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The evolutionary mechanism of haze collaborative governance: novel evidence from a tripartite evolutionary game model and a case study in China

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The topic of haze collaborative governance has become a hot policy issue attracting worldwide attention. However, existing studies do not pay enough attention to haze collaborative governance in the process of central environmental protection inspection (CEPI). This paper employs a tripartite evolutionary game model to explore the evolutionary mechanism of haze collaborative governance among China's central and local governments and verifies its findings further through a case study of CEPI for air pollution in Beijing-Tianjin-Hebei and surrounding regions. The results show that haze collaborative governance is mainly affected by the performance evaluation system, policy implementation cost, clean government construction, industrial transfer trend, fiscal subsidy, environmental inspection cost, environmental accountability, and public participation. The implementation of CEPI is conducive to haze collaborative governance among central government and local governments. To promote the full implementation of air pollution control policies, the local governments need to optimize the performance evaluation system by considering economic development and environmental protection, reduce policy implementation costs by cost-sharing, and strengthen clean government construction by preventing rent-seeking corruption. In addition, the local governments need to strengthen the coordination of cross-regional industrial development and optimize fiscal subsidies to promote ecological compensation and transfer payments. For supervising the policy implementation of local governments thoroughly, the central government needs to reduce the environmental inspection cost using the evaluation framework of cost-benefit analysis, strengthen the haze governance accountability through normalizing supervision, and broaden the public's external supervision channels. It is vital to take effective measures to carry out haze collaborative governance, providing a useful experience for developing countries.

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Introduction

As a serious threat to human health, the worsening air pollution around the world has prompted research related to improving the performance of air pollution governance through various policy interventions (Gabrys, 2020). Although the air pollution situation is still severe, China has achieved remarkable performance in air pollution control by formulating and applying many new policy interventions (Zhang et al., 2022). Yet, some institutional arrangements between the Chinese central government and local governments have aroused widespread concern among scholars and policymakers. Some policy interventions, such as mandatory target policies and total pollutant control policies, have been widely discussed by scholars (Gao, 2015; Liang and Langbein, 2019). In recent years, the central environmental protection inspection (CEPI) system has been a significant institutional breakthrough in Chinese ecological environment administration. As a special institutional arrangement for campaign-style governance (Jia and Chen, 2019), CEPI has only recently attracted the attention of academia.

It is important to note that, in the context of a Chinese-style fiscal decentralization system, the central government and local governments have different system interests (Lv and Landry, 2012). China implements a local government accountability system under unified regulation, and local governments are accountable for the environmental quality within their jurisdiction. On one hand, economic decentralization gives local governments room for decision-making and action, making it possible for local governments to behave opportunistically in haze governance. On the other hand, due to restrictive factors such as regulatory costs and bounded rationality, the central government cannot fully participate in the local government's specific process of haze governance, resulting in information asymmetry among the central government and local governments. To effectively cope with the principal-agent problem, the central government supervises the local government's haze governance through CEPI. Conflicting interests have resulted in a tripartite evolutionary game relationship between the inspection of the central government and the local governments involved in implementing local policy (Zhang et al., 2019; Chu et al., 2021).

Meanwhile, this tripartite evolutionary game relationship between the central government and local governments fits the characteristics of collaborative governance well. Collaborative governance is a voluntary resource transfer behaviour of participants based on cost-benefit analysis (Amirkhanyan, 2009; Nowell, 2010). For environmental governance, especially for haze governance, which is a complex cross-domain public affair, collaborative governance can reflect the complex dynamics and subject diversity of multi-level governmental collaborative haze governance. As a typical practice of central-local collaborative governance under China's hierarchical system, CEPI changes the incentive structure of local governments through top-down institutional arrangements, thus shaping the motivation of local governments to participate in the collaborative governance of haze (Mu et al., 2019; Zhou and Dai, 2023).

The main research objective of this paper is to answer the following research questions: how do the central and local governments act in haze collaborative governance under the CEPI system? What is the tripartite evolutionary game strategy of such a collaboration? What factors affect the actions of the central government and of local governments? This paper constructs a tripartite evolutionary game model (TEGM) among the central government and two local governments during the implementation and inspection of air pollution control and investigates the law of countermeasures and the acting factors between the two levels of government. This paper further verifies the evolutionary mechanism by combining specific cases under the background of CEPI, providing a theoretical and practical basis for haze collaborative governance among central government and local governments to promote the full implementation of air pollution control policies (APCP).

