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A futile help: do vertical transfer payments promote haze control?

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Abstract

Most existing studies believe that vertical transfer payments (VTPs) can enhance the fiscal capacity of local governments, thus improving the environment. Taking China's VTPs to resource-exhausted cities as an example, we analysed the impact of the VTP on city haze pollution (CHP) by using a progressive difference-in-difference (DID) model. Instead of improving city haze control in other studies, our results show that VTPs given by the central government to resource-exhausted cities aggravate CHP. Robustness tests based on several methods still confirm the above findings. Dynamic feature analysis shows that the aggravating effect of VTPs on CHP in resource-exhausted cities may continue for years. The mediating effect results show that VTPs aggravate CHP by inhibiting technological innovation and high-tech industrial agglomeration, which partly confirm the path-dependence theory. In addition, environmental regulation reduces the aggravating effect of VTPs on the CHP. Our conclusion supplements the ecological effect research of the VTP and has important reference significance for developing countries to improve the ecological governance of resource-exhausted cities by building and improving fiscal transfer systems and ecological compensation institutions.

Keywords Vertical transfer payment · Resource-exhausted city · Haze pollution · Environmental regulation

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1 Introduction

Resource-exhausted cities' transformative development and ecological improvement have become a worldwide problem. By definition, resource-exhausted cities mainly refer to cities whose exploitation of mineral resources has already decreased and reached later, final or end stages in which the accumulated mining reserves have surpassed 70% of the recoverable reserves (Zhang et al. 2018a). According to traditional literature in resource economics, the excessive expansion of the resource sector will absorb a large number of production factors and squeeze out manufacturing and emerging industries, which is also called the "Dutch disease" (Corden and Neary 1982). Economic growth, which relies heavily on resource exploitation, has led to resource exhaustion and environmental pollution (Naseer et al. 2020). It has also further worsened the investment environment, resulting in the outflow of capital and high-quality talent as well as economic stagnation (Woods 2006; Konisky 2007; Zhang et al. 2022). One important policy for such cities to achieve sustainable development is to implement different types of transfer payments (Yang et al. 2022a). To help resource-exhausted cities with their transformative development and pollution control, a series of measures have been adopted by many countries (Brimblecombe and Zong 2019), which, to some extent, have improved environmental quality. Transfer payment is one of those measures (Chu et al. 2021; Lin and Jia 2018). The longitudinal fiscal imbalance between central and local governments and the horizontal fiscal imbalance among local governments have given birth to transfer payments (Wu et al. 2017). Transfer payments have two aspects: horizontal transfer payments (HTPs) and vertical transfer payments (VTPs) (Bahl and Linn 1992; Guo et al. 2022). VTP is the total funds that the country allocates to governments at all levels below the national level, while HTP is usually a transfer payment behaviour among local governments at the same level, which generally means that the funds are offered by wealthy areas to poor areas. Currently, most studies focus on HTP (Bahl and Wallace 2004). Little attention is given to the VTP that the central government offers to resource-exhausted cities.

VTPs are important sources of local fiscal expenditure (Li and Du 2021). The central government allocates financial resources to local governments through VTPs for specific purposes (Guerrero et al. 2022), which has significantly controlled the vertical fiscal imbalance (Bahl and Wallace 2004; Marconi et al. 2009; Du et al. 2019), provided lower-level governments with hedge funds (Eyraud and Lusinyan 2013), promoted their economic growth (Limoeiro 2015) and bridged regional disparities (Bird and Tarasov 2004). VTPs can also enable the central government to better control local governments' spending and regulate their behaviours through incentive and accountability mechanisms. The cost compensation mechanism of VTPs can both improve local governments' performance (De Mello 2000) and strengthen state control over local revenue and expenditure behaviour. In other words, the ultimate goal of VTPs is to balance funds in local governments and equalize public service (Bahl and Linn 1992). In fact, due to the positive externalities of environmental quality, VTPs aimed at environmental

governance are also part of promoting the equalization of public services (Greenstone and Hanna 2014), which will undoubtedly have some impact on environmental control (He et al. 2017).

Current studies generally hold the view that VTPs or ecological compensation mechanisms based on VTPs play an important role in promoting ecological governance (Bhat and Huffaker 2007; Dijkstra 2022; Pan and Tang 2020; Roolfs et al. 2021). For example, according to environmental federalism theory, it is the local government that knows how to protect and develop local ecological resources better. To utilize the advantages of decentralized decision making effectively, local governments should be encouraged through VTPs (Ring 2008). VTP mechanisms may encourage local governments to provide the public with more environmental public goods and play a special role in environmental governance (Santos et al. 2015). The theory of fiscal decentralization argues that VTPs are a complement to decentralization, which can minimize the potentially adverse effects of decentralization (Boadway and Shah 2007). In addition, based on ecological compensation theory, the appropriate design of the VTP can effectively encourage local governments to adopt environmental protection incentives, provide local residents with more environmental public goods and fix the externality of environmental governance as well as the "free rider problem" to improve the efficiency of environmental governance (Bennett et al. 2018).

The theories above all recognized the importance of VTPs in promoting environmental governance. In developed countries, the sound financial federalism system and professional supervision mechanism ensure the uninterrupted operation of the VTP system (Blanco et al. 2021; Cao et al. 2021). However, for the vast majority of developing countries, the VTP system is not perfect. It is immature in terms of institutional arrangements and mechanism design and needs to be continuously improved (Lu et al. 2022). Because the data are hard to access, empirical studies of developing countries are limited, and there are some divergences (Li et al. 2013). Taking China as an example, some literature has confirmed the importance of VTPs in environmental improvement (Gan et al. 2020). For instance, Li and Wang (2022) analysed the influence of VTPs on resource-exhausted cities and discovered that VTPs can promote upgrades in technologies and industries and urge local governments to improve environmental systems, thereby pushing low-carbon development.

However, due to the deficiencies of the environmental system (Schreifels et al. 2012), there is a huge gap between the local government's implementation of environmental policies and the central government's goals (Zhang and Wen 2008). Some studies hold that China's VTPs cannot effectively promote local ecological improvement (Tosun 2012; Dongol and Heinen 2012). On the one hand, due to limited resources, local governments tend to prioritize economic development goals rather than environmental goals (Ran 2013). When there is a potential conflict between top-down environmental policies and local economic interests, local governments may limit or hinder the implementation of the central government's top-down environmental policies (Van Rooij 2006). On the other hand, the implementation of China's environmental policies is also limited by many organizations and contextual factors. The administrative capacity of local governments' environmental agencies is often weak (Greenstone and Hanna 2014). Local governments refuse to follow

market-based environmental regulations (Fu and Jian 2021), leading to the poor enforcement of environmental laws and regulations (Zhan et al. 2014). In this context, it is difficult for VTPs to promote the improvement of the local environment.

