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Environmental regulation, abatement strategy, and labor income share

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Firms need to adopt abatement strategies and change their modes of production and resource allocation under the strict environmental policy, which affects the labor income share. Based on the firm-level data of China's Industrial Enterprise Database and Pollution Emission Database from 1998 to 2013, this study uses the difference-in-differences framework to test the effects and mechanisms of environmental policy on labor income share with different abatement strategies. We find that the Two Control Zone policy coupled with Environmental Performance Assessment policy (EPA-TCZ policies) in China, significantly increases the labor income share by 2.6% and reduces sulfur dioxide (SO₂) emissions. Mechanism analyses further find that firms primarily adopt abatement strategies of source control and end-of-pipe treatments to cope with environmental regulation, and labor income share is enhanced through the factor-substitute effect and the cost effect. As the result of labor income share, low-skilled firms and state-owned firms are more sensitive to environmental regulation. The results from this study provide an empirical basis for the formulation and evaluation of environmental policies in developing countries.

KEYWORDS

environmental regulation, labor income share, air pollution, abatement strategy, China

Introduction

Environmental pollution is the negative externality of economic and social activities to the environment. In order to solve this massive, spatio-temporal externality, we must internalize the externality. The implementation of a strict environmental policy is an important method for solving the internalization of externalities, but it will also lead to social problems, such as unemployment and a widening income gap. In particular, China as a developing country in the process of rapid development, the question of how to balance environmental protection and social stability is the key issue of environmental policy-making. Recently, some relevant studies have primarily examined the environmental effects, the output effects, and the trade effects of environmental policy (Chen et al., 2018). Research about the social effect of environmental policy focus on employment and income distribution (Fan, 2019; Liu et al., 2021), and the study on the labor income share effect of environmental policy is becoming an important research

topic. In particular, low-income employments and low-skilled workers are more easily affected by environmental regulation, and the widening income gap will cause serious social problems.

The existing literature mainly believes that with the continuous improvement of environmental regulation, the relative changes in labor productivity and average wages are caused by cost effects and innovation compensation effect, and the effect of the labor income share is uncertain from a theoretical point of view (Hu and Yang, 2020; Li and Hu, 2021). To cope with strict environmental policies, profit-maximizing firms will choose differentiated abatement strategies, such as “changes in production processes”, and “end-of-pipe” treatments, to alter the mode of production and resources allocation, leading to relative changes in labor productivity and wages, and thus affect the labor income share. Therefore, the total impact of environmental policy on the labor income share is uncertain and requires empirical analysis. This study attempts to explore the effects and mechanisms of environmental policy on labor income share through the identification of a firm’s abatement strategy, which is helpful in the formulation and evaluation of environmental policies.

Theoretically, the effects of environmental regulation on income distribution are mainly reflected in three components: skill premium, firm scale, and industry characteristics (Qin and Qi, 2019). Environmental regulation changes the firm’s factor structure and affects the income distribution of workers with different skill levels (Fullerton and Monti, 2013). Small firms, polluting firms, and labor-intensive firms are more susceptible to environmental regulation policies (Wang et al., 2019). Empirically, there is no consistent conclusion on the income distribution effect of environmental regulation (Chao et al., 2012; Fan, 2019), and requires sufficient empirical evidence (Pi and Shi, 2018).

In previous empirical studies, three articles were very similar to this study which all considered that environmental rules had a non-linear relationship with labor income share (Hu and Yang, 2020; Liu and Wang, 2020; Li and Hu, 2021). Using industry data, Hu and Yang (2020) found that environmental regulation was an important factor affecting labor income share. More specifically, environmental regulation had a significant U-shaped impact on labor income share through the labor skill structure. Liu and Wang (2020), using provincial panel data from 1997 to 2015, explained the inverted-U-shaped impact of environmental pollution and environmental regulation on labor income share based on the wage compensation theory. Li and Hu (2021) argued that the impact of environmental regulation on labor income share was near the inverted U-shaped inflection point using provincial panel data, with technological innovation, industrial structure adjustment, and foreign direct investment contributing to the improvement of the labor income share. The above literatures use provincial or industry data, however, the research on micro firm-level data is very scarce. How environmental policies affect firms abatement strategies and

the heterogeneous impacts on labor income share remain to be explored.

Previous studies had shown that the indicators of environmental regulation were difficult to select. Investments in pollution control, pollutant emissions, and the number of administrative penalty cases were usually used to measure environmental regulation in existing studies, which may lead to estimation bias because of endogenous problems. This study chooses two landmark policies, China’s Two Control Zones (TCZ) policy during the 10th Five-Year Plan (FYP) and the Environmental Performance Assessment (EPA) policy of the 11th FYP as quasi-natural experiments, which may overcome the endogenous problem of environmental pollution indicators used in previous studies. According to the TCZ policy in 1998, 64 cities were classified as sulfur dioxide pollution control areas and 109 cities were designated as acid rain control areas depending on the level of regional pollution, which represents a total control policy for key areas of pollution sources. The EPA policy takes the total discharge of major pollutants as a binding indicator for governments at all levels, which is a total control policy for different pollutants. The combination of TCZ and EPA (hereafter, EPA-TCZ) policies promotes the achievement of abatement targets since 2005.

This study considers the impact of the environmental regulations on the labor income share using the EPA-TCZ policies. The effects of the TCZ policy or EPA policy on the environment, trade, employment and infant mortality were respectively analyzed (Hering and Poncet, 2014; Tanaka, 2015; Cai et al., 2016). However, there are few studies about the effects of EPA-TCZ policies. Only Chen et al. (2018) and Zhang et al. (2020) combine the TCZ policy and EPA policy to study their impacts on resource allocation and economic growth.

Unlike existing studies that have paid more attention to the cost effect, innovation compensation effect and wage compensation effect (Hu and Yang, 2020; Liu and Wang, 2020; Li and Hu, 2021), we explore the influence mechanism from the view of the factor-substitute effect. Under the strict environmental policy, firms need to adopt abatement strategies and change their modes of production and resource allocation, such as replacing polluted raw materials with clean raw materials. What’s more, this paper examines the effects and mechanisms of environmental regulation on labor income share with different abatement strategies, which serves as a useful supplement to the existing research from the theoretical and empirical view.

This study enriches the empirical research on the resource allocation effect of firms’ abatement strategies. Abatement strategies discussed in the literature mainly consist of “changes in production process” and “end-of-pipe” treatments (Berman and Bui, 2001; Liu et al., 2021). In practice, firms may use fuel coal with lower sulfur content or replace pollution factors with more labor, and this “source control” strategy has been ignored in existing research. This paper shows that in addition to the above two abatement strategies, firms will also adopt “source

control” strategy to cope with environmental policy, and thus influence the labor income share. These results have practical values for making environmental policy.

