-0.075^{**} \)  
  \(-0.045^{***} \)  
  \(0.034\)  
  \(0.017\)
- Observations  
  4338  
  13,512
- \( R \)-squared  
  0.729  
  0.693
- Control variables  
  \( Y \)  
  \( Y \)
- Firm fixed effects  
  \( Y \)  
  \( Y \)
- Year fixed effects  
  \( Y \)  
  \( Y \)

Standard errors are clustered at the firm level.
- *Indicates a significance level of 10%
- **Indicates a significance level of 5%
- ***Indicates a significance level of 1%
of environmental regulations on the wages of employees. In Panel A in Table 4, we find that the conclusions of this study have not been affected by the global financial crisis and are basically consistent with the findings of the baseline results.

Fourth, firms enter or exit the market. In the above analysis, this study mainly uses noncontinuous samples of firms for empirical testing, and there may be a gap between the wages of employees before the firm enters or exits the market and the normal operating firm, which may affect the estimation results of this study. To eliminate the impact of the behavior of firms entering or exiting the market, this study retains only the samples of firms that exist continuously in the sample interval and uses balanced panel data for empirical analysis. The results are shown in panel B in Table 4. The conclusions of this study have not changed significantly.

Fifth, firms’ relocation is considered. Existing studies have shown that when facing strict environmental regulations, firms will evade supervision by relocating to areas with relatively loose environmental regulations (Chen et al. 2018a, b; Zhao et al. 2020). After the signing of the PRTRL in 2007, some prefecture-level cities issued clear environmental regulation goals while others did not. This makes it possible for firms to relocate to prevent the impact of environmental regulations. Since the introduction of the environmental regulation targets of each city, a total of 32 firms in our sample have undergone relocation. Correspondingly, we exclude these firms and re-estimate the impact of environmental regulations on the income of employees. The results are shown in panel C in Table 4. Environmental regulations have indeed reduced the average wage of employees in polluting firms, while the average wage level of employees in nonpolluting firms has not been significantly affected.

Sixth, regional time trends. In the parallel trend test in Fig. 2, the wage level of polluting firm employees has a certain downward trend before the policy is implemented, which may mean that the decline in wages of polluting firm employees is not entirely caused by environmental regulatory policies. Therefore, in panel A of Table 5, we add the city time trend item to eliminate the impact of this downward trend. The results show that after controlling the city time trend items, environmental regulations still significantly reduce the wages of polluting firms, and the conclusions of this article have not changed.

Seventh, change estimation method is considered. Although our treatment group and control group have a strict common trend in the dependent variable, if the treatment group and the control group differ greatly in other aspects, the accuracy of our estimated results may also be affected. For this reason, we replaced the original estimation method and adopted propensity score matching with a difference-in-difference (PSM-DID) estimator to re-examine the results of this article. The specific method is to use the propensity score matching method to screen out samples of the control group that are similar to other aspects of the treatment group and use the screened treatment group and control group to re-estimate the difference-in-difference model. In Table 12, we performed a balance test of the matching variables. The results showed that the prematching treatment group and control group differ greatly in other aspects, the common trend in the dependent variable, if the treatment group and control group have a strict common trend, the results in Table 12 show that after control, the difference in wages of polluting firms and nonpolluting firms have indeed reduced the average wage of employees in polluting firms, while the average wage level of employees in nonpolluting firms has not been significantly affected.

| Table 4 | Other robustness checks |
| --- | --- |
| Dependent variable | Inwage |
| | Polluting industries | Nonpolluting industries |
| Panel A: the global financial crisis | | |
| ER × Post | −0.079** | −0.036 |
| (0.037) | (0.027) |
| Observations | 1174 | 3347 |
| R-squared | 0.623 | 0.581 |
| Panel B: enter or exit the market | | |
| ER × Post | −0.040** | −0.009 |
| (0.019) | (0.012) |
| Observations | 2861 | 8232 |
| R-squared | 0.738 | 0.708 |
| Panel C: firms’ relocation | | |
| ER × Post | −0.030** | −0.013 |
| (0.014) | (0.009) |
| Observations | 4273 | 13,256 |
| R-squared | 0.728 | 0.708 |
| Control variables | Y | Y |
| Firm fixed effects | Y | Y |
| Year fixed effects | Y | Y |

Standard errors are clustered at the firm level.