Similar to the above studies, our study also focuses on the ecological effects of China's VTP policies. We choose China as the object mainly because it is a typical developing country. On the one hand, after over 70 years of development, China has gradually established a multilevel financial system combining centralization and decentralization, which has the general characteristics of a country with a centralized and decentralized fiscal revenue and expenditure system. Examining the impact of China's VTP system on the local ecological environment is helpful for countries with the same systems to build and improve their VTP systems as well as ecological compensation systems. On the other hand, due to the huge population pressure and China's weak economic foundation, the Chinese government implemented a growth-first development strategy for a long time (Fu and Jian 2021). Predatory exploitation in some resource-based cities has resulted in resource exhaustion and ecological destruction (Liang and Jin 2011; Zhang et al. 2018a). To promote resource-exhausted cities' economic growth and ecological improvement, the Chinese government has identified 69 cities in succession since 2008 and provided them with VTPs. This provides a good realistic basis for our research.

Different from previous studies, we focus on the influence of VTPs on the CHP of resource-exhausted cities. Environmental pollution mainly includes air pollution, water pollution, soil pollution and noise pollution, among which the problems caused by air pollution are particularly serious. The extraction, processing, transportation and use of mineral resources have serious negative effects on air quality, in which the smoke and dust emitted directly lead to CHP. As a global problem, CHP control is becoming increasingly urgent (Gan et al. 2020). We hope that through this study, some developing countries that implement the combined system of centralization and decentralization can find a solution for the optimal allocation of financial resources for haze control.

Specifically, we use a progressive difference-in-difference (DID) model to test the CHP effects of VTPs in China. In addition, we apply the mediation effect model and the moderation effect model to further explore the impact mechanisms of VTPs on CHP. Different from the previous view that VTPs can promote ecological and environmental governance, we found that VTPs can hardly promote CHP in resource-exhausted cities. This is partly because VTPs have restrained resource-exhausted cities' technological innovation level and the formation of high-tech industry agglomeration. However, high-intensity environmental policies may weaken the influence of VTPs on the CHP.

Our marginal contributions are as follows. First, whether based on the theory of decentralization, the theory of environmental federalism or the motivation of ecological compensation, VTPs are conducive to enhancing local environmental governance capacity (Gillroy 1999; Guo and Jiang 2022; Sjöberg and Xu 2018). However, based on VTPs to resource-exhausted cities in China, the largest developing country, we find that instead of reducing CHP, VTPs lead to an increase in pollution. We explain this phenomenon based on path dependence theory. Our findings not only extend the study of the ecological effects of fiscal transfer payments (Gong et al. 2021; Roolfs et al. 2021) but also have practical reference value for the eco-environmental

management of resource-exhausted cities in developing countries (Sun and Liao 2021; Long et al. 2021). Second, similar to Li and Wang (2022), we examine the mechanism of the effect of VTPs on haze pollution in resource-exhausted cities from two perspectives: the industrial structure effect and the technological innovation effect. However, unlike Li and Wang (2022), we find that the path-dependent effect of VTPs on the development of resource-exhausted cities inhibits industrial structure upgrading and technological innovation, thereby exacerbating CHP. Of course, we are not alone. Lu et al. (2022) find that VTPs to resource-exhausted cities inhibit urban innovation. Compared to Lu et al. (2022), we extend our discussion on the impact of VTPs further into the ecological domain. Our research clarifies the relations among VTPs, technological innovation and industrial development as well as CHP and deepens the study of the ecological effects of VTPs. Third, environmental institutions are the key to local ecological governance (Yan et al. 2022; Galinato and Chouinard 2018). However, the literature has not considered the synergistic effect between VTP policies and environmental policies. By the moderation effect model, we investigate the compatibility of the VTP system and environmental system, which confirms that environmental regulation weakens the VTPs' effects on CHP and affirms the necessity of strict environmental regulation policies.

2 Hypothesis

As mentioned above, VTP is an important source of local fiscal expenditure. Generally, the central government's fundamental goal of VTP is to promote the balance of financial resources among local governments and the equal share of public services (Bird and Smart 2002). While improving the financial expenditure capacity and governance capacity of local governments (Guerrero et al. 2022), VTPs will inevitably have an impact on local government behaviour and further affect local economic and social development (Li and Du 2021). Specifically, VTPs have two main ways to potentially affect the local economy. For one, VTPs can enhance local governments' fiscal spending capability by narrowing the financial gap and promote local economic and social development by restricting the behaviour of local governments through incentives, supervision, accountability and other mechanisms (Wang et al. 2022), which is the central government's original purpose of offering VTPs to resource-exhausted cities. However, if the central government commits to "back" local government finances with VTPs, it could lead to moral hazard problems such as the "common pool" effect and "soft budget constraint" syndrome and distort local government revenue and expenditure behaviour (Eyraud and Lusinyan 2013). In practice, it is local governments' misallocation of VTPs that further strengthens the path dependence of local economic development (Qian and Cheng 2022). Apparently, which VTPs' two diametrically opposed effects on local economic and social development are dominant depends on the incentive and constraint mechanism of the central government on local governments' fiscal expenditure.

Pursuing fast economic growth at the expense of the environment is one of the main ways for local governments in China to compete (Qian and Weingast 1997). In resource-abundant areas, local governments generate lucrative revenues and returns

by relying on the exploitation of natural resources (Naseer et al. 2020). This mode has led to the overexploitation of resources, resulting in large amounts of resource-exhausted cities. Those cities are problematic in many aspects, such as economic growth, industrial transformation, people's livelihood security and environmental pollution (Zhang et al. 2018a). In the early stage, the central government provided resource-exhausted cities with VTPs to promote sustainable economic development and solve various economic, social and environmental problems brought about by industrial structures relying on a single resource. China, although a centralized country, is still in an institutional adaptation phase in terms of adjusting the relationship between the powers and responsibilities of the central and local governments in the allocation of financial resources compared with developed countries. That is, China's central government has failed to establish a clear and efficient system of fiscal expenditure rights and responsibilities and lacks an effective supervision and restraint mechanism for local governments' fiscal expenditure (Yang et al. 2020). In this condition, due to the lack of effective tracking supervision and correction mechanisms, it is difficult to achieve the desired results and even strengthen the path dependence even though the central government has declared the intention through incentives and binding clauses when making transfers.