The innovations introduced by the paper are as follows. First, existing studies on environmental action strategy do not pay enough attention to haze collaborative governance in the process of CEPI, which is the most significant institutional innovation in the ecological environment field. This paper explores the haze collaborative governance by the central and local governments in the context of CEPI, which further enriches the application scenarios of collaborative governance theory. Second, due to the complexity of the haze pollution problem, the incompleteness of information, and the limited computing power of the participants, the central and local governments cannot find the optimal strategy through one game alone. Instead, the most stable strategy is explored through the process of gradual adjustment (Zhang et al., 2016). Based on the bounded rationality of the game participants and the repeatability of the game strategies, this paper uses the TEGM to carry out relevant research, which is more in line with the reality of CEPI. Third, existing studies do not apply a combination of a TEGM and case analysis to solve the problem of CEPI. The TEGM among central government and local governments has not previously been tested with actual cases. In this paper, the results of the TEGM are further verified by the case study of haze collaborative governance in CEPI.

The rest of the paper is structured as follows. Section "Literature review" reviews relevant literature. Section "Research background" introduces the research background of CEPI. Section "Tripartite evolutionary game model" elaborates on the TEGM among central government and local governments. Section "Discussion on the evolutionary mechanism" presents the evolutionary mechanism of haze collaborative governance. Section "Case study" introduces the case study of haze collaborative governance in CEPI. Section "Conclusions and policy recommendations" concludes the research and makes policy recommendations.

Literature review

Practice and performance of environmental collaborative governance. For environmental governance which is a complex public affair or even a "wicked problem", collaborative governance is its proper meaning. Collaborative governance refers to the process of communication, sharing of information and resources, and joint decision-making among multiple subjects, to obtain solutions beyond their own limitations (Ansell and Gash, 2008; Emerson et al., 2012). The subject of collaborative governance comes from the state, the government, the private sector, the community, and other subjects, which can deal with public goals that cannot be accomplished by a single subject (Emerson et al., 2012). Inter-governmental cooperation can be manifested as horizontal cooperation between governments at the same level, which is manifested as spontaneous behaviour. Previous cooperation experience, resources, environment, and common goals can enhance the motivation of horizontal coordination (Amirkhanyan, 2009; Calanni et al., 2015; Nowell, 2010; Smith, 2009). In China, influenced by top-down institutional arrangements, vertical intervention by the central government can change the incentive structure of local governments, thus promoting the coordination between central and local governments. Therefore, the vertical coordination between central and local governments under the hierarchical system is also an important

embodiment of collaborative governance (Mu et al., 2019; Zhou and Dai, 2023).

Existing studies have focused on the importance of informal elements such as trust, leadership, social capital, and social norms to cooperation in collaborative environmental governance (Berardo et al., 2014; Calanni et al., 2015; de Boer et al., 2016). Trust and resources are more important than shared beliefs in driving the coordination of marine aquaculture partnerships (Calanni et al., 2015). In addition, the types of issues and participants have significant impacts on whether collaborative governance can be achieved (Berardo et al., 2014). Governance systems that guide and organize related operations and interactions deeply influence the effect of collaboration, especially the potential importance of collaborative processes and the characteristics of collaborative participants (de Boer et al., 2016).

Similar to other governance situations, environmental collaborative governance also follows performance standards. Studies have confirmed that there is a positive correlation between collaborative governance and the improvement of environmental effects (Biddle and Koontz, 2014). The governance system composed of multi-agencies and multi-governance levels can produce higher environmental outputs compared with single-centre governance (Newig and Fritsch, 2009). However, despite numerous studies endorsing the effects of collaborative environmental governance, collaboration is not a panacea (Koontz and Thomas, 2006). How to explain the performance of collaborative governance? Some studies have summarized the mechanism between collaborative governance and collaborative effect into several aspects: representation of environmental concerns, the role of participants' environmental knowledge, conversational interactions in decision-making, and collaborative networks for conflict resolution and decision implementation (Newig et al., 2018).