This study also provides a sample of empirical research about the impact of environmental regulation on labor income share in developing countries. As China’s economy continues to grow, more attention will be paid to environmental protection, and more stringent environmental policies will be implemented, which may create more problems in income distribution. This study matches firm-level data of China’s Industrial Enterprise Database (CIED) and Pollution Emission Database (CPED) to test the effect of the total amount control policy on labor income share. This study provides support for the social effect assessment of China’s environmental policy.

The remainder of this article is arranged as follows. The second section introduces the TCZ policy and EPA policy background. The third section presents a theoretical analysis about the impact of environmental regulation on labor income share under abatement treatments. The fourth section is estimation strategy. The fifth section is the empirical analysis, which estimates the impact of EPA-TCZ policies on labor income share with the robustness test, and presents the mechanism test and heterogeneity analysis. Finally, the sixth section offers the conclusion and presents policy implications.

Policy background

Since the implementation of “Environmental Protection Law” in 1998, the central government has continuously deepened its understanding and protection of the ecological environment, and successively issued a series of environmental policies. These policies are roughly divided into three stages, the exploration stage based on the introduction of laws and regulations, the policy implementation stage based on the government performance assessment and the promotion stage of diversified environmental policies based on the combination of government administrative instructions and marketization (Yu and Yin, 2022). Among them, the most iconic policies are the TZC policy and EPA policy. The former embodies total pollution control at the regional level, and the latter addresses the discharge of various pollutants, which are respectively in the first two stages of environmental policies. During this period, the attributes of emission reduction indicators have changed from anticipatory to binding.

In 1998, the State Council formulated a sulfur dioxide emission reduction plan (that is TCZ policy) to address the increase of SO₂ emissions and the severity of acid rain. The policy classifies 64 cities as sulfur dioxide pollution control areas and 109 cities as acid rain control areas, where SO₂ emissions account for more than 60% of total emissions. The emission reduction measures proposed by the central government mainly include restricting high sulfur coal’s mining, production, transportation

and use, and emphasizing pollution control throughout the whole production process from the selection of raw materials to the production process management and “end-of-pipe” treatments. The TCZ policy also sets short-term and long-term environmental control objectives for the TCZ cities. Specifically, by the end of 2000, the SO₂ emissions in TCZ city will be lower than the quota set by the central government. By the end of 2010, the SO₂ emission will not exceed the level of 2000, and the SO₂ density in TCZ city should meet the environmental quality standard (lower than 60ug/m³).

However, the emission reduction effect of the TCZ policy was not remarkable by the end of 2000, which may be related to the anticipation of emission reduction targets and the lack of specific abatement targets (Zhang et al., 2020). In 2002, the central government assigned exact SO₂ reduction targets to provincial governments at all levels, but the reduction effect was still unsuccessful. SO₂ emissions fluctuated down from 1998 to 2002, but then increased rapidly (Figure 1). By 2005, total SO₂ emissions in TCZ cities had not declined, but enhanced by 2.9% compared to that of 2000, which may be due to the lack of effective restraint mechanism for local governments (Chen et al., 2018).

In 2005, the central government allocated the 10% reduction in major pollutants to governments at all levels as a binding condition, which has been a part of the 11th FYP (2006–2010) for the first time and a close relation to the promotion of local officials. Environmental objectives were incorporated into the environmental performance assessment of local officials, which was EPA policy implemented at the end of 2005.

During the 11th FYP period, total SO₂ emissions decreased by 12.5%. As of 2010, the SO₂ emission reduction target was achieved, and the total national SO₂ emission had decreased by 14.29%. The EPA policy continued through the 12th FYP (2011–2015). Implementation of EPA policy is helpful for the emission reduction target of the TCZ policy, which is a successful practice of the total amount control policy (Zhang et al., 2020). This study analyzes the impacts of these two combination policies (EPA-TCZ policies) on labor income share, which gives more accurately evaluation of the income distribution effect of comprehensive environmental policies and provides practical significance in the formulation and assessment of environmental policies.

Theoretical analysis

The existing studies mainly discuss the impact of environmental regulation on labor income share through two mechanisms. The first is the cost effect. Pollution emission is a part of the production function in the form of input or output (Fullerton and Metcalf, 1998; Berman and Bui, 2001; Sanz and Schwartz, 2013). Strict environmental policies make pollution emissions have a “price” and increase the marginal cost, which

not only crowds out productive investment, reducing labor productivity (Ferjani, 2011), but also reduces the output and profitability, falling average wages. The impact of environmental regulation on labor income share depends on the relative extent of the decline in labor productivity and wages¹. The second is the innovation compensation effect. Firms may adjust production behavior under environmental policies, and turn to increase research to innovate green or production technology (Porter and van der Linde, 1995), which may offset the negative impact of cost effect on output. Meanwhile, the proportion of high-skilled workers is enhanced and the average wage level is increased (Hu and Yang, 2020). Thus, the effect of environmental regulation on labor income share depends on the relative extent of the improvement in wages and labor productivity under the innovation compensation effect.

In addition to the above cost effect and innovation compensation effect, this paper regards that environmental policy may also affect the labor income share by factor-substitute effect. Environmental protection activities may be more labor-intensive than traditional production (Morgenstern et al., 2002; Zhang et al., 2020). For example, cleaner operations may require less polluting fuel and materials, or more labor for inspection, installation and maintenance activities. Firms tend to use labor to replace capital and other polluting factors of production to reduce pollution, and the demand for labor is relatively increasing, which means the labor income share has risen. However, environmental regulation policies may cause firms to adopt advanced technology processes and reduce labor demand (Berman and Bui, 2001), leading to the replacement with labor by capital and a decline in labor income share. From the above, we find that the factor-substitute effect of environmental regulation on labor income share is closely related to abatement strategy.

Abatement activities are mainly divided into two categories: “changes in production processes”, and “end-of-pipe” treatments (Liu et al., 2021). The former, such as the adoption of advanced production technology or green technology, and updating equipment to generate less emission, may require more capital and less labor. The latter refers to technologies used at the end of a production process to reduce emissions by removing produced pollutants, such as the installation of desulfurization devices. This paper regards that in response to stringent environmental policy, firms may reduce pollution emissions from the production source and adopt clean production factors to replace high-emission factors, such as the use of cleaner energy and more

labor rather than capital. We refer to this abatement strategy as “source control” strategy.