Both the proponents of path dependency theory and horizontal competition theory believe that China's current VTP system will not only bring about the "flypaper effect" of local fiscal expenditure but also cause the local government's fiscal expenditure structure to deviate from the goal of VTPs to continue the inherent growth priority development path (Fu and Shen 2012; Fell and Kaffine 2014; Zhang et al. 2018a), which finally results in the degeneration of the environment (Woods 2006; Konisky 2007). Path dependency can be understood as a theoretical model of exclusivity (Abeysinghe 2012); that is, once the local economic development model is formed, it will be "fixed", persistent and hard to replace by another model (Bulmer and Burch 2001; Greener 2002), even though there exist more effective or better alternatives (Patrick 2020). Resource-exhausted cities, because they have long obtained vested development benefits from resource-based industries and subsidies from the central government, often stick to a single structure with resource-based industries as the core. In addition, high reliance on VTPs can "soften" local government budget constraints. Instead of fully internalizing the cost of local government spending, VTPs create relief expectations for local governments, who label themselves as weak to gain more benefits (Eyraud and Lusinyan 2013). All these factors have decreased local governments' drive to transform economically and increased the dependence of local governments on the original economic development path.

From the perspective of horizontal competition, the competition and promotion qualification of local governments is mainly based on economic growth, while the characteristics of environmental governance, such as a long cycle and poor economic benefit, make local officials lack the motivation to manage the local environment both objectively and subjectively (Qian and Weingast 1997). In other words, local officials may ignore the negative impact on the environment in their pursuit of short-term economic growth (Zhang et al. 2018a), making environmental pollution a persistent and cumulative problem (Zhang et al. 2017). At the expense of the environment and resources, this race to the bottom has a certain path dependence.

Local governments' motivation to transform their economies is rather weak, and they are unwilling to use VTPs for energy conservation and environmental protection projects that are less beneficial to economic growth. Instead, local governments devote VTPs to resource-based economic construction, which deteriorates CHP in resource-exhausted cities (Fell and Kaffine 2014). Although the central government has put emphasis on environmental protection and even increased its importance in local performance assessment, local governments still have the incentive to relax environmental regulation. An obvious paradox in China's environmental politics is that there is a huge gap between the environmental policies of the central government and their implementation results at the local level (Ran 2013). Based on the above analysis, the following hypothesis is presented.

Hypothesis 1 Central government's VTPs exacerbate the CHP in resource-exhausted cities.

As mentioned above, VTPs may strengthen the path dependence of local economic development so that local governments can integrate regional resource endowments by relying on the fiscal expenditure capacity boosted by VTPs and promote the agglomeration of local resource-intensive industries (Yang et al. 2022a). While further exacerbating environmental pollution, resource-based industrial agglomeration has left no room for technological innovation and the agglomeration of high-tech industries (Zhang et al. 2018b; Sun et al. 2021). The development of the green economy depends largely on emerging green technologies and high-tech industries (Jin et al. 2020). However, due to large-scale resource exploitation in the early stage, resource-exhausted cities have massive fixed asset investments related to resource exploitation and initial processing, which has become the sunk cost for cities' development after resources are exhausted (Qi and Yang 2021). Local governments tend to invest part of VTPs in original resource-based industries or even zombie enterprises and duplicate construction in low-end areas to "salvage" the sunk costs of previous development, which inevitably squeezes out government investment in innovation and high-tech industries (Lu et al. 2019; Naseer et al. 2020). Scholars who hold the view of market failure generally believe that government participation is an important guiding force for regional innovation and the development of high-tech industries (Yang et al. 2022a). Local governments allocate VTPs wrongfully to traditional industries, which is not conducive to resolving overcapacity and industrial structure transformation, further impeding the agglomeration of elements of innovation and high-tech industries and aggravating cities' "Dutch disease" (Auty and Warhurst 1993). Therefore, VTPs strengthen the path dependence of local economic development, which inhibits technological innovation, crowds out high-tech industries and further obstructs environmental governance. Based on the above analysis, we propose the following hypotheses.

Hypothesis 2.1 Central government's VTPs reinforce the path dependence of local economic development and inhibit technological innovation, thereby aggravating CHP.

Hypothesis 2.2 Central government's VTPs reinforce the path dependence of local economic development and squeeze out high-tech industries, thereby exacerbating CHP.

According to the theory of public finance and externalities, environmental pollution has obvious negative externalities, which contribute to differences between private and social net marginal costs and lead to the misallocation of resources and low efficiency (Fan et al. 2022). Market mechanisms alone may not be able to solve the problem of environmental externalities. Environmental governance requires the deep involvement of local governments (Yang et al. 2021). In recent years, due to gradually intensifying environmental problems, China's central government has begun to incorporate environmental governance into local governments' performance ratings and adopted a "one-vote veto" assessment method (Zhang et al. 2016). In other words, if the performance of local environmental governance does not meet the requirements of the central government, local government officials will not be allowed to receive promotions (Wu et al. 2018; Gao et al. 2020). This has created top-down environmental pressure within China's administrative system. While striving to scale their economies, local governments will also improve their environmental governance performance (Gao et al. 2020).

The central government's vertical environmental pressure may be an important factor in urging local governments to actively improve air quality (Jia and Chen 2019). Under the system constraints of environmental performance appraisal, local governments have implemented unprecedented strict environmental policies (Kou and Han 2021; Lin et al. 2022). Wu et al. (2018) found that under intense environmental pressure, local governments have become increasingly intolerant of perceived and visible pollutants, such as SO_2 and haze. Strict environmental policies may decrease the environmental efficiency losses caused by economic development strategies to some extent (Lin et al. 2022). This is generally supported by current studies (Sigman 2014; Yan et al. 2022). For example, Zhao et al. (2022) found that formal environmental regulation has abated the adverse impact of fiscal decentralization on green poverty reduction. Sun et al. (2022) also discovered that environmental regulation can reduce the inhibitory effects of local governments' economic growth targets on green economic development. Based on this, we infer that strict environmental regulations may mitigate the impact of VTPs on CHP to some extent.

Hypothesis 3 Strict environmental regulation weakens the impact of VTPs on the CHP in resource-exhausted cities.

3 Methodology

3.1 Model setting

The policy of resource-exhausted cities in China was first identified in 2008, and then the central government started giving VTPs to these cities. Subsequently, the second and third batches of resource-exhausted cities were identified in 2009 and

2012, respectively. We regard the event of resource-exhausted cities identified by the central government as a quasi-natural experiment and base on a progressive difference-in-difference (DID) model to assess the impact of VTP policy on CHP. Formula (1) shows our benchmark model.

$$\text{Haze}_{\text{it}} = \alpha_0 + \alpha_1 \text{Did}_{it} + \alpha_j \text{Control}_{jit} + \mu_t + \upsilon_i + \varepsilon_{it} \tag{1}$$

Formula (1) is a two-way fixed effect DID model. Haze_{it} indicates the level of CHP of city i in year t. Did_{it} is the dummy variable for policy implementation, and if city i is identified as a resource-exhausted city in year t, then Did_{it} is assigned to 1 for that year and subsequent years and 0 for previous years. Its coefficient α_1 reflects the effect of the VTP policy on the CHP of resource-exhausted cities. Control_{jit} is a series of control variables affecting the CHP. μ_t and υ_i represent the city dummy variables and time dummy variables, respectively. ε_{it} denotes the random error term.