Government strategies and dilemma in haze governance. Due to the governance failure of the private sector, every level of government has a dominant position in haze pollution management, and their behavioural strategies have an important impact on haze pollution control (Zhang et al., 2020). In terms of choosing to stress economic development or environmental protection, local governments do not have enough incentives to prioritize environmental issues (Ali and de Oliveira, 2018). GDP growth performance is much more important than environmental performance in the Chinese traditional official evaluation system. Political incentives prompt local governments to prioritize economic growth at the expense of environmental benefits (Shih et al., 2012; Peng et al., 2019). Also, the regular rotation of local officials creates inherent tensions between the pursuit of economic growth and environmental sustainability (Alkon and Wong, 2020; Eaton and Kostka, 2014). To pursue their own economic interests, local officials may form alliances with economic entities such as state-owned enterprises to implement symbolic pollution-reducing policies, such as only imposing a nominal fine (van Rooij, 2006; Zhang et al., 2010; Lo et al., 2012). In this context, they tend to value short-term economic growth more than the long-term benefits of environmental protection.

Political and financial incentives are essential incentive mechanisms that affect the implementation of APCP (Lv and Landry, 2012). However, principal-agent problems such as inconsistent goals and information asymmetry have led to multiple factors affecting APCP. Due to the limited capacity of the central government to supervise local governments, there is a non-cooperative relationship between "top-down policies and bottom-up countermeasures" in the enforcement of environmental regulation (Zhang et al., 2019). Faced with the incomplete implementation of environmental regulation by local governments, the central government is forced to carry out administrative control.

Evolutionary process and haze governance effect of CEPI. The former National Environmental Protection Agency established Regional Environmental Protection Supervision (REPS) centres in 2002 to respond effectively to regulatory issues in environmental governance (Tan and Mao, 2021). While REPS centres strengthened the ability of cross-domain environmental pollution control, they still faced a series of problems in terms of function positioning, matching of powers and responsibilities, and coordination mechanisms. In this case, the Chinese ecological environment supervision system has undergone a transformation from the REPS system to the CEPI system (Lin et al., 2021).

The "inspection" part of the CEPI acronym refers to the establishment of special working groups authorized by higher-level governments to supervise lower-level governments regarding certain types of specific matters (Zheng and Na, 2020). CEPI aims to overcome the shortcomings of the existing bureaucratic environmental governance system and resolve the logical contradiction between bureaucracy and public participation in haze governance, which is regarded as a concrete practice of campaign-style governance (Xiang and van Gevelt, 2020). The authority of CEPI has been strengthened by raising the task of environmental protection to the national level (Jia and Chen, 2019). Nevertheless, public participation is of great significance to environmental pollution control (Chen et al., 2015; Li and Tilt, 2019). Therefore, the sustainability of CEPI has been strengthened by vigorously supporting public participation in environmental pollution control (Jia and Chen, 2019). CEPI not only encourages the local government to pay attention to environmental pollution control by transmitting environmental protection pressure, but it also further reduces the asymmetry of information between the central government and local governments by improving the inspection information channels (Wang et al., 2021).

The Chinese environmental inspection system has gradually evolved from the "supervision of enterprises" and "supervision of governments" to the stage of "equal responsibility between the party and government" (Jia and Chen, 2019). CEPI has revealed various practical problems, including the formalism of the environmental protection responsibility and assessment systems, the inadequate implementation by local governments, and the serious lag in constructing environmental protection facilities. The disclosure of practical issues has had a certain role in promoting the environmental governance capabilities of local governments through the improvement of environmental protection regulations (Ding et al., 2022).

Existing studies have carried out empirical research on the effect of CEPI on the governance of haze pollution. As discussed by Li et al. (2020), CEPI has made significant progress in environmental governance, and the environmental governance effect of the provinces in the central region is significantly higher than that of other regions. CEPI has significantly improved air quality in a short period of time, and major single pollutants—such as fine particulate matter ($PM_{2.5}$) and inhalable particles (PM_{10})—have been significantly reduced (Wang et al., 2021). Wu and Hu (2019) posit that the sustainability of the improvement effect is not significant due to the high operating cost of CEPI. However, based on urban daily air pollution data, a study by Jia and Chen (2019) finds that CEPI has had a positive effect on improving environmental performance by using the difference-

in-differences model, and this positive policy effect continues after CEPI.