*Indicates a significance level of 10%

**Indicates a significance level of 5%

***Indicates a significance level of 1%
regulations on firm employee income in different regions and different levels of political promotion incentives. First, the pollution reduction targets of various regions in China during the 11th Five-Year Plan period are very different. Pollution in the eastern region is approximately twice as high as that in the central and western regions (Geng et al. 2021). In the actual implementation process, the enforcement of environmental regulations in the eastern region is also significantly stricter than that in the central and western regions (Shi and Xu 2018). Therefore, this study predicts that after the implementation of environmental regulations, the average wage of firm employees in the eastern region will drop significantly. The regression results by region are shown in panel A in Table 6. Compared with polluting firms in the central and western regions, the negative impact of environmental regulations on the average wage of polluting firms in the eastern region is more obvious. This effect only in polluting firms and the average wage of employees in nonpolluting firms has not been affected by environmental regulations. This also provides strong evidence for the previous analysis of this study.

Second, we also investigated the important role of political promotion incentives in the impact of environmental regulations on the income of employees. As a result of the signing of the PRTRL in 2007, pollution reduction has been included in the assessment of the political promotion of local officials, and local government officials with obvious political promotion incentives will more actively and conscientiously implement the environmental regulation goals of the central government to seek political position promotion. Existing research shows that when China’s prefecture-level city leaders (the highest-ranked political leader in a prefecture-level city) are over 57 years old, they will be successively selected for “second-line” jobs such as the National People’s Congress and the Chinese People’s Political Consultative Conference, and their chances of political promotion will be greatly reduced (Wang 2016). Following the example of He et al. (2020), we divide the whole sample into a “strong political promotion incentive group” and a “weak political promotion incentive group” with the 57-year-old secretary of the municipal party committee as our example and explain that the impact of environmental regulations on the income of employees is heterogeneous in the degree of political promotion incentives for different officials. Panel B in Table 6 shows that compared with regions with weak political promotion incentives, the negative impact of environmental regulations on the average wage of polluting firms in regions with strong political promotion incentives is more pronounced. At the same time, whether it is a strong political promotion incentive area or a weak political promotion incentive area, environmental regulations have no significant impact on the average wage of nonpolluting employees.

### Mechanism analysis

Our theoretical analysis shows that environmental regulations will reduce employee income by increasing costs and raising financing constraints. In this section, we present our verification.

#### Increasing cost

In Table 7, we discuss the impact of environmental regulations on firm costs. We use the difference between the total cost and the wages paid by the firm to the employees and the cash paid for the employees to measure the cost of the firm. The advantage of this approach is that it can observe the direct impact of environmental regulations on other costs in addition to the cost of firm wages. In addition, we controlled the natural logarithm of the firm’s wage cost to prevent indirect changes in other costs caused by changes in the firm’s wage cost. The results show that environmental regulations have increased the cost of polluting firms, and the regression coefficient is significant at the 5% level. Compared with polluting firms in the control group, environmental regulations have increased the cost of polluting firms.
in the treatment group by 4.4%. For nonpolluting firms, the impact of environmental regulations on their costs is not obvious. The above results show that environmental regulations have indeed increased the cost of polluting firms and have a negative impact on the average wage of polluting firms’ employees.

**(Improving financing constraints)**

Improving financing constraints is another important channel. Drawing on the research of Hadlock and Pierce (2010), we use the SA index to measure firms’ financing constraints. The SA index is a commonly used index to measure financing constraints. The larger the value is, the stronger the financing constraints faced by the firm. The calculation method is

\[
SA_{index} = -0.737 \times size + 0.043 \times size^2 - 0.040 \times age
\]  

### Table 6

|                          | Polluting industries | Nonpolluting industries |
|--------------------------|----------------------|-------------------------|
| **Panel A: eastern versus central and western regions** |                      |                         |
| ER × Post – eastern regions | \(-0.033^*\)          | \(-0.011\)               |
| (0.017)                  | (0.010)              |                         |
| Observations             | 2628                 | 9991                    |
| R-squared                | 0.720                | 0.688                   |
| ER × Post – central and western regions | \(-0.026\)          | 0.013                   |
| (0.022)                  | (0.018)              |                         |
| Observations             | 1710                 | 3521                    |
| R-squared                | 0.747                | 0.720                   |
| **Panel B: strong versus weak political incentives** |                      |                         |
| ER × Post – strong incentive | \(-0.036^{**}\)       | \(-0.016\)               |
| (0.016)                  | (0.011)              |                         |
| Observations             | 3191                 | 8694                    |
| R-squared                | 0.737                | 0.691                   |
| ER × Post – weak incentive | 0.008               | 0.025                   |
| (0.029)                  | (0.019)              |                         |
| Observations             | 1147                 | 4818                    |
| R-squared                | 0.708                | 0.699                   |
| Control variables        | Y                    | Y                       |
| Firm fixed effects       | Y                    | Y                       |
| Year fixed effects       | Y                    | Y                       |
| Observations             | 4341                 | 13,331                  |
| R-squared                | 0.671                | 0.567                   |