To explore the mechanism by which VTPs influence the CHP, we further set up the regression models shown in Eq. (2) and Eq. (3).

$$\text{Med}_{it} = \beta_0 + \beta_1 \text{Did}_{it} + \beta_j \text{Control}_{jit} + \mu_t + \nu_i + \varepsilon_{it} \tag{2}$$

$$\text{Haze}_{\text{it}} = \gamma_0 + \gamma_1 \text{Did}_{\text{it}} + \gamma_2 \text{Med}_{it} + \gamma_j \text{Control}_{jit} + \mu_t + \nu_i + \varepsilon_{it} \tag{3}$$

Med_{it} is a mediating variable including the level of city-tech innovation and the concentration of high-tech industries within the city.

Considering the important role of government's environmental regulation in regional environmental governance, we further introduce the multiplicative term of environmental regulation and the policy dummy variable and the moderating effect model shown in Formula (4). The coefficient of the multiplicative term δ_2 reflects the moderating mechanism by which environmental regulation influences the impact of VTPs on CHP.

$$\text{Haze}_{it} = \delta_0 + \delta_1 \text{Did}_{it} + \delta_2 \text{Did}_{it} \bullet ER\_\text{word}_{it} + \delta_3 ER\_\text{word}_{it} + \alpha_j \text{control}_{jit} + \mu_t + \upsilon_i + \varepsilon_{it} \tag{4}$$

3.2 Variables

3.2.1 Core variables

The dependent variable: the degree of CHP (*Haze*). We collected CHP data from the nonpoint source data disclosed by Washington University in St. Louis website. Specifically, based on cutting and collecting, the global raster data provided by this website were aggregated to obtain city-level annual average PM2.5 data in China. The nonpoint source data provided by satellites are more suitable than the point source monitoring data to reflect the overall situation of haze pollution and even better reflect the true and overall degree of CHP and the changing

characteristics. To alleviate the impact of heteroscedasticity caused by data fluctuations, we also logarithmically processed the annual mean data of PM2.5.

The independent variable: central government's VTPs (*Did*). The dummy variable of VTPs we set is based on official documents of the Chinese central government identifying resource-exhausted cities. Specifically, the three batches of resource-exhausted cities were identified by the Chinese central government in 2008, 2009 and 2012, covering 69 cities. We regard the identification of resource-exhausted cities as a quasi-natural experiment and set the policy dummy variable accordingly. If city *i* is identified as a resource-exhausted city in year *t*, it is the experimental group, and then we assign Did_{it} to 1 for that year and subsequent years and 0 for previous years. If city *i* is not identified as a resource-exhausted city from beginning to end, it belongs to the control group, and then we assign Did_{it} to 0 for all years.

3.2.2 Mediating variables

As mentioned earlier, we explore the influence mechanism of VTPs on CHP from two perspectives: technological innovation and high-tech industry agglomeration. The most commonly used indicator to measure the level of innovation is patents. Among the three types of patents, invention patents are considered the most innovative and economically valuable. Thus, we use the number of invention patent applications per capita in cities as a measure of the level of city-tech innovation. The available statistical yearbooks do not include indicators related to high-tech industries at the city level. Hence, referring to the method used by Liu et al. (2022), the scale of agglomeration of high-tech industries in cities is measured by the logarithm of the number of employees in the city's scientific research and technology services industry.

3.2.3 Control variables

In addition to the VTPs, we also control the following potential variables affecting the CHP. The opening degree (FDI) is measured by the ratio of foreign direct investment to regional GDP. The scale of financial development (Finance) is measured by the ratio of the balance of deposits and loans of financial institutions to the regional GDP at the year end. The structure of the industry (Industry) is measured by the value added of the secondary and tertiary sectors as a share of regional GDP. Environmental regulation (ER_word) is measured by the percentage of environmentally related terms in the annual government work report. Economic development level (Pgdp) is measured by the log-value of per capital GDP.

3.3 Data

As noted above, the CHP data originate from global grid data disclosed at Washington University in St. Louis website. The dummy variable of VTPs we set is based on official documents of the Chinese central government identifying resource-exhausted cities. Patent data are obtained from the Chinese Research Data Service

Platform (CNRDS). The data on environmental regulation are crawled and collated from the annual government work reports of different cities through Python software. Specifically, we first counted the government work reports of each city for each year by word separation. Then, we counted the words related to the environment, including environmental protection, pollution, energy consumption, emission reduction, ecology, green, low carbon, etc. Ultimately, we calculated environmental regulation intensity based on the proportion of all environment-related words in the government work reports. Other data can be obtained from the China City Statistical Yearbook. Table 1 shows the variable descriptive statistical characteristics.

4 Results and discussion

4.1 Influence of VTPs on CHP: baseline estimation

Formula (1) is estimated to test the CHP effect of VTPs in resource-exhausted cities, and the results are presented in Table 2. In regression (1), only the policy dummy variable of VTPs is used as the independent variable. The coefficient of VTPs is significantly negative at the 1% level. The reasons for this result can be analysed from three aspects. First, the time trend effect, that is, in recent years, the Chinese government has attached great importance to environmental governance, and urban haze pollution has a trend of easing year by year. Second, the bias of sample selection, that is, the degree of CHP in the experimental group, is inherently lower than that in the control group. Third, VTPs significantly decreased the CHP in resource-exhausted cities. For this reason, we examine the above possible causes one by one. We include a year dummy variable to control the time trend effects in regression (2). The significance of the coefficient of VTPs remains unchanged, but its coefficient unexpectedly becomes positive. After controlling the time trend effect, we find that the VTPs may worsen the CHP. This is an interesting but unexpected result. We further exclude the effect of sample selection bias, which means we introduce more stringent city fixed effects. Regression (3) still confirms the interesting conclusion, that is, the coefficients of VTPs remain significantly positive after excluding the first and second reasons above. That is, VTPs aggravate the CHP in resource-exhausted