Some studies have found that the effects of CEPI on various forms of air pollution are heterogeneous. Compared with other non-adjacent cities, CEPI has reduced the air quality index and the concentration of atmospheric pollutants such as $PM_{2.5}$, PM_{10}, sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) significantly in the inspected cities. However, CEPI has significantly increased the Ozone (O_3) concentration and has had no substantial impact on the carbon monoxide (CO) concentration (Lin et al., 2021). CEPI has been effective in detecting and rectifying violations of environmental laws and regulations but, as Xiang and van Gevelt (2020) point out, it is inefficient and highly resource-intensive and may produce unexpected results in the medium and long term.

Comments. In summary, existing studies have analysed the environmental collaborative governance, government strategies in haze governance, and the haze governance effect of CEPI. These studies have focused on the role and effect of CEPI in haze governance, based on analysing the characteristics of the CEPI system. However, some aspects of the system still need to be further explored. First, current research on environmental governance action strategy does not pay enough attention to CEPI, which is the major institutional innovation in the ecological environment field. Mandated collaborative governance refers to the coordination that the central or superior government forces local governments through legislation, administration, or contract (Rodriguez et al., 2007). CEPI is an important practice of mandated collaborative governance.

Second, due to the complexity of the haze pollution problem, the incompleteness of information, and the limited computing power of the participants, the central and local governments cannot find the optimal strategy through one game alone. Instead, the most stable strategy should be explored through the process of gradual adjustment (Zhang et al., 2016). Based on the bounded rationality of the game participants and the repeatability of the game strategies, it is necessary to use the TEGM to carry out relevant research.

Third, in terms of research methods, the constructed TEGM among central government and local governments has not been verified using real and specific cases. By taking the bounded rationality of the game participants and the repetitiveness of the game strategies as the premise, this paper uses the TEGM and the case study method to explore the evolutionary mechanism of haze collaborative governance among central government and local governments in the context of CEPI.

Therefore, based on the existing research, this paper incorporates the actions of the central government and of local governments into the same analytical framework and explores the evolutionary logic of the haze collaborative governance by using the TEGM and the case study method, which provides a new theoretical contribution to haze collaborative governance.

Research background

China has implemented a regional environmental management model of "block-block management" in the field of air pollution supervision—that is, the local government of a region is only responsible for the air pollution problem in that region (Young et al., 2015). However, due to the cross-domain flow properties of air pollution, the negative externalities of air pollution have brought great challenges to haze pollution control. The traditional territorial management model cannot effectively deal with the problem of cross-domain haze pollution (Zhang et al., 2018). To effectively cope with the disadvantages of the territorial management model and to solve the supervision problem of environmental pollution control, China has successively implemented the REPS centres and CEPI to strengthen the ecological environment supervision system (Lin et al., 2021).

The REPS centres were founded under the real problem of cross-domain environmental pollution supervision. In June 2002, the former State Environmental Protection Administration first completed the construction of REPS centres in eastern and southern China. Subsequently, the former State Environmental Protection Administration completed the construction of REPS centres in the northwest, northeast, and southwest of China in July 2006. Finally, the former Ministry of Environmental Protection (MEP) completed the construction of a REPS centre in North China in December 2008. After completing the construction of the six REPS centres, a regional environmental inspection system covering the whole country was established. The REPS centres improved the implementation of environmental protection laws and strengthened the ability of cross-domain collaborative governance of environmental pollution. However, they also faced a series of problems in terms of functional positioning, matching of powers and responsibilities, and coordination mechanisms (Tan and Mao, 2021). From the perspective of the institutional system, the REPS centres had no direct law enforcement power. They needed to report to the MEP and obtain consent before they could enforce laws. Therefore, the efficiency of the inspection was relatively low. From the perspective of the governance effect, the status of the REPS centres was not clear, and their governance objectives were not always the same as the governance objectives of the local government, making it difficult to effectively achieve the inspection effect.

Due to the real problem of REPS, China's ecological environment supervision system underwent a transformation process from REPS to CEPI (Lin et al., 2021). In July 2015, the Central Leading Group for Comprehensively Deepening Reforms (CLGCDR) issued the *Environmental Protection Inspection Plan* (*Trial*), which explicitly proposed the establishment of CEPI. Subsequently, the CEPI team carried out Round 1 of CEPI covering 31 provinces, as well as a Round 1 evaluation of CEPI in 20 provinces. To further improve CEPI, the CEPI Office was established in 2017 with responsibility for inspecting related affairs and specific coordination tasks. The six REPS centres were upgraded and became part of the inspection bureau of the MEP, and the environmental protection institutions were transformed into administrative agencies. In 2019, the *Central Ecological and Environmental Protection Supervision Work Regulations* regulated CEPI work for the first time in the form of internal party regulations (Table A1 in the Appendix).