Standard errors are clustered at the firm level. *Indicates a significance level of 10% **Indicates a significance level of 5% ***Indicates a significance level of 1%

### Table 7

|                           | Incost                  |
|---------------------------|-------------------------|
|                           | Polluting industries    | Nonpolluting industries |
| **Dependent variable**    |                         |                         |
| ER × Post                 | 0.044^{**}              | 0.023                   |
| (0.022)                  | (0.017)                 |                         |
| Control variables         | Y                       | Y                       |
| Firm fixed effects        | Y                       | Y                       |
| Year fixed effects        | Y                       | Y                       |
| Observations              | 4341                    | 13,331                  |
| R-squared                 | 0.671                   | 0.567                   |

Standard errors are clustered at the firm level. Control variables are factors that affect firm costs, including firm wage costs, asset structure, sales expense ratio, and financial expense ratio. *Indicates a significance level of 10% **Indicates a significance level of 5% ***Indicates a significance level of 1%
Polluting industries

| Dependent variable | Polluting industries | Nonpolluting industries |
|--------------------|----------------------|-------------------------|
|                    | SA Index | Inwage | SA Index | Inwage |
| ER × Post          | 0.012*** | −0.029** | 0.004 | −0.013 |
|                    | (0.004) | (0.014) | (0.002) | (0.009) |
| SA Index           | −0.273* | 0.138 | (0.154) | (0.105) |
| Control variables  | Y | Y | Y | Y |
| Firm fixed effects | Y | Y | Y | Y |
| Year fixed effects | Y | Y | Y | Y |
| Observations       | 4338 | 4338 | 13,513 | 13,512 |
| R-squared          | 0.992 | 0.729 | 0.990 | 0.693 |

Standard errors are clustered at the firm level.

*Indicates a significance level of 10%

**Indicates a significance level of 5%

***Indicates a significance level of 1%

where size is the logarithm of total assets and age is firm age. Since the impact of firms’ financing constraints on employee income is not as direct as firm costs, we use the mediation effect model for analysis. In column (1) of Table 8, the regression coefficient of environmental regulations on the financing constraints of polluting firms is significantly positive at the level of 1%, indicating that environmental regulations have indeed increased the level of financing constraints faced by polluting firms. In column (2), we put the environmental regulation variable and the SA index variable into the regression at the same time. We find that both are significantly negative and that the coefficient of the environmental regulation variable is lower than the coefficient of the baseline regression result. This shows that environmental regulations have indeed reduced the average wage of polluting firms’ employees by increasing financing constraints. Similarly, the results in columns (3) and (4) show that environmental regulations have not increased the level of financing constraints faced by nonpolluting firms. These results also mean that environmental regulations have indeed reduced the average wage of firms by increasing financing constraints.

Further analysis: who truly bears the costs?

Our research proves that environmental regulations will lower the average wage of employees. However, a more concerning issue is who among the firms has experienced a decline in wages, that is, who truly bears the cost of environmental regulations. To further analyze this issue, referring to the ideas of Card et al. (2016) and Kline et al. (2019), we calculated the average wage of firm management and ordinary employees separately and then examined the impact of environmental regulations on the average wage of firm management and ordinary employees. Specifically, we calculated the average wage of management based on the total annual wage of directors, supervisors, and senior management disclosed in the annual report of the listed firm divided by the size of the management. Among these, the management scale refers to the “total number of directors, supervisors, and senior executives” minus the “number of independent directors” and “the number of unpaid directors, supervisors, and senior executives.” At the same time, we use “wages paid by the firm to the employees and the cash paid for the employees” in the cash flow statement minus “total annual wage of directors, supervisors, and senior management” to indicate the total wage of ordinary employees and then divide by the number of ordinary employees to obtain the average wage of ordinary employees. The number of ordinary employees is the total number of employees after deducting all management and the number of unpaid directors, supervisors, and senior executives.

The results of columns (1) and (2) in Table 9 show that the impact of environmental regulations on the average wage of polluting firm management is not significant and that the impact on the average wage of ordinary employees is significantly negative at the 5% level. This shows that environmental regulations have reduced the average wage of ordinary employees in polluting firms but have not reduced the average wage of management in polluting firms. On average, the average wage of ordinary employees has dropped by 3.1%. The results in columns (3) and (4) show that environmental regulations have no significant impact on the average wage of management and ordinary employees of nonpolluting firms. This result means that ordinary employees of polluting enterprises are one of the primary bearers of the cost of environmental regulations. Taking into account the social impact of the decline in the average wages of ordinary employees, environmental regulations have further expanded the functional income distribution.