The impact mechanism of environmental regulation policies on labor income share depends on different abatement strategies. If a “source control” strategy is adopted, on the one hand, the stringent environmental policies make firms use more labor to replace capital and other polluting factors. The demand for labor is relatively increasing with the factor-substitute effect, and the labor income share is rising. On the other hand, firms input cleaner energy, and production costs increase, which makes the impacts of environmental regulation on labor income share depend on the relative decline of labor productivity and wage growth rate through the cost effect. With the strategy of “changes in production processes”, labor productivity and wage level are both improved through the innovation compensation effect, which will cause uncertain changes in the labor income share. In addition, the adoption of advanced production processes may raise the substitution of capital for labor, reducing labor demand and labor income share through the factor-substitute effect. If firms adopt “end-of-pipe” treatments, they not only need to purchase decontamination equipment, but also match the labor for maintenance and operation, which may reduce production investment and result in the decline of labor productivity and wage level with the cost effect. From the above theoretical analysis, it can be seen that the impact of environment regulation on labor income share is uncertain, and further empirical analysis is needed.

Estimation strategy

Estimation framework

To evaluate the labor income share effect of EPA-TCZ policies, we divide TCZ cities into treatment groups and non-TCZ cities into control groups, and then compare the changes in labor income share before and after the implementation of EPA policy using a difference-in-differences (DID) model. Referring to Chen et al. (2018), the regression model is as follows:

$$ls_{ijt} = \beta TCZ_i \times Post_t + \rho \ln(SO_2)_i \times f(t) + \alpha_i + \delta_t + \varepsilon_{ijt} \quad (1)$$

where ls_{ijt} represents labor income share in firm j at year t . According to Lu and Tian (2020), a firm's labor income share is defined as the proportion of total wages to total income including wages, profits, depreciation, and tax. TCZ_i equals one if firm i is located in TCZ city i in 1998, and otherwise TCZ_i equals 0. $Post_t$ equals one for all years after 2005 (policy period) and otherwise equals 0. We control city fixed effect and year fixed effect, and cluster the standard errors at the city level, following the suggestion of Bertrand et al. (2004). α_i is city fixed effect, catching the time-invariant city-specific characteristics. δ_t is

¹ By definition, labor income share (ls) can be written as wage (w) divided by labor productivity (y), $ls = w \cdot L / Y = w / (Y/L) = w/y$. It can be inferred that $\Delta \ln(ls) = \Delta \ln(w) - \Delta \ln(y)$, which depend on the relative changes in wages and labor productivity. If the changes in wage are greater than that of labor productivity, the labor income share will increase. Conversely, the labor income share will decrease.

year fixed effect, capturing factors that impact all cities over time such as macroeconomic shocks, and ε_{it} is the error term.

The coefficient β measures the DID effect of the EPA-TCZ policies on labor income share as follows:

$$\beta = \left[E(Is_{ijt}|TCZ = 1, Post = 1) - E(Is_{ijt}|TCZ = 1, Post = 0) \right] - \left[E(Is_{ijt}|TCZ = 0, Post = 1) - E(Is_{ijt}|TCZ = 0, Post = 0) \right] \quad (2)$$

The coefficient estimation of β with the DID method requires random grouping that if there is no EPA policy in 2005, the labor income share of TCZ cities has the same time trend as that of non-TCZ cities after 2005. Otherwise, there is a systematic difference between the control group and the treatment group before the implementation of the policy in 2005, which may cause the selection bias from the correlation between $TCZ_i \times Post_t$ and ε_{it} . The classifications of TCZ cities are based on the “Air Pollution Prevention and Control Law” (APPCL) revised in 1995, which stipulates that according to natural condition, such as meteorological, topographical, and soil conditions, areas producing acid rain or other areas with serious sulfur dioxide pollution are designated as acid rain control areas or sulfur dioxide pollution control areas. Obviously, TCZ cities are not randomly grouped. In order to reduce the estimation error caused by the non-random grouping of policies, we calculate the average surface concentration of urban sulfur dioxide ($\ln(SO_2)$) from 1990 to 1997 and multiplies it with the third-order polynomial of time trend ($f(t)$), which is used to capture the changes of SO_2 emissions before 1998. In addition, we perform a common trend test and a placebo test, as well as robustness tests such as replacing variables and changing sample size.

The implementation of the TCZ policy may change the characteristics of the treatment group and the control group, making them incomparable when the EPA policy was in place at the end of 2005. Existing studies show that the TCZ policy has affected exports (Hering and Poncet, 2014), GDP growth (Chen et al., 2018), and employment (Zhang et al., 2020). In order to solve this problem, we add a set of variables known in the literature that are affected by TCZ policy, including export and size at the firm level, per-capita GDP and unemployment rate at the city-level. In addition, market structure is added to reflect industry characteristics. The specific models are as follows:

$$Is_{ijt} = \beta TCZ_i \times Post_t + \rho \ln(SO_2)_i \times f(t) + \gamma Z_{ijt} + \alpha_i + \delta_t + \varepsilon_{ijt} \quad (3)$$

Where Z_{ijt} contains city and industry characteristic variables that affect labor income share, namely, urban unemployment rate, per-capita GDP, and market structure, as well as export and size at the firm level. The labor market, one of the important variables that affect the labor income share, is competitive intense and labor income share will increase (Mangin and Sedlacek, 2017). The actual per-capita GDP measured by its logarithmic form represents the economic growth of the city and is deflated by the GDP deflator in 1998 as the base year.

Previous studies have shown that market structure is also the main factor affecting labor income share, and measured by market concentration with the Herfindahl-Hirschman index in this paper. Considering the availability of data, the variable of export is measured with dummy variables, which equals one if the export delivery value of the firm is greater than 0 and otherwise equals 0. Size represented the scale of the firm, which is measured by the logarithmic form of the number of workers.

Data sources and descriptive statistics

In order to analyze the effect of the EPA-TCZ policies on labor income share, this study uses combined firm data with CIED and CPED from 1998 to 2013. We also use economic data at the city and industry levels including China’s City Statistical Yearbooks from 1999 to 2014.

China’s Industrial Enterprise Database (CIED) contains rich economic and financial information on industrial firms, such as output, assets and liabilities, and the number of employees, which are self-reported quarterly and annually by the firm and collected in a step-by-step process undertaken by the National Bureau of Statistics. The CIED covers all state-owned and nonstate-owned firms with an annual business income of more than five million, whose total output is accounting for roughly 90% of total industrial output in China, and thus has been widely used in economic literature. In this paper, we use information on the output value, the number of employees, wages, profits, value-added tax, ownership type, city, and industry code.

China’s Pollution Emission Database (CPED) is currently the most comprehensive firm-level pollution emission data in China, covering 85% of the emissions of major pollutants in each region, including SO_2 , chemical oxygen demand, and so on. This data is the original environmental data reported by industrial firms collected by the National Bureau of Statistics, and it is the specific data source for China’s Environmental Statistics Yearbooks issued every year, which has only recently been made available to researchers. The CPED contains basic firm information (firm name, legal representative information, area code, industry code), including energy use, major pollutant discharges, and treatment information, etc. In this study, we extract SO_2 emissions, SO_2 production, average sulfur of fuel coal, clean energy use, statistical year, ownership type, city, and industry code from the CPED.