Tripartite evolutionary game model

TEGMs have been extensively used in various fields, including physics (Park and Traulsen, 2017), medicine (Sartakhti et al., 2017), and social science (Su et al., 2021). In the field of environmental management, Estalaki et al. (2015) examined the effect of penalty mechanisms on water pollution control using evolutionary game theory. Zhang et al. (2019) used evolutionary game theory to explore regional cooperation in environmental pollution control. Based on existing research, this paper adopts TEGM to construct the evolutionary path of haze collaborative governance among central government and local governments and to explore the influence mechanism that promotes the formation of game equilibrium.

Model assumption. This paper explores the evolutionary mechanism of haze collaborative governance among central

Table 1 Assumptions of the TEGM among central government and local governments.

Assumptions	Contents
1	The game participants are central government, local government A and local government B.
2	On one hand, local governments implement the central government's APCP. On the other hand, they take advantage of fiscal decentralization to safeguard the interests of the region. Therefore, the local government's strategy set is {completely implementing, incompletely implementing}.
3	Both the central government and local governments are affected by local economic growth and air quality.
4	The central government monitors the implementation of the local government's APCP. The strategy set of the inspection is {completely inspecting, incompletely inspecting}.
5	In the scenario of inspecting thoroughly, if the central government finds that a local government did not fully implement the APCP, it would impose penalties on the local government.

Table 2 Variable definition of the TEGM among central government and local governments.

Variable name	Variable meaning
C_A, C_B	Full implementation cost changes by local government A or B, compared with implementing incompletely.
Cc	Thorough inspection cost changes by the central government, compared with inspecting incompletely.
Q_A, Q_B	Changes in environmental loss between incomplete implementation and full implementation of APCP for local government A or B.
G_A, G_B	Changes in economic benefits between incomplete implementation and full implementation of APCP for local government A or B.
δ_1, δ_2	Weight of environmental indicators or economic indicators in the performance evaluation system. $0<\delta_1<1$, $0<\delta_2<1$.
R_A, R_B	Industrial transfer loss buried by full implementation of APCP for local government A or B, when local government B or A implements APCP incompletely.
T_A, T_B	Industrial transfer benefits for incomplete implementation of APCP for local government A or B.
W_A, W_B	Environmental loss for local government A or B, when local government B or A implements APCP incompletely.
M_A, M_B	Fiscal subsidy from the central government for local governments A or B that fully implements APCP.
F_A, F_B	Penalty amount imposed by the central government to the local government A or B, when the central government thoroughly inspects that the local government A or B does not implement APCP fully.
Fc	Environmental pressure and reputation loss to the central government when the central government does not thoroughly inspect.
H	Reputation benefits of the central government when the public finds that the air quality has improved and recognizes the work of the central government.
B	Bribed amount of rent-seeking corruption that the person in charge of the local government may obtain when not fully implementing the APCP.
λ	The proportion of rent-seeking corruption that has an impact on the benefits of local governments.

government and local governments under the framework of CEPI by constructing a TEGM. The specific assumptions and variable definitions of the TEGM are shown in Tables 1 and 2.

Model construction. Considering the TEGM, local government A and local government B select the "implementing fully" strategy or the "implementing incompletely" strategy randomly and independently, while the central government selects the "inspecting thoroughly" strategy or the "inspecting incompletely" strategy randomly and independently. This paper uses the replication dynamic mechanism (Su et al., 2021; Chu et al., 2021) to simulate the tripartite evolutionary game process among the central government and two local governments (Table 3). If the proportion of the central government choosing to inspect thoroughly is x, the proportion of the central government that chooses to inspect incompletely is $1-x$. If the proportion of local government A or B that choose to implement APCP fully is y or z, the proportion of local government A or B incompletely implementing is $1-y$ or $1-z$.