Table 1 Variable descriptive statistics

Variable	N	Mean	Std. dev	Min	Max
Haze	4845	3.766	0.333	2.591	4.690
Did	4845	0.049	0.216	0.000	1.000
FDI	4845	0.023	0.043	0.000	0.448
Finance	4845	2.168	1.076	0.508	11.173
Industry	4845	0.857	0.090	0.501	1.000
ER_word	4845	0.005	0.002	0.000	0.023
Pgdp	4845	10.210	0.840	4.595	13.056

Table 2 Baseline estimation results

	(1)	(2)	(3)	(4)
Did	− 0.070***	0.029***	0.030***	0.025***
	(0.011)	(0.006)	(0.006)	(0.006)
FDI				0.013
				(0.029)
Finance				0.008***
				(0.002)
Industry				− 0.141***
				(0.043)
ER_word				− 1.405**
				(0.662)
Pgdp				− 0.009
				(0.007)
Cons	3.772***	3.776***	3.776***	3.959***
	(0.0182)	(0.019)	(0.004)	(0.062)
CV	NO	NO	NO	YES
Two-way fixed	NO	YES	YES	YES
Obs	4845	4845	4845	4845
R^2	0.009	0.705	0.705	0.707

(1) In parentheses are standard errors. (2) ***, **, *, respectively, represent 1%, 5% and 10% significance levels. (3) CV represents the control variables

cities. We further add control variables to regression (4), and the coefficient of VTPs remains significantly positive.

In China, the government is the leading force in economic development (Zhang et al. 2018a), and subsidies and other fiscal policies are the basic means for the government to lead economic development (Lee 2011). Previous studies have affirmed the positive impact of special central government policies for resource-exhausted cities in driving urban economic growth and improving energy efficiency (Yang et al. 2021; Yu et al. 2022); however, our results suggest that this driving effect on economic growth may come at the expense of the environment. Although this result is somewhat unexpected, we are not alone. For example, we mentioned earlier that Lu et al. (2022) found that China's VTPs for resource-exhausted cities failed to promote regional innovative economic development. The reason why it is difficult for VTPs to improve haze control in resource-exhausted cities may lie in the fact that resource-exhausted cities face greater growth pressure than other cities. On the one hand, although VTPs alleviate the fiscal expenditure constraints of local governments, local governments tend to invest more VTPs in areas that promote growth in the short term under the condition that VTPs are not constrained by a strict expenditure structure (Li et al. 2013; Yang et al. 2021). For instance, in the context of resource exhaustion, many sunk costs are generated in traditional resource-based enterprises, which also tend to be the key areas of local government investments (Qi and Yang 2021). The behaviours of local governments using VTPs to rescue sunk costs not only make it difficult to improve economic transformation but also lead to more environmental pollution and blind expansion of resource-based enterprises.

On the other hand, new industries and new technology development lack government financing support when VTPs are used for traditional resource-based industries (Yang et al. 2020). Sun and Liao (2021) also found that VTPs from the central government did not have a favourable impact on resource-based sectors but rather worsened the situation with more assistance. In addition, instead of improving the business environment for new technologies and industries, VTPs also crowd out private investments in technological innovation and emerging industries to some degree, which also leads to further deterioration of the environment in resource-exhausted cities (Lu et al. 2022).

4.2 Parallel trend and dynamic feature analysis

The application premise of the DID model is to meet the parallel trend hypothesis, i.e. there is the same time trend of CHP between resource-exhausted cities and non-resource-exhausted cities before 2008. We apply the event analysis framework to test the premise and the dynamic feature of the impact of VTPs on CHP in resource-exhausted cities. Our model setting is shown in formula (5).

$$Haze_{it} = \rho_1 + \sum \rho_k Did_{it}^k + \rho_j control_{jit} + \mu_t + \upsilon_i + \varepsilon_{it} \quad (5)$$

In formula (5), Did_{it}^k is the annual dummy variable being recognized as a resource-exhausted city. If city i is identified as a resource-exhausted city in year n, then $k = t\text{-}n$. When $k \leq$ -7, Did_{it}^7 is 1; otherwise, it is 0. When $k =$ -7, − 6……6, 7, the corresponding Did_{it}^k value is 1; otherwise, it is 0. When $k \geq 7$, Did_{it}^7 is 1; otherwise, it is 0. The results of formula (5) are presented in Fig. 1. It is obvious that the coefficient ρ_k mainly fluctuates around the zero axis before 2008, which indicates that there is no significant difference in the degree of CHP between resource-exhausted cities and nonresource-exhausted cities before the implementation of the policy. However, there is a significant difference in the degree of CHP between the two groups of cities after the implementation of the policy. This means that the experimental and control groups satisfy the parallel trend hypothesis. In addition, VTPs significantly increase the degree of CHP in the first five years after the implementation of the policy, and this effect lasts for approximately five years. This not only confirms our baseline estimation results but also confirms the conclusion of Lu et al. (2022) that the negative impact of VTPs on resource-exhausted cities will last for five or more years.

4.3 Robustness tests

4.3.1 Placebo test

The effect of VTPs on CHP demonstrated in the baseline estimation may be realized because of other unobserved shocks. This dynamic trend in the CHP may also exist in two groups of cities without the external shock of VTPs. To test the

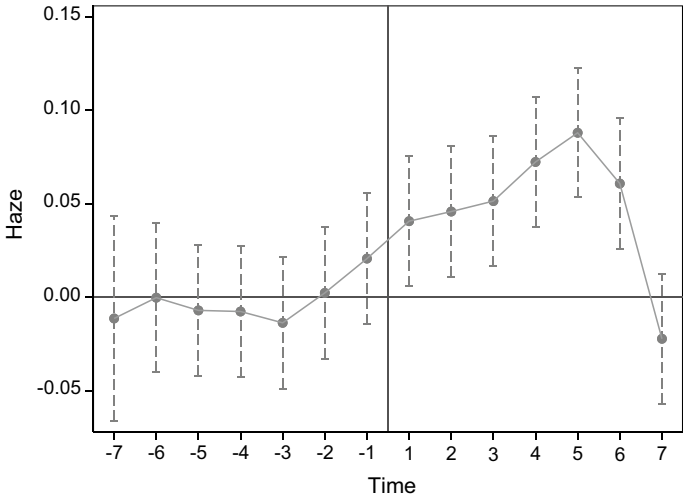

Fig. 1 Parallel trend and dynamic feature analysis

robust relationship between VTPs and CHP, we use two approaches for the placebo test. First, we randomly set the beginning time of the VTP policy. Specifically, we assume that the samples of the two groups of cities remain unchanged, and we randomly advance the beginning time of the VTP policy. That is, if city *i* is identified as a resource-exhausted city in year *t*, then a year from the range of years [2003, t-1] is randomly selected as the policy beginning time for city *i*. Based on the above set, we estimate formula (1) and repeat the process 500 times to obtain the nonrealistic coefficients, standard errors, t values and p values. Figure 2 shows the kernel density diagram of the above t values. It is clear that the t values are approximately concentrated near 0 and are normally distributed, and most of their values are in the range of -2 to 2, which tells us that most of the coefficients of VTPs are insignificant in the 500 regressions. Therefore, the previous estimated results are not invalid.