Referring to the research of Brandt et al. (2012), First, CIED and CPED are matched respectively across years according to the firm name, postal code, legal representative, etc. Then, the two databases are matched according to the firms’ organizational code² in the CIED and CPED. The data from

² Considering there is some deviations in the organizational code when entering data, we remove words that are not helpful in matching the firm name to improve the matching rate

TABLE 1 Descriptive statistics.

Variables	N	Mean	SD	Min	Median	Max
ls	313742	0.351	0.196	0.0260	0.329	0.885
Export	313742	0.498	0.500	0	0	1
Size	313742	5.732	1.094	2.197	5.697	11.990
HHI	313742	0.256	0.077	0.200	0.228	0.658
Unemployment	313742	0.017	0.012	0	0.016	0.427
ln (GDP)	313742	10.128	0.900	6.905	10.179	13.056

2008 to 2010 is dropped due to the lack of wage information. In addition, we also delete samples with missing key variables and outliers that do not meet the following accounting standards as follows. 1) the number of employees in the firm is greater than 8; 2) total asset is greater than fixed assets; 3) total asset is greater than the liquid asset; 4) the accumulated depreciation value is greater than the depreciation value in the current year; 5) the output is less than five million; 6) the labor income share is between 0 and 1. The variable of labor income share is winsorized at the 1% level. Finally, we get the unbalanced panel data of 81,735 firms and 313,742 observations.

The city-level variables are from the China Statistical Yearbook and the China City Statistical Yearbook, providing some city-level economic variables, such as unemployment rate and per capita GDP. The descriptive statistics of the variables are shown in Table 1.

Main results

Baseline results

Table 2 reports the baseline results of Equation 1 and 3. Column 1) in Table 2 shows that $TCZ \times Post$, as well as city and year fixed effects, are added to Eq. 1. In order to alleviate policy selection bias, we add $\ln(SO_2) \times f(t)$ in column (2), which also contains ownership and industry fixed effect. Firm-level variables are included in column (3), and the industry-level and city-level variables are added in column (4). After adding variables one by one, the coefficients of $TCZ \times Post$ decrease gradually, but they are all significantly positive, which indicates that after the implementation of EPA-TCZ policies, firms in the TCZ cities facing stricter environmental regulations have higher significantly labor income share. From the result of point estimation, the average DID effect of the EPA-TCZ policies is 0.026, showing that compared with the firms in non-TCZ cities, the average labor income share in TCZ cities increases by 2.6%.

TABLE 2 Baseline results.

Variables	(1)	(2)	(3)	(4)
	ls	ls	ls	ls
$TCZ \times Post$	0.041*** (0.009)	0.035*** (0.008)	0.035*** (0.008)	0.026*** (0.007)
Export	—	—	-0.005 (0.004)	-0.003 (0.004)
Size	—	—	0.007*** (0.001)	0.006*** (0.001)
HHI	—	—	—	0.014 (0.016)
Unemployment	—	—	—	0.119 (0.128)
ln (GDP)	—	—	—	-0.083*** (0.009)
$\ln(SO_2) \times f(t)$	NO	YES	YES	YES
City Fixed Effect	YES	YES	YES	YES
Year Fixed Effect	YES	YES	YES	YES
Ownership Fixed Effect	NO	YES	YES	YES
Industry Fixed Effect	NO	YES	YES	YES
N	313742	313742	313742	313742
R ²	0.089	0.165	0.166	0.170

Note: Standard errors in parentheses are clustered at the city level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. If the firm is in the TCZ cities, TCZ equals one; otherwise, TCZ equals 0. $Post = 1$ for all years after 2005; otherwise $Post$ equals 0. $\ln(SO_2) \times f(t)$ indicates the interaction term of logarithmic form of SO_2 surface concentration of the city where the firm is located from 1990 to 1997 and the third-order polynomial of the time trend.

Robustness checks

Common trend test. The key assumption of the DID method is the common trend hypothesis, which means that before the implementation of the EPA-TCZ policies, labor income share in TCZ and non-TCZ cities exhibits the same trend. Figure 2 shows the changing trend of the labor income share in TCZ and non-TCZ cities. It can be found that the labor income share declined from 1998 to 2013, which is consistent with the fact that China's labor income share was reducing at the macro level during the same period. In particular, labor income share in TCZ and non-TCZ cities has the similar declining trend before 2005, but after the implementation of the EPA in 2005, the declining trend of labor income share in TCZ cities is alleviate obviously, which reveals that the treatment group and the control group meet the common trend assumption before the implementation of the policy.

In order to furtherly investigate the common trend and dynamic effect, we use the case study to explore the dynamic effect of the EPA-TCZ policies. The equation is as follows:

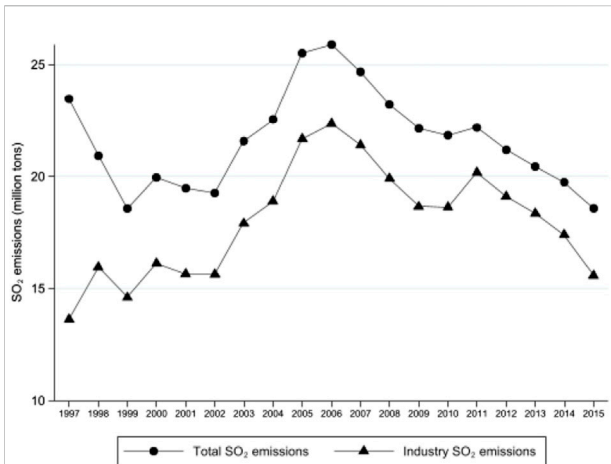


FIGURE 1
SO₂ emissions trend in 1997–2015.

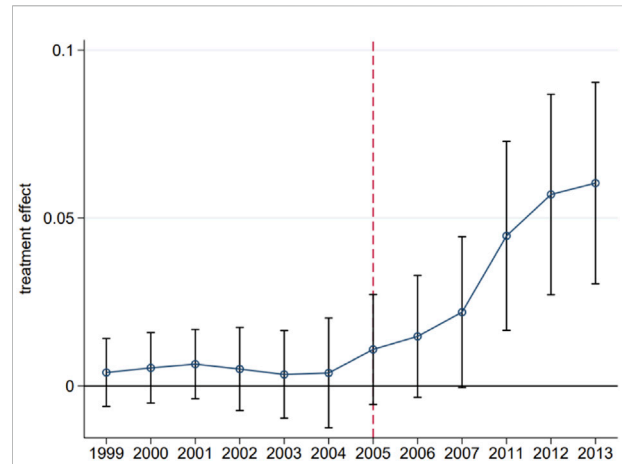


FIGURE 3
Estimated coefficients.