Conclusions

Where environmental regulations are generally implemented, the spillover effects of environmental regulations have also received increasing attention. This study uses the quasi-natural experiment of the Chinese central government to incorporate environmental performance into the assessment targets of municipal officials in 2007 and the panel data of listed firms to explore the impact of environmental regulations on firm employee income. We found that (1) environmental regulations reduced the average wage of
employees in polluting firms by 3.2%, while the average wage of employees in nonpolluting firms was not affected. This result still exists after excluding the policies of the same period, financial crisis, firm entry, exit from the market, or relocation. (2) The impact of environmental regulations on the average wage of polluting firms is more pronounced in eastern China, where environmental regulations are more stringent, and in areas with stronger political promotion incentives. (3) Firm costs and financing constraints are important channels through which environmental regulations affect firm employee income. When environmental regulations lead to an increase in firm costs and financing constraints, firms will reduce the average wage of their employees. (4) Our research further finds that the decline in firm employee income is mainly reflected in the decline in ordinary employee income, and management income shows no obvious impact. In other words, environmental regulations have expanded the functional income distribution.

The conclusions of this study have two findings: (1) Many countries in the world have environmental regulatory measures. As environmental pollution problems are becoming increasingly serious, more stringent environmental regulations may be implemented in the future. When evaluating these environmental regulations, we should not only consider the improvement of the ecological environment but should also pay attention to the negative impact of environmental regulation on firms, especially the negative impact on the income of employees in polluting firms. In the process of top-level design of environmental regulations, the benefits and costs of environmental regulations should be fully considered. (2) According to our research conclusions, government departments should consider introducing some supporting policies to reduce firm costs and financing constraints to alleviate the adverse effects of environmental regulations on the income of firm employees, such as providing special government subsidies, tax incentives, loan interest concessions, and expansion of bank credit. At the same time, in the long run, firms should be encouraged to use cleaner energy and green equipment to achieve a win–win situation between the improvement of the ecological environment and the green and healthy development of firms.

### Appendix 1

**Table 9 Who bears the cost?**

| Dependent variable | Polluting industries | Nonpolluting industries |
|--------------------|----------------------|-------------------------|
|                    | lnmw                 | lncw                    | lnmw           | lncw           |
|                    | (1)                  | (2)                     | (3)            | (4)            |
| ER × Post          | −0.017               | −0.031**                | −0.012         | −0.014         |
|                    | (0.023)              | (0.016)                 | (0.011)        | (0.010)        |
| Control variables  | Y                    | Y                       | Y              | Y              |
| Firm fixed effects | Y                    | Y                       | Y              | Y              |
| Year fixed effects | Y                    | Y                       | Y              | Y              |
| Observations       | 4158                 | 4171                    | 12,874         | 12,886         |
| R-squared          | 0.559                | 0.712                   | 0.612          | 0.707          |

*Indicates a significance level of 10%

**Indicates a significance level of 5%

*Indicates a significance level of 1%

### Table 10 Variable definitions

| Variable | Definition |
|----------|------------|
| lnwage   | Logarithm of (wages paid by the firm to the employees and the cash paid for the employees/the number of employees) |
| ER × Post| If a clear environmental regulation target is issued in a certain year after the PRTRL is signed, the value is 1; 0 otherwise |
| lnage    | Logarithm of (firm’s age) |
| lev      | Total liabilities/total assets |
| size     | Logarithm of total assets |
| roa      | Net profit/total assets |
| Lncapital| Logarithm of (the annual average balance of net fixed assets/the annual average number of employees) |
| lnL      | Logarithm of the number of employees |
| tang     | (net fixed assets + inventories)/total assets |
Appendix 2

Table 11  Polluting vs. nonpolluting industries

| Polluting industries                        | Code | Nonpolluting industries                                      |
|--------------------------------------------|------|-------------------------------------------------------------|
| Coal mining and washing industry          | 6    | All industries except finance-related industries and polluting industries |
| Oil and natural gas mining industry        | 7    |                                                             |
| Ferrous metal mining and dressing industry | 8    |                                                             |
| Nonferrous metal mining and dressing industry | 9    |                                                             |
| Textile industry                          | 17   |                                                             |
| The leather, fur, and feather products and shoemaking industry | 19 |                                                             |
| Paper and paper product industry          | 22   |                                                             |
| Petroleum processing, coking, and nuclear fuel processing industry | 25 |                                                             |
| Chemical raw material and chemical product manufacturing | 26 |                                                             |
| Chemical fiber manufacturing              | 28   |                                                             |
| Rubber and plastic product industry       | 29   |                                                             |
| Nonmetallic mineral product industry      | 30   |                                                             |
| Ferrous metal smelting and rolling processing industry | 31 |                                                             |
| Nonferrous metal smelting and rolling processing industry | 32 |                                                             |
| Metal products industry                   | 33   |                                                             |
| Electric power, heat production, and supply industry | 44 |                                                             |