The expected revenue of the central government choosing to inspect thoroughly is

$$\begin{aligned} E_{x1} = {} & yz\left(H - C_C - M_A - M_B\right) \\ & + y(1-z)\left(-C_C - M_A + F_B\right) \\ & + (1-y)z\left(-C_C + F_A - M_B\right) \\ & + (1-y)(1-z)\left(-C_C + F_A + F_B\right) \end{aligned} \tag{1}$$

The expected revenue of the central government choosing to inspect incompletely is

$$\begin{aligned} E_{x2} = {} & yz\left(H - M_A - M_B\right) \\ & + y(1-z)\left(-F_C - M_A\right) \\ & + (1-y)z\left(-F_C - M_B\right) \\ & + (1-y)(1-z)\left(-F_C\right) \end{aligned} \tag{2}$$

The average revenue of the central government is:

$$E_x = xE_{x1} + (1-x)E_{x2} \tag{3}$$

Based on the Malthusian dynamic equation (Jiang et al., 2019), the replicator dynamic equation of the central government choosing to inspect thoroughly is:

$$\begin{aligned} F(x) = \tfrac{dx}{dt} = {} & x(1-x) \\ & \left(-yzF_C - yF_A - zF_B - C_C + F_A + F_B + F_C\right) \end{aligned} \tag{4}$$

The expected revenue of the local government A choosing to implement fully is:

$$\begin{aligned} E_{y1} = {} & xz\left(-C_A + M_A\right) \\ & + x(1-z)\left(-C_A - R_A - \delta_1 W_A + M_A\right) \\ & + (1-x)z\left(-C_A + M_A\right) \\ & + (1-x)(1-z)\left(-C_A - R_A - \delta_1 W_A + M_A\right) \end{aligned} \tag{5}$$

Table 3 Benefit matrix of the TEGM for the central government, local government A and B.

Strategy Combinations	Benefit for the central government	Benefit for local government A	Benefit for local government B
(1,1,1)	$H-C_C-M_A-M_B$	$-C_A+M_A$	$-C_B+M_B$
(1,1,0)	$-C_C-M_A+F_B$	$-C_A-R_A-\delta_1W_A+M_A$	$-\delta_1Q_B+\delta_2G_B-F_B+T_B+\lambda B$
(1,0,1)	$-C_C-M_B+F_A$	$-\delta_1Q_A+\delta_2G_A-F_A+T_A+\lambda B$	$-C_B-R_B-\delta_1W_B+M_B$
(0,1,1)	$H-M_A-M_B$	$-C_A+M_A$	$-C_B+M_B$
(1,0,0)	$-C_C+F_A+F_B$	$-\delta_1Q_A+\delta_2G_A-\delta_1W_A-F_A+\lambda B$	$-\delta_1Q_B+\delta_2G_B-\delta_1W_B-F_B+\lambda B$
(0,1,0)	$-M_A-F_C$	$-C_A-R_A-\delta_1W_A+M_A$	$-\delta_1Q_B+\delta_2G_B+T_B+\lambda B$
(0,0,1)	$-M_B-F_C$	$-\delta_1Q_A+\delta_2G_A+T_A+\lambda B$	$-C_B-R_B-\boldsymbol{\delta}_1W_B+M_B$
(0,0,0)	$-F_C$	$-\delta_1Q_A+\delta_2G_A-\delta_1W_A+\lambda B$	$-\delta_1Q_B+\delta_2G_B-\delta_1W_B+\lambda B$

The expected revenue of the local government A choosing to implement incompletely is

$$\begin{aligned}E_{y2}=&xz\left(-\delta_1Q_A+\delta_2G_A-F_A+T_A+\lambda B\right)\\&+x(1-z)\left(-\delta_1Q_A+\delta_2G_A-\delta_1W_A-F_A+\lambda B\right)\\&+(1-x)z\left(-\delta_1Q_A+\delta_2G_A+T_A+\lambda B\right)\\&+(1-x)(1-z)\left(-\delta_1Q_A+\delta_2G_A-\delta_1W_A+\lambda B\right)\end{aligned}\tag{6}$$

The average revenue of local government A is

$$E_y=yE_{y1}+(1-y)E_{y2}\tag{7}$$

Based on the Malthusian dynamic equation (Jiang et al., 2019), the replicator dynamic equation of the local government A choosing to implement fully is

$$F(y)=\frac{dy}{dt}=y(1-y)\left(xF_A-zT_A+zR_A-C_A-R_A+M_A+\delta_1Q_A-\delta_2G_A-\lambda B\right)\tag{8}$$

The expected revenue of the local government B choosing to implement fully is

$$\begin{aligned}E_{z1}=&xy\left(-C_B+M_B\right)\\&+x\left(1-y\right)\left(-C_B-R_B-\delta_1W_B+M_B\right)\\&+(1-x)y\left(-C_B+M_B\right)\\&+(1-x)\left(1-y\right)\left(-C_B-R_B-\delta_1W_B+M_B\right)\end{aligned}\tag{9}$$