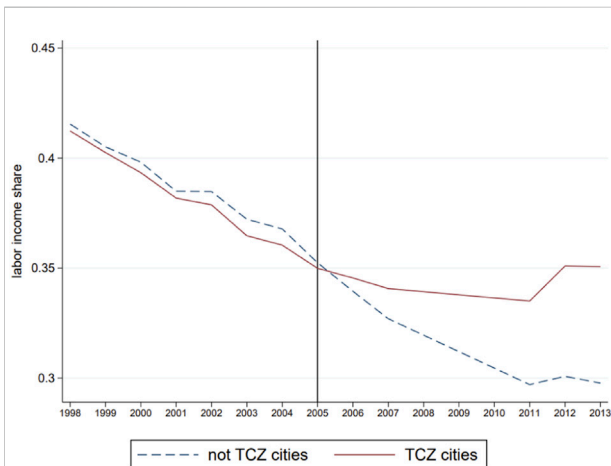


FIGURE 2
Labor income share trend in 1998–2013.

$$ls_{ijt} = \sum_{t=1998}^{2013} \beta_t TCZ_i \times \delta_t + \rho \ln(SO_2)_i \times f(t) + \gamma Z_{ijt} + \alpha_i + \delta_t + \varepsilon_{ijt} \tag{4}$$

β_t represents a series of estimation coefficients from 1998 to 2013, which captures the differences in the labor income share between TCZ and non-TCZ cities before and after the implementation of the EPA policy. As shown in Figure 3, there is no significant difference between the coefficient β and 0 before the occurrence of the EPA policy, and the effect of the policy on labor income share gradually increased after the implementation of the EPA policy in the TCZ cities compared with non-TCZ cities. This not only suggests that the common

trend assumption is met, but also indicates environmental policy has a continuous positive effect on labor income share.

Placebo test. In order to ensure a more robust conclusion, with reference to Chetty et al. (2009)’s method, we undertake a placebo test. First, the treatment firms are randomly selected from the full samples, and the other firms are regarded as the control group. Then, we define and calculate the DID dummy. Finally, the DID effect is estimated. The above processes are repeated 500 times, and the distribution of DID coefficients is shown in Figure 4, where β is primarily distributed around 0 and does not reach the real value of 0.026. This reveals that the virtual policy grouping does not have the increasing effect of labor income share, and the placebo test is consistent with expectations. Further, it shows that the increase in labor income share is caused by the EPA policy implemented in 2005.

Alternative samples. Previous studies have shown that after 2005, in order to achieve environmental performance goals, local officials in TCZ cities would rather give up economic growth and take various measures to reduce pollution emissions within their jurisdictions (Chen et al., 2018). Other policies or major events will also affect local governments to make a trade-off between economic growth and pollution emissions after 2005. For example, in order to ensure the air quality during the 2008 summer Olympic Games, local governments may further sacrifice economic growth and require most industrial firms to limit or stop production. The samples of host cities as well as co-host cities are removed to reduce the impact of the major event of the Olympic Games on the results, including Beijing, Shanghai, Tianjin, Shenyang, Qinhuangdao and Qingdao, which are given in columns 1) and 2) of Table 3. We find that β coefficient is still significantly positive, showing that the baseline result is not affected by the major events.

Change the variable definition. Considering that the value of labor income share is between 0 and 1, consistent with the work of Wei et al. (2013), we define the “odds ratio” of ls in

TABLE 3 Robustness checks.

Variables	(1) ls	(2) ls	(3) $\ln(ls/(1-ls))$	(4) $\ln(ls/(1-ls))$
$TCZ \times Post$	0.038*** (0.009)	0.025*** (0.007)	0.214*** (0.046)	0.146*** (0.037)
Control Variables	NO	YES	NO	YES
$\ln(SO_2) \times f(t)$	YES	YES	YES	YES
City Fixed Effect	YES	YES	YES	YES
Year Fixed Effect	YES	YES	YES	YES
Ownership Fixed Effect	NO	YES	NO	YES
Industry Fixed Effect	NO	YES	NO	YES
N	290660	290660	313742	313742
R^2	0.094	0.175	0.095	0.174

Note: Standard errors in parentheses are clustered at the city level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. If the firm is in the TCZ cities, TCZ equals one; otherwise, TCZ equals 0. $Post = 1$ for all years after 2005; otherwise $Post$ equals 0. Control variables include Export, Size, HHI, Unemployment and $\ln(GDP)$. $\ln(SO_2) \times f(t)$ indicates the interaction term of the average SO_2 surface concentration of the city where the firm is located from 1990 to 1997 and the third-order polynomial of the time trend.

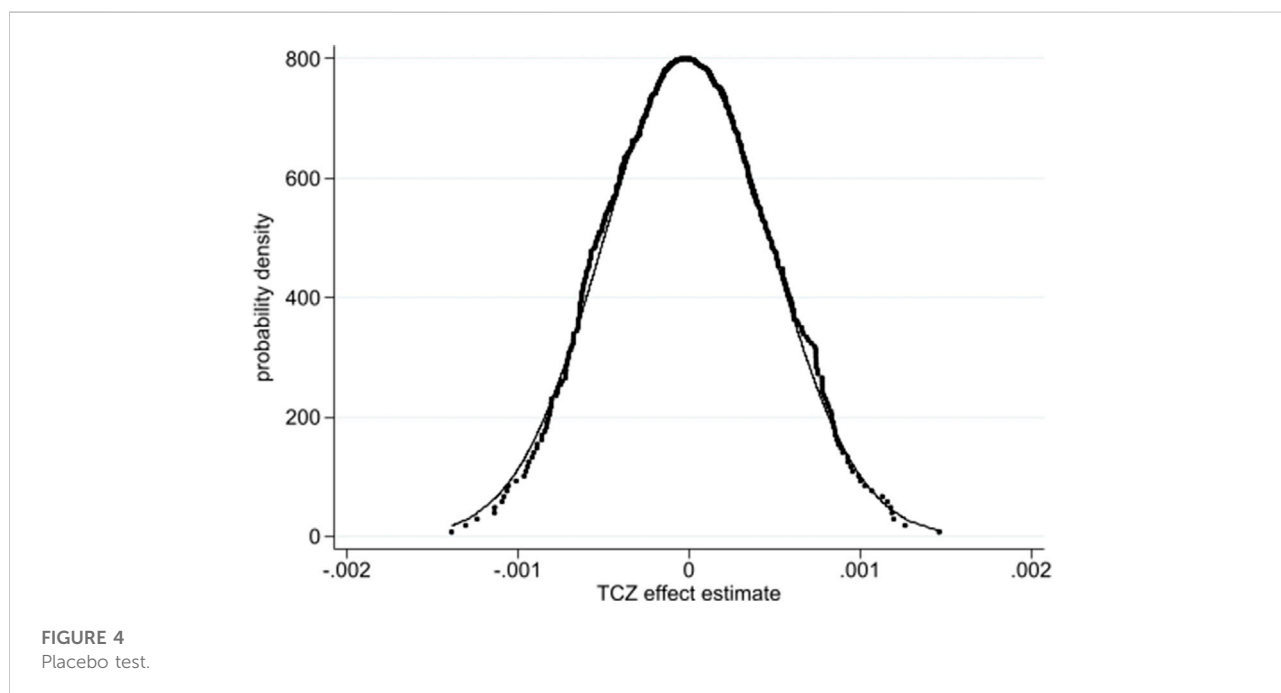


FIGURE 4
Placebo test.

the logistic model as $\ln(ls/(1-ls))$, the logarithm of the labor-capital income ratio, which is the dependent variable used in the regression. The estimated results in columns 3) and 4) show that after changing the definition of labor income share, the coefficient of $TCZ \times Post$ is still significantly positive and the point estimation suggests that the labor capital income ratio increases by 15.8% more than the non-TCZ firms, which supports the baseline conclusion.