We further conduct counterfactual analysis by randomly setting the experimental and control groups. As mentioned earlier, our sample involves 69 resource-exhausted cities; therefore, we choose 69 cities at random from 285 cities to be the experimental group and the others to be the control group. For the newly selected 69 cities, we randomly set the beginning time of the policy to 2008, 2009 or 2012. We repeat the above settings 500 times and perform the DID model estimation on the basis of the samples after each setup. We plot the coefficients obtained from the 500 estimations as a nuclear density graph, which is shown in Fig. 3. The red vertical dashed line represents the value of the coefficient obtained by the above baseline estimation. The coefficients in the counterfactual analysis show an approximately normal distribution concentrated on zero, with rarely coefficient values near or over the actual estimates. Moreover, the distribution of p values shows that the majority of p values are greater than 0.1. Thus, most of the coefficients based on the dummy experimental group and corresponding control group are insignificant, which further

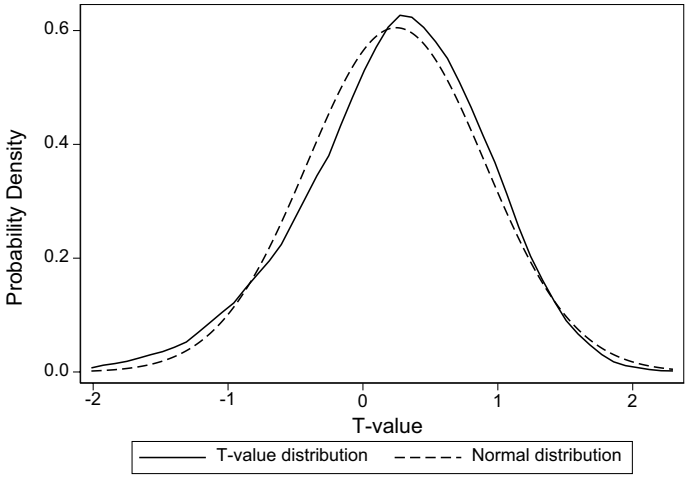

Fig. 2 Counterfactual analysis

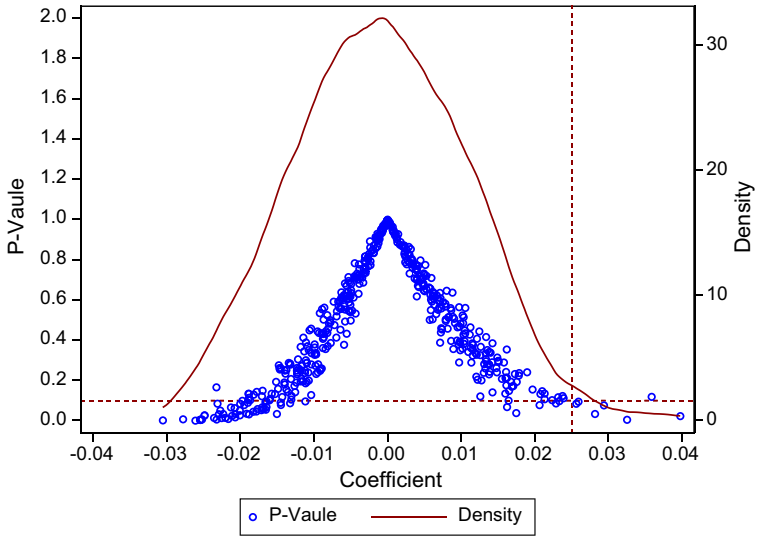

Fig. 3 Placebo test

indicates that our model passes the placebo test and that the above conclusions are not coincidental but true and valid.

4.3.2 Results of after matching samples

Although all of the above results suggest that VTPs deteriorate the CHP of resource-exhausted cities, this method that directly compares the difference in CHP between the two groups of cities cannot avoid selectivity bias caused by subjective factors.

Table 3 PSM-DID

	(1)	(2)	(3)	(4)	(5)	(6)
	Kernel matching		Nearest neighbour matching		Radius matching	
Did	0.029*** (0.006)	0.024*** (0.007)	0.033*** (0.007)	0.028*** (0.007)	0.031*** (0.007)	0.026*** (0.007)
Cons	3.777*** (0.004)	3.942*** (0.062)	3.775*** (0.005)	3.989*** (0.072)	3.782*** (0.005)	3.975*** (0.068)
CV	NO	YES	NO	YES	NO	YES
Two-way fixed	YES	YES	YES	YES	YES	YES
Obs	4817	4817	4592	4592	4295	4295
R^2	0.706	0.709	0.713	0.715	0.703	0.706

(1) In parentheses are standard errors. (2) ***, **, *, respectively, represent 1%, 5% and 10% significance levels. (3) CV represents the control variables

To further exclude the estimation bias caused by sample selectivity bias, we use the propensity score matching (PSM) method to match the data and re-estimate formula (1). We choose the above control variables as our characteristic variables and select kernel matching, 1:1 nearest neighbour matching with replacement and radius matching as matching methods. Based on the matched samples, all results are presented in Table 3. All the results confirm the exacerbating effect of VTPs on CHP in resource-exhausted cities.

4.3.3 More robustness tests

The credibility of the baseline results also depends on many factors, such as the measurement of related variables and differences in individual characteristics of samples. We further change the measurement of CHP, adjust samples and correct outliers to check the robustness of earlier conclusions.