Industrial classification for “Industrial Classification of National Economy (GB/T 4754–2011).” The division between polluting industries and nonpolluting industries is according to the “Announcement on the Implementation of Special Emission Limits for Air Pollution” issued by the Ministry of Ecology and Environment of the People’s Republic of China and the study of He et al. (2020)
Appendix 3

Table 12  The balancing test

| Variables | Unmatched matched | Mean | %bias | %reduct | t test | t | p>|tl| |
|-----------|-------------------|------|-------|---------|--------|---|-----|
|           | Treated            | Control |       |         |        |   |     |
| Panel A: polluting industries                      |                   |       |       |         |        |   |     |
| lnage     | U                  | 2.426 | 2.466 | −8.8   | 79.7   | −2.61 | 0.009 |
|           | M                  | 2.452 | 2.460 | −1.8   | 67.3   | −0.42 | 0.673 |
| lev       | U                  | 0.503 | 0.483 | 10.0   | 63.2   | 2.95  | 0.003 |
|           | M                  | 0.504 | 0.500 | 3.7    | 85.9   | 0.85  | 0.394 |
| size      | U                  | 22.215| 21.927| 20.3   | 78.3   | 6.32  | 0.000 |
|           | M                  | 21.979| 22.041| −4.4   | −0.42  | −1.16 | 0.246 |
| roa       | U                  | 0.039 | 0.033 | 9.6    | 83.6   | 0.86  | 0.004 |
|           | M                  | 0.037 | 0.037 | 3.7    | 69.7   | 0.39  | 0.697 |
| Incapital | U                  | 12.949| 12.935| 1.3    | −156.4 | 0.39  | 0.695 |
|           | M                  | 12.900| 12.937| −3.3   | −0.77  | 0.443 |
| lnL       | U                  | 8.039 | 7.803 | 18.2   | 97.9   | 5.52  | 0.000 |
|           | M                  | 7.897 | 7.902 | 0.4    | 0.93   | 0.925 |
| tang      | U                  | 0.491 | 0.495 | −2.2   | 79.2   | −0.66 | 0.511 |
|           | M                  | 0.494 | 0.495 | −0.5   | 91.5   | −0.11 | 0.915 |
| Panel B: nonpolluting industries                   |                   |       |       |         |        |   |     |
| lnage     | U                  | 2.414 | 2.493 | −16.1  | 87.6   | −8.78 | 0.000 |
|           | M                  | 2.460 | 2.450 | 2.0    | 93.1   | 0.93  | 0.351 |
| lev       | U                  | 0.439 | 0.444 | −2.4   | 98.5   | −1.29 | 0.196 |
|           | M                  | 0.441 | 0.441 | −0.0   | 98.7   | −0.02 | 0.987 |
| size      | U                  | 21.614| 21.529| 6.9    | 96.2   | 3.77  | 0.000 |
|           | M                  | 21.587| 21.584| 0.3    | 90.5   | 0.12  | 0.905 |
| roa       | U                  | 0.047 | 0.038 | 16.3   | 79.8   | 8.83  | 0.000 |
|           | M                  | 0.047 | 0.045 | 3.3    | 117.1  | 1.57  | 0.117 |
| Incapital | U                  | 12.171| 12.318| −13.1  | 92.6   | −7.13 | 0.000 |
|           | M                  | 12.214| 12.203| 1.0    | 659.0  | 0.44  | 0.659 |
| lnL       | U                  | 7.372 | 7.297 | 5.6    | 84.6   | 3.06  | 0.002 |
|           | M                  | 7.349 | 7.338 | 0.9    | 695.0  | 0.39  | 0.695 |
| tang      | U                  | 0.380 | 0.399 | −10.5  | 98.2   | −5.68 | 0.000 |
|           | M                  | 0.385 | 0.386 | −0.2   | 932.0  | −0.09 | 0.932 |

The matching process uses radius matching, and the radius is 0.0001

Author contribution Renrui Xiao conceived and designed the study and analyzed the results. Guangrong Tan provided the data and wrote the paper. Baocong Huang provided the data, wrote the paper, and analyzed the results. Yuanyue Luo provided the data and wrote the paper. All authors read and approved the final manuscript.

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Data availability The data and materials used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate  Not applicable.

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