Mechanism analysis

The main purpose of the TCZ policy is to reduce the emissions of major pollutants such as SO_2 , and the policy effectiveness need to be confirmed before carrying out the mechanism analysis. With $\ln(SO_2)$ as the proxy variable of the environmental regulation level, the EPA-TCZ policy significantly reduces sulfur dioxide emissions after control other variables in columns 2) in Table 4. With the level of

TABLE 4 Mechanism check: “source control” treatments.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	ln(SO ₂)	ln(SO ₂)	ln(K/L)	ln(K/L)	ln(clean energy)	ln(clean energy)
TCZ × Post	-0.105 (0.083)	-0.167** (0.073)	-0.103** (0.049)	-0.147*** (0.044)	0.558*** (0.214)	0.461** (0.181)
Control Variables	NO	YES	NO	YES	NO	YES
ln(SO ₂) × f(t)	YES	YES	YES	YES	YES	YES
City Fixed Effect	YES	YES	YES	YES	YES	YES
Year Fixed Effect	YES	YES	YES	YES	YES	YES
Ownership Fixed Effect	NO	YES	NO	YES	NO	YES
Industry Fixed Effect	NO	YES	NO	YES	NO	YES
N	382576	382576	528446	528446	179077	179077
R ²	0.086	0.367	0.150	0.253	0.194	0.257

Note: Standard errors in parentheses are clustered at the city level. ***p < 0.01, **p < 0.05, *p < 0.1. If the firm is in the TCZ cities, TCZ equals one; otherwise, TCZ equals 0. Post = 1 for all years after 2005; otherwise Post equals 0. Control variables include Export, Size, HHI, Unemployment and ln(GDP). ln(SO₂) × f(t) indicates the interaction term of the average SO₂ surface concentration of the city where the firm is located from 1990 to 1997 and the third-order polynomial of the time trend. Dependent variables in columns (1) and (2) are ln(SO₂) represented by the logarithmic form of SO₂ emissions. Dependent variables in columns (3) and (4) are ln(K/L) represented by the logarithmic form of per capita capital. Dependent variables in columns (5) and (6) are ln(clean energy) represented by the logarithmic form of clean energy consumption.

TABLE 5 Mechanism check: “changes in production processes” treatments.

Variables	(1)	(2)	(3)	(4)
	ln(SO ₂ sensity)	ln(SO ₂ sensity)	D _{newproduct}	D _{newproduct}
TCZ × Post	0.053 (0.032)	-0.001 (0.023)	0.053 (0.032)	-0.001 (0.023)
Control Variables	NO	YES	NO	YES
ln(SO ₂) × f(t)	YES	YES	YES	YES
City Fixed Effect	YES	YES	YES	YES
Year Fixed Effect	YES	YES	YES	YES
Ownership Fixed Effect	NO	YES	NO	YES
Industry Fixed Effect	NO	YES	NO	YES
N	383513	383513	383513	383513
R ²	0.129	0.435	0.708	0.749

Note: Standard errors in parentheses are clustered at the city level. ***p < 0.01, **p < 0.05, *p < 0.1. If the firm is in the TCZ cities, TCZ equals one; otherwise, TCZ equals 0. Post = 1 for all years after 2005; otherwise Post equals 0. Control variables include Export, Size, HHI, Unemployment and ln(GDP). ln(SO₂) × f(t) indicates the interaction term of the average SO₂ surface concentration of the city where the firm is located from 1990 to 1997 and the third-order polynomial of the time trend. Dependent variables in columns (1) and (2) are ln(SO₂ sensity) represented by the logarithm of SO₂ generated per unit of output. Dependent variables in columns (3) and (4) are D_{newproduct} which equals one if the firm has new product output; otherwise it equals 0.

environmental regulation represented by the SO₂ remove rate, the results are significantly positive shown in columns 1) and 2) in Table 6. These results offer evidence that the EPA-TCZ policy is effective at reducing firm-level SO₂ emissions in TCZ cities, which is consistent with the findings of Chen et al. (2018) and Zhang et al. (2020). On this basis, we test the mechanism of

the policy on labor income share by identifying abatement strategies.

Firms mainly adopt three abatement strategies: “source control,” “changes in production processes,” and “end-of-pipe”. Under the constraints of environmental policy, if firms adopt “source control” treatments to reduce emissions, they will

TABLE 6 Mechanism check: “end-of-pipe” treatments.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	SO ₂ remove rate	SO ₂ remove rate	ln(K)	ln(K)	ln(y)	ln(y)	ln(w)	ln(w)
TCZ × Post	0.049** (0.021)	0.044** (0.020)	-0.003 (0.050)	-0.152*** (0.047)	-0.198*** (0.051)	-0.123*** (0.035)	-0.064** (0.029)	-0.080*** (0.023)
Control Variables	NO	YES	NO	YES	NO	YES	NO	YES
ln(SO ₂) × f(t)	YES	YES	YES	YES	YES	YES	YES	YES
City Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effect	YES	YES	YES	YES	YES	YES	YES	YES
Ownership Fixed Effect	NO	YES	NO	YES	NO	YES	NO	YES
Industry Fixed Effect	NO	YES	NO	YES	NO	YES	NO	YES
N	213212	213212	528443	528443	313742	313742	313742	313742
R ²	0.194	0.223	0.121	0.466	0.287	0.389	0.306	0.376

Note: Standard errors in parentheses are clustered at the city level. ****p* < 0.01, ***p* < 0.05, **p* < 0.1. If the firm is in the TCZ cities, TCZ equals one; otherwise, TCZ equals 0. Post = 1 for all years after 2005; otherwise Post equals 0. Control variables include Export, Size, HHI, Unemployment and ln(GDP). ln(SO₂) × f(t) indicates the interaction term of the average SO₂ surface concentration of the city where the firm is located from 1990 to 1997 and the third-order polynomial of the time trend. Dependent variables in columns (1) and (2) are SO₂ remove rate calculated using the ratio of the amount of SO₂ removed over the sum of SO₂ generation. Dependent variables in columns (3) and (4) are ln(K) represented by the logarithm of fixed assets. Dependent variables in columns (5) and (6) are ln(y) represented by the logarithm of per capita output. Dependent variables in columns (7) and (8) are ln(w) represented by the logarithm of per capita wage.