First, we replace the dependent variable. Referring to Liu et al. (2022), we measure the CHP by using the log value of the total yearly value of the PM2.5 concentration. These data are also obtained from the grid data disclosed by Washington University in St. Louis website on a global scale. The estimations are presented in regressions (1) and (2) in Table 4. With or without control variables, the effect of VTPs on CHP in resource-exhausted cities is significantly positive at the 1% level, which means that the previous conclusions are robust. Second, considering the differences in political status and economic and social status in different cities in China, we exclude provincial capitals, cities directly under the central government and cities specifically designated in the plan from the total sample. Based on the remaining samples, formula (1) is estimated, and the results are shown in regressions (3) and (4) in Table 4. The coefficients of VTPs are still significantly positive at the 1% and 5% levels, which again confirm the exacerbating effect of VTPs on CHP in resource-exhausted cities. Finally, we eliminate the bias of the results caused by outliers. Specifically, we winsorize the values within the upper and lower 1% quantiles of all variables. The results are displayed in regressions (5) and (6) in

Table 4 Other robustness test

	(1)	(2)	(3)	(4)	(5)	(6)
	Replace dependent variables		Change samples		Reduce outliers	
Did	0.028*** (0.006)	0.024*** (0.006)	0.019*** (0.007)	0.017** (0.007)	0.028*** (0.006)	0.023*** (0.006)
Cons	13.081*** (0.004)	13.319*** (0.062)	3.769*** (0.005)	3.946*** (0.063)	3.777*** (0.004)	3.898*** (0.070)
CV	NO	YES	NO	YES	NO	YES
Two-way fixed	YES	YES	YES	YES	YES	YES
Obs	4845	4845	3859	3859	4845	4845
R^2	0.702	0.705	0.743	0.745	0.705	0.708

(1) In parentheses are standard errors. (2) ***, **, *, respectively, represent 1%, 5% and 10% significance levels. (3) CV represents the control variables

Table 4. The results after reducing outliers indicate that the central government's VTPs significantly aggravate the CHP in resource-exhausted cities, which is consistent with the previous conclusions.

4.4 Mechanism analysis

4.4.1 Mediating roles of technology innovation and high-tech industry agglomeration

Instead of reducing the CHP, the above results indicate that VTPs given to resource-exhausted cities caused more serious CHP. Technological innovation and industrial structure are important reasons for CHP. The Chinese government has formulated the National Plan for Sustainable Development of Resource-based Cities (2013–2020), which aims to accelerate the transformation and development process within these cities. The core of this plan is to fuel the growth of continuous industries supported by city-tech innovation. Therefore, we try to explore the mechanism by which VTPs affect the CHP.

Technological innovation is crucial to the economic growth and environmental improvement of resource-exhausted cities (Jin et al. 2022), so we first test the mediating effect of technological innovation. Taking technological innovation as the mediating variable, we estimate Eqs. (2) and (3), and the estimations are presented in Table 5. Regression (1) indicates that VTPs significantly inhibit technological innovation in resource-exhausted cities. This result is consistent with Lu et al. (2022), who believe that VTPs for resource-exhausted cities strengthen the path dependence of the original development model, squeeze out investment in innovation activities and are not conducive to technological innovation. On the one hand, local governments rescue the sunk costs formed by the predevelopment of resource-based enterprises. On the other hand, to maintain regional security and stability and ensure people's livelihood, local governments are forced to invest more VTPs into resource-based industries or enterprises because resource-based enterprises often

Table 5 Mediating mechanism analysis

	(1)	(2)	(3)	(4)
	City-tech innovation		High-tech industrial concentration	
	Inn	Haze	High_con	Haze
Did	−0.035*** (0.005)	0.021*** (0.006)	−0.068*** (0.010)	0.022*** (0.006)
Innovation		−0.127*** (0.019)		
High_agg				−0.049*** (0.009)
Cons	0.581*** (0.051)	3.854*** (0.065)	0.626*** (0.102)	3.810*** (0.064)
Sobel test	0.004*** (Z=4.767; P=0.000)	0.003*** (Z=4.124; P=0.000)		
Bootstrap test (Ind_effect)	0.004*** (Z=6.26; P=0.000)	0.003*** (Z=4.34; P=0.000)		
Bootstrap test (Dir_effect)	0.021*** (Z=2.95; P=0.003)	0.022*** (Z=3.24; P=0.001)		
CV	YES	YES	YES	YES
Two-way fixed	YES	YES	YES	YES
Obs	4845	4845	4845	4845
R^2	0.676	0.955	0.955	0.955

(1) In parentheses are standard errors. (2) ***, **, *, respectively, represent 1%, 5% and 10% significance levels. (3) CV represents the control variables

supply a large number of jobs (Hao and Lu 2018). However, an increasing number of VTPs being applied to resource-based industries or enterprises may attract private capital inflows and crowd out regional innovation investments. Therefore, instead of promoting technological innovation, VTPs lead to less innovation.

The inhibiting effect of technological innovation on CHP in regression (2) is consistent with existing conclusions (such as Liu et al. 2023). CHP may be inhibited by technological innovation and application by increasing the utilization efficiency of energy and resources and reducing the negative output of the productive process (Liu 2018). Regressions (1) and (2) tell us that VTPs inhibit technological innovation, which in turn leads to more serious CHP. In addition, the results of the Sobel test and bootstrap test confirm the mediating effect of city-tech innovation. When the mediating effect of city-tech innovation is controlled, VTPs still have a significant exacerbating effect on CHP in resource-exhausted cities. Therefore, technological innovation is a partly mediating variable, and VTPs can exacerbate CHP in resource-exhausted cities directly or indirectly through other mechanisms.

Song et al. (2022) believe that the agglomeration of high-tech industries is an important foundation for environmental improvement. Regressions (3) and (4) test the mediating effect of high-tech industrial concentration. In regression (3), the

coefficient of VTPs on high-tech industrial concentration is significantly negative, i.e. VTPs inhibit high-tech industrial concentration in resource-exhausted cities. This verifies the conclusion of Qian and Cheng (2022) that transfer payments strengthen the path dependence of local development. Local governments use more VTPs for resource-based industries, which certainly crowds out public and private investment in high-tech industries. This is not beneficial to the agglomeration of high-tech industries. In regression (4), we find that high-tech industrial concentration has an inhibiting effect on CHP, which is in line with the conclusion of Liu et al. (2022). High-tech industries may directly reduce the negative output of economic growth and inhibit environmental pollution by replacing existing resource-based industries. Based on regressions (3) and (4), we can arrive at the conclusion that VTPs inhibit high-tech industry concentration in resource-exhausted cities, which in turn exacerbates CHP. Both the Sobel test and bootstrap test results confirm the mediating effect of high-tech industrial agglomeration.

In summary, instead of effectively inhibiting the CHP, VTPs may inhibit the regional innovative economy, including city-tech innovation and high-tech industrial concentration, thereby further exacerbating the CHP.