The expected revenue of the local government B choosing to implement incompletely is

$$\begin{aligned}E_{z2}=&xy\left(-\delta_1Q_B+\delta_2G_B-F_B+T_B+\lambda B\right)\\&+x\left(1-y\right)\left(-\delta_1Q_B+\delta_2G_B-\delta_1W_B-F_B+\lambda B\right)\\&+(1-x)y\left(-\delta_1Q_B+\delta_2G_B+T_B+\lambda B\right)\\&+(1-x)\left(1-y\right)\left(-\delta_1Q_B+\delta_2G_B-\delta_1W_B+\lambda B\right)\end{aligned}\tag{10}$$

The average revenue of the local government B is

$$E_z=zE_{z1}+(1-z)E_{z2}\tag{11}$$

Based on the Malthusian dynamic equation (Jiang et al., 2019), the replicator dynamic equation of the local government B choosing to implement fully is

$$F(z)=\frac{dz}{dt}=z(1-z)\left(xF_B-yT_B+yR_B-C_B-R_B+M_B+\delta_1Q_B-\delta_2G_B-\lambda B\right)\tag{12}$$

According to the replicator dynamic Eqs. (4), (8), and (12), the Jacobian Matrix can be obtained. The Jacobian Matrix can be used to analyse the asymptotic stability of the equilibrium point and to obtain the evolutionarily stable strategy (Friedman, 1991; Sheng et al., 2020). The Jacobian Matrix is

$$J=\begin{pmatrix}(1-2x)\begin{pmatrix}-yzF_C-yF_A\\-zF_B-C_C+F_A+F_B\\+F_C\end{pmatrix} & x(1-x)\begin{pmatrix}-zF_C-zF_B\\-C_C+F_B+F_C\end{pmatrix} & x(1-x)\begin{pmatrix}-yF_C-yF_A\\-C_C+F_A+F_C\end{pmatrix}\\ y(1-y)\begin{pmatrix}F_A-zT_A\\+zR_A-C_A-R_A+M_A\\+\delta_1Q_A-\delta_2G_A-\lambda B\end{pmatrix} & (1-2y)\begin{pmatrix}xF_A-zT_A\\+zR_A-C_A-R_A+M_A\\+\delta_1Q_A-\delta_2G_A-\lambda B\end{pmatrix} & y(1-y)\begin{pmatrix}xF_A-T_A\\-C_A+M_A+\delta_1Q_A\\-\delta_2G_A-\lambda B\end{pmatrix}\\ z(1-z)\begin{pmatrix}F_B-yT_B\\+yR_B-C_B-R_B+M_B\\+\delta_1Q_B-\delta_2G_B-\lambda B\end{pmatrix} & z(1-z)\begin{pmatrix}xF_B-T_B\\-C_B+M_B+\delta_1Q_B\\-\delta_2G_B-\lambda B\end{pmatrix} & (1-2z)\begin{pmatrix}xF_B-yT_B\\+yR_B-C_B-R_B+M_B\\+\delta_1Q_B-\delta_2G_B-\lambda B\end{pmatrix}\end{pmatrix}\tag{13}$$

The eigenvalues of each equilibrium point state are shown in Table 4. According to the stability theory of the Lyapunov system, the stability of the evolution system can be judged by the eigenvalue of the Jacobian Matrix. When the system is gradually stable, the eigenvalue of the matrix is negative.

Discussion on the evolutionary mechanism

Perspective of the local governments. According to the eigenvalues at each equilibrium state in Table 4, if the local government is to implement APCP fully, the following conditions must be satisfied:

$$\begin{cases}T_A-M_A-\delta_1Q_A+\delta_2G_A+\lambda B+C_A<0\\T_B-M_B-\delta_1Q_B+\delta_2G_B+\lambda B+C_B<0\end{cases}\tag{14}$$

Therefore, it makes sense in practice to analyse the parameter changes that have positive effects on λ_2 or λ_3. Based on the results in Table A2 in the Appendix, if the local government is to fully implement APCP, it is necessary to work from three aspects. First, it needs to increase (reduce) the weight of environmental (economic) indicators in the system for evaluating performance. Second, it is necessary to adopt various measures to reduce the execution cost when local governments strictly implement APCP. Third, it needs to strengthen clean government construction to reduce the impact of corruption in the environmental field on government decision-making. Fourth, it is necessary to further strengthen the coordination of cross-regional industrial development in terms of the industrial transfer trend. Finally, it needs to optimize fiscal subsidies to promote ecological compensation and

Table 4 Eigenvalues at each equilibrium state.