increase the use of clean energy or use labor instead of capital. Here, we use capital intensity (logarithm of per capita capital, ln(K/L)), and clean energy use as measures of “source control” treatments³. The capital intensity effect of the EPA-TCZ policy is presented in columns 3) and 4) in Table 4, which reveal that the strict environmental regulation significantly reduces firm-level capital intensity and significantly increases the labor income share. This suggests that firms adopt the strategy of labor instead of capital in the short term to fight the SO₂ emissions, which is consistent with the conclusion of Zhang et al. (2020) that more labor are allocated to polluted areas. The demand effect of the EPA-TCZ policy on clean energy is provided in column 5) and (6), which demonstrates that improvements in environmental regulation help to enhance clean energy use in firms, implying that the cost effect will work and wages decline as well as labor productivity.

If “changes in production processes” treatments are adopted, firms will increase their R&D investment and improve production technology to reduce generated SO₂ before entering abatement facilities. Referring to Liu et al. (2021)’s practice, the production of SO₂ per unit output is taken as the abatement measurement of “changes in production processes” treatments. In addition, the CIED provides information in firms’ innovation behavior, and we take

3 We also find that the use of average sulfur of coal is decreasing after the implementation of EPA policy

whether a firm has a new product output (*D_{newproduct}*) as another measurement. If the firm has new product output, the value of *D_{newproduct}* equals one; otherwise it equals 0. In Table 5, the amount of SO₂ produced per unit output (columns 1) and (2)), and *D_{newproduct}* (columns 3) and (4)) are used as depended variables. The results show that the coefficients of policy variables are not significant, indicating that the environmental regulation does not encourage firms to choose the path of technological innovation to improve production efficiency and reduce pollution emissions, suggesting innovation compensation effect does not exist.

If adopting “end-of-pipe” treatments, firms do not change the production process and SO₂ generated, but only reduce SO₂ emissions by abatement facilities. Here, we use the SO₂ remove rate as the measurement of “end-of-pipe” treatments⁴. Columns 1) and 2) in Table 6 provide the results that EPA-TCZ policy

4 We also treat the number of abatement facilities as the “end-of-pipe” treatment, and estimate it as the depended variable. The results show that the impact on the number of abatement facilities is not significant, which is consistent with the results obtained by Liu et al. (2021). This may be explained as the demand for abatement equipment and statistics on the number of abatement facilities. Large-scale desulfurization equipment has strong pollutant handling capacity, and firms need a small amount of equipment to meet the abatement requirements. Thus, the amount of equipment needed will not be very significant. In addition, in order to avoid environmental regulation, firms may not report or underreport pollution emissions and abatement treatment

TABLE 7 Heterogeneous effects by workforce types.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Is	ln(K/L)	D _{newproduct}	SO ₂ remove rate	ln(y)	ln(w)
TCZ × Post × highskilled	0.008 (0.008)	-0.096 (0.063)	-0.002 (0.009)	0.064*** (0.023)	-0.039 (0.039)	-0.073** (0.028)
TCZ × Post × lowskilled	0.016* (0.009)	-0.209*** (0.064)	-0.022** (0.010)	0.060** (0.026)	-0.191*** (0.043)	-0.167*** (0.031)
Control Variables	YES	YES	YES	YES	YES	YES
ln(SO ₂) × f(t)	YES	YES	YES	YES	YES	YES
City Fixed Effect	YES	YES	YES	YES	YES	YES
Year Fixed Effect	YES	YES	YES	YES	YES	YES
Ownership Fixed Effect	YES	YES	YES	YES	YES	YES
Industry Fixed Effect	YES	YES	YES	YES	YES	YES
N	45579	95271	95287	61610	45579	45579
R ²	0.185	0.165	0.565	0.216	0.380	0.397

Note: Standard errors in parentheses are clustered at the city level. ***p < 0.01, **p < 0.05, *p < 0.1. If the firm is in the TCZ cities, TCZ equals one; otherwise, TCZ equals 0. Post = 1 for all years after 2005; otherwise Post equals 0. Firms in the treatment group are classified into two groups, high-skilled or low-skilled, according to the ratio of high school or above workers for year 2004 (a census year). Control variables include Export, Size, HHI, Unemployment and ln(GDP). ln(SO₂) × f(t) indicates the interaction term of the average SO₂ surface concentration of the city where the firm is located from 1990 to 1997 and the third-order polynomial of the time trend. SO₂ remove rate is the ratio of the amount of SO₂ removed over the sum of SO₂ generation. ln(K/L) represents the logarithmic form of per capita capital. D_{newproduct} equals one if the firm has new product output; otherwise it equals 0. ln(y) represents the logarithm of per capita output. ln(w) represents the logarithm of per capita wage.

TABLE 8 Heterogeneous effects by ownership.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Is	ln(K/L)	D _{newproduct}	SO ₂ remove rate	ln(y)	ln(w)
TCZ × Post × State-owned	0.020* (0.011)	-0.213*** (0.069)	-0.009 (0.012)	0.075*** (0.028)	-0.112* (0.063)	-0.149*** (0.049)
TCZ × Post × Private-owned	0.005 (0.009)	-0.101 (0.063)	-0.006 (0.009)	0.057** (0.024)	-0.065 (0.042)	-0.087*** (0.031)
TCZ × Post × Foreign-owned	0.019 (0.017)	-0.051 (0.112)	0.003 (0.018)	0.070** (0.031)	-0.032 (0.089)	-0.011 (0.050)
Control Variables	YES	YES	YES	YES	YES	YES
ln(SO ₂) × f(t)	YES	YES	YES	YES	YES	YES
City Fixed Effect	YES	YES	YES	YES	YES	YES
Year Fixed Effect	YES	YES	YES	YES	YES	YES
Ownership Fixed Effect	YES	YES	YES	YES	YES	YES
Industry Fixed Effect	YES	YES	YES	YES	YES	YES
N	45579	95271	95287	61610	45579	45579
R ²	0.185	0.165	0.565	0.216	0.379	0.397

Note: Standard errors in parentheses are clustered at the city level. ***p < 0.01, **p < 0.05, *p < 0.1. If the firm is in the TCZ cities, TCZ equals one; otherwise, TCZ equals 0. Post = 1 for all years after 2005; otherwise Post equals 0. State-owned equals one if a firm is state-owned; otherwise, State-owned equals 0. Private-owned equals one if a firm is private-owned; otherwise equals 0. Foreign-owned equals one if a firm is foreign-owned; otherwise, Foreign-owned equals 0. Control variables include Export, Size, HHI, Unemployment and ln(GDP). ln(SO₂) × f(t) indicates the interaction term of the average SO₂ surface concentration of the city where the firm is located from 1990 to 1997 and the third-order polynomial of the time trend. SO₂ remove rate is the ratio of the amount of SO₂ removed over the sum of SO₂ generation. ln(K/L) represents the logarithmic form of per capita capital. D_{newproduct} equals one if the firm has new product output; otherwise it equals 0. ln(y) represents the logarithm of per capita output. ln(w) represents the logarithm of per capita wage.

significantly improves SO₂ remove rate, which is consistent with the results obtained by Han et al. (2021).