4.4.2 Moderating role of environmental regulation

The conclusion of Liu et al. (2022) emphasizes the importance of multidimensional policy synergy in environmental governance. Environmental regulation is an important part of social regulation. It is an institutional arrangement that aims to protect the environment and restrict behaviours that pollute the environment (Galinato and Chouinard 2018). Local governments use environmental policy tools to constrain production activities and living behaviours, which have a significant impact on city pollution control. As the results of the baseline regression in Table 2 indicate, high-intensity environmental regulation restrained the CHP. Based on the moderating effect model shown in formula (4), we further test the effect of VTPs on CHP in resource-exhausted cities under different intensities of environmental regulations, and the results are shown in Table 6. VTPs still significantly aggravate CHP. However, the coefficient of the multiplicative term between VTPs and environmental regulation tells us that environmental regulation weakens the negative effect of VTPs on CHP in resource-exhausted cities. It can be seen that an important prerequisite for improving the ecological environment through VTPs is to build a matching environmental system. This is similar to existing studies. For example, Yang et al. (2022b) discuss the environmental effects of innovation policies in China and find that policy synergy among different sectors is an important prerequisite for promoting a win−win situation for both technology and ecology. The practical implications of this finding are that only by building a top-down incentive and constraint mechanism for environmental protection and strengthening the environmental regulation intensity of local governments can we curb the ecological loss caused by VTPs.

Table 6 Moderating role of environmental regulation

	(1)	(2)
Did	0.038***	0.032***
	(0.008)	(0.008)
Did • ER_word	−0.018**	−0.015*
	(0.008)	(0.008)
Cons	3.777***	3.963***
	(0.004)	(0.061)
CV	NO	YES
Two-way fixed	YES	YES
Obs	4845	4845
R^2	0.706	0.708

(1) In parentheses are standard errors. (2) ***, **, *, respectively, represent 1%, 5% and 10% significance levels. (3) CV represents the control variables

5 Conclusion

VTP is not only an important part of local government expenditure but also one of the main means for the central government to conduct macroeconomic regulation and promote the equalization of public services. Existing research focuses on the ecological effect of horizontal transfer payments, while research on how VTPs affect local environmental governance is relatively limited. Using the central government's VTPs to resource-exhausted cities in China as an example, we explored the effect and the mechanisms of VTPs on the CHP. The results are as follows. First, instead of effectively promoting city environmental management in other studies, VTPs exacerbate CHP. This conclusion is supported by robustness tests based on several methods. This also supports the view of Cao et al. (2021) and Lu et al. (2022); that is, even though the design of VTPs conveys the central government's expectations for local environmental management in developing countries, in practice, VTPs have failed to play their incentive and concordant role effectively. We also find that the exacerbating effect of VTPs on CHP in resource-exhausted cities may last for several years. It is obvious that constructing a sound ecological compensation mechanism to promote green development in resource-exhausted cities is an important issue facing developing countries today. In fact, the negative effects of VTPs on the local economy or environment have long been proposed, and our results have enriched such literature from the perspective of the CHP of resource-exhausted cities.

Second, the mediating effect model indicates that VTPs may exacerbate CHP by inhibiting technological innovation and urban high-tech industrial agglomeration. This confirms path-dependency theory and is in line with Corden and Neary's (1982) view of the transformation dilemma of resource-based cities, i.e. the "Dutch disease". VTPs reinforce the path dependence of local economic development, i.e. local governments integrate regional natural endowments and promote the agglomeration of local resource-intensive industries by relying on the fiscal spending power obtained from VTPs (Yang et al. 2020). Consequently, innovation factors and high-tech industries may withdraw, and CHP will be

further exacerbated as well. How to apply VTPs to technological development and industrial transformation and upgrading through institutional constraints is an issue that developing countries must consider to improve the relationship between the central government and local government in fiscal powers and responsibilities.

Third, the moderating effect analysis suggests that environmental regulation weakens the exacerbating effect of VTPs on CHP in resource-exhausted cities. This is similar to Yang et al. (2022a), who claim that an important prerequisite for promoting eco-environmental management through fiscal systems is the construction of environmental institutions that match the fiscal systems. Environmental institutions are crucial for developing countries. Under the condition of relatively loose budget constraints, local governments tend to invest more fiscal resources in productive areas that can expand the size of economies in the short term, which can help local officials accumulate promotion capital (Yang et al. 2022b; Liu et al. 2022). However, this self-interested investment preference ignores the loss of environmental benefits in the process of local economic development. Therefore, to curb the loss of ecological benefits caused by VTPs, it is necessary to construct a top-down incentive and restraint mechanism for environmental protection and strengthen the intensity of environmental regulation of local governments.

Our study not only complements the research on the environmental management effect of VTPs from the perspective of transfer payments for resource-exhausted cities in developing countries but also has some reference significance for developing countries to promote local environmental governance based on vertical ecological compensation systems. Unlike most studies, our results do not confirm the beneficial effect of VTPs on local environmental management. This reminds us that the ecological compensation mechanisms in developing countries, which are structured in the form of VTP, are not well developed. A well-designed institution is an important safeguard for balancing economic and environmental gains. In many cases, it can achieve a win−win situation for both the economy and the environment. When constructing the VTP system, the central government should further strengthen environmental objectives and simultaneously enhance the restraint, supervision and accountability mechanisms for local government spending behaviours. The central government should prevent the path-dependent effect brought by VTPs, such as strengthening the regulation and supervision of the use of VTPs and preventing local governments from using VTPs to guide and solidify the traditional resource-dependent development model. In addition, both the People's Political Consultative Conference and the People's Congress can play a supervisory role in local government expenditures. The central government should also attach great importance to guiding resource-exhausted cities to implement innovation-driven development strategies and promote transformation development and ecological management with the support of innovation and emerging technologies. Industry is an important support for innovation, and it is a major source of environmental pollution as well. Therefore, the development of local high-tech and low-carbon industries should be guided through VTPs. In addition, VTP systems need to match environmental institutions to achieve the goal of ecological management. Hence, while improving VTP systems, developing countries should also build matching environmental institutions

to achieve harmonization and unification between fiscal systems and environmental institutions.

We explore the haze effects of VTPs from the central government to resource-exhausted cities and try to clarify the potential mechanisms of their effects. However, limited by data and other factors, our study has the following limitations and room for expansion. First, we only explored the environmental effects of VTPs from the perspective of haze pollution. However, environmental pollution is multifaceted, including sulphur dioxide pollution, water pollution and noise pollution. In the context of obtaining more data on other pollutants, the environmental impact of VTPs from more perspectives should be explored. Second, we lack the exploration of micromechanisms. The formation of macroeconomic phenomena often has a microscopic basis. However, due to the lack of firm-level emission data and other reasons, we have not analysed the micromechanisms by which VTPs affect CHP. This is an issue that needs to be clarified in the future. Finally, our study mainly explores the mechanism of VTPs' influence on CHP from two perspectives, technological innovation and high-tech industrial agglomeration, but does not exclude the possibility of the existence of other mechanisms. Therefore, referring to studies such as Lu et al. (2022) and Li and Wang (2022), future studies can further clarify the mechanisms from the perspectives of resource allocation and government behaviour.

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Declarations

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

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