“End-of-pipe” treatments require firms to enhance investments in abatement facilities and increase labor for the installation, maintenance, and operation of facilities, which will crowd out the investment in production, resulting in a decline in output and lower profits and wages, and leading to changes in the labor income share. The results in Table 6 provide evidence in support of this point, and are shown that environmental regulation have significantly reduced investment in firm-level fixed assets (columns 3) and (4)) and per capita output (columns 5) and (6)), as well as wages (columns 7) and (8)). The point estimates show that compared with those of non-TCZ cities, firm-level outputs in TCZ cities have decreased by 13% and wages in TCZ cities have decreased by 8.3%, which result in labor income share increasing due to the greater decline in output and the smaller decline in wage rigidity.

To summarize, under strict environmental regulation, firms choose “source control” and “end-of-pipe” abatement strategies and labor income share is increased though factor-substitute effect and cost effect.

Heterogeneous analysis

In addition to policies’ average effects on the labor income share, we are also concerned about which firms are more vulnerable to environmental policies. Therefore, this paper further discusses the heterogeneous impacts of environmental rules on the labor income share from different skill employment structures and ownership.

Workforce skill. Compared with low-skilled workers, high-skilled labor has higher labor productivity and wages. Under stringent environmental policies, firms may reduce the demand for low-skilled workers in order to reduce costs or carry out technological innovation (Liu et al., 2021). For this reason, the impact of environmental rules on labor income share is different in firms with different skill structures. There is a survey on the employment structure of labor force in China’s Economic Census in 2004. Therefore, we will retain the firms in 2004 and match them with other years according to their unique identification codes, and divide the firms in the treatment groups into high-skilled and low-skilled firms according to the median of the proportion of the labor force above the high school level. Table 7 shows that the policies have a positive effect on labor income share and SO₂ remove rate, and have significant negative effects on capital intensity and the possibility of a new product in low-skilled firms, suggesting that environmental regulation reduce the labor income in low-skilled firms with “source control” and “end-of-pipe” treatments through the factor-substitute effect and cost effect.

Ownership. Previous studies have shown that the environmental performance in foreign-owned firms is better

than that of domestic firms. Therefore, environmental regulations have little impact on pollution emissions and operations of foreign-owned firms (Dean et al., 2009). In domestic firms, environmental regulation policies have a greater impact on the labor demand of state-owned firms than private firms (Liu et al., 2021). Therefore, environmental policy has heterogeneous impacts on the labor income share within different ownership firms. The results in column 1) in Table 8 show that the policies only significantly increases labor income share in state-owned firms, which use more labor instead of capital strategy and “end-of-pipe” treatments (see column 2) and column 4) in Table 8), through factor-substitute effect and cost effect as shown in column 5) and column (6). The possible explanation is two reasons as follows. On the one hand, strict environmental regulation means that the prices of production factors such as raw materials rise faster than those of labor, thus enabling firms to increase labor input (Bezdek et al., 2008), thereby increasing the labor income share. This is in line with the factor-substitute effect of environmental regulation, so that labor resources are allocated to the area with strict policy implementation (Zhang et al., 2020). On the other hand, in the face of local environmental policies, state-owned firms have greater social responsibilities in employment and pollution reduction.

Conclusion

This study theoretically analyzes the impact mechanisms of environmental regulation on labor income share with different abatement strategies and empirically tests the effects and impact mechanisms of the TCZ policy on labor income share after incorporating EPA policy using matching data from the CIED and the CPED. We find that the policies of EPA-TCZ significantly reduces the emission of sulfur dioxide (SO₂) and increases the labor income share by 2.6%.

Furthermore, we identify the impact mechanisms of environmental regulation on labor income share through firms’ abatement strategies. The results demonstrate that under strict environmental policy constraints, firms primarily adopt “source control” and “end-of-pipe” strategies to achieve emission reduction in the short term. When firms choose “source control” abatement, they use clean production factors such as labor and energy, which make the factor-substitute effect and cost effect of environmental regulation act, to increase the labor income share. When firms choose “end-of-pipe” treatments, it requires the investment in abatement facilities and increases labor for the installation, maintenance, and operation of facilities, which will crowd out the investment in production, resulting in a decline in output and lower profits and wages under the cost effect, and leading to increase in the labor

income share due to wage rigidity. Moreover, the heterogeneous effects of environmental regulation on labor income share can be found in low-skilled firms and state-owned firms.

This study supplements the literature on the firm-level resource allocation and income distribution effects of abatement strategies. Existing literature have focused on the impact of firms' different abatement strategies ("changes in production processes" and "end-of-pipe") on labor demands (Berman and Bui, 2001; Liu et al., 2021). We find that "source control" treatments are always neglected, which refer that firms reducing emissions at the source of the production process will choose cleaner input factors, such as using labor instead of capital and other polluting factors, which in turn impact the labor income share. In addition, we get that under strict environmental policies, firms tend to select "source control" and "end-of-pipe" treatments, and especially "end-of-pipe" strategy is not a long-term strategy to reduce pollution emissions. Thus, market-oriented environmental policies should be formulated, and may encourage firms to shift to "changes in production processes" treatments that can play an innovative compensation effect in the long term.

This study provides complements to the existing research on the impacts of environmental policies in developed countries. In contrast to the policies market-oriented in these countries, the early environmental policies in China are mainly on the form of laws, regulations, and government performance appraisal, which helps to reduce pollution emissions at the cost of reducing production investment and productivity as shown in our results, without fundamentally solving the contradiction between pollution control and growth. This paper provides a new empirical research from developing countries and effective references for the formulation of China's environmental regulation policy.

Future research can compare the impact of differentiated environmental regulation policies (for example, early environmental policies and market-oriented environmental policies, amount control policies and structural control policies) on firms abatement strategies and labor income share. We can consider internalizing the externality of pollution through

coordinated decision-making between local governments (Pan and Chen, 2021). Moreover, we can also consider more heterogeneity analysis, such as different industries and regions.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

YH:Theoretical Analysis, Methodology, Writing-original draft. JZ:Writing-review and editing. JL:Theoretical Analysis, Writing-review and editing. The corresponding author is responsible for ensuring that the statement is correct and agreed by all authors.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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