Equilibrium point	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3
(1,1,1)	C_C	$T_A - F_A + C_A - M_A - \delta_1 Q_A + \delta_2 G_A + \lambda B$	$T_B - F_B + C_B - M_B - \delta_1 Q_B + \delta_2 G_B + \lambda B$
(1,1,0)	$C_C - F_B - F_C$	$\delta_2 G_A + \lambda B - F_A - M_A - \delta_1 Q_A + C_A + R_A$	$F_B - T_B + M_B + \delta_1 Q_B - \delta_2 G_B - \lambda B - C_B$
(1,0,1)	$C_C - F_A - F_C$	$F_A - T_A + M_A + \delta_1 Q_A - \delta_2 G_A - \lambda B - C_A$	$\delta_2 G_B + \lambda B - F_B - M_B - \delta_1 Q_B + C_B + R_B$
(1,0,0)	$C_C - F_A - F_B - F_C$	$F_A + M_A + \delta_1 Q_A - \delta_2 G_A - \lambda B - C_A - R_A$	$F_B + M_B + \delta_1 Q_B - \delta_2 G_B - \lambda B - C_B - R_B$
(0,1,1)	$-C_C$	$T_A - M_A - \delta_1 Q_A + \delta_2 G_A + \lambda B + C_A$	$T_B - M_B - \delta_1 Q_B + \delta_2 G_B + \lambda B + C_B$
(0,1,0)	$-C_C + F_B + F_C$	$\delta_2 G_A + \lambda B - M_A - \delta_1 Q_A + C_A + R_A$	$-T_B + M_B + \delta_1 Q_B - \delta_2 G_B - \lambda B - C_B$
(0,0,1)	$-C_C + F_A + F_C$	$-T_A + M_A + \delta_1 Q_A - \delta_2 G_A - \lambda B - C_A$	$\delta_2 G_B + \lambda B - M_B - \delta_1 Q_B + C_B + R_B$
(0,0,0)	$-C_C + F_A + F_B + F_C$	$M_A + \delta_1 Q_A - \delta_2 G_A - \lambda B - C_A - R_A$	$M_B + \delta_1 Q_B - \delta_2 G_B - \lambda B - C_B - R_B$

transfer payments, thus stimulating the active governance behaviour of local governments.

Perspective of the central government. According to the eigenvalues at each equilibrium state in Table 4, when at least one of the local governments decides not to fully implement APCP, the condition that makes the central government inspect thoroughly needs to be met:

$$\begin{cases} C_C - F_B - F_C < 0 \\ C_C - F_A - F_C < 0 \\ C_C - F_A - F_B - F_C < 0 \end{cases} \quad (15)$$

Therefore, it makes sense in practice to analyse the parameter changes that have positive effects on λ_1. Based on the results in Table A3 in the Appendix, if the central government is to thoroughly inspect, it is necessary to work from three aspects. First, various measures are needed to reduce the inspection cost when the central government thoroughly inspects the implementation of APCP. Second, the central government needs to appropriately increase the actual penalties for local governments that do not fully implement APCP. Third and finally, the public needs to participate actively in the process of CEPI to enhance diversified participation and process transparency.

Summary of the evolutionary mechanism. To summarize the laws of haze collaborative governance among central government and local governments, Fig. 1 shows the evolutionary mechanism based on the tripartite evolutionary game results in Tables A2 and A3 in the Appendix. From the perspective of local governments, the performance evaluation system, policy implementation cost, clean government construction, industrial transfer trend, and fiscal subsidy are the main factors affecting the local government's action strategy. The increase (decrease) of the weight of environmental (economic) indicators in the system for evaluating performance, the decrease of policy implementation cost when local governments strictly implement APCP, the reduced impact of corruption in the environmental field on government decision-making, the decreased industrial transfer trend, and the increased fiscal subsidy, are conducive to encouraging local governments to implement APCP fully.

From the point of view of the central government, the main factors that affect their action strategy are the environmental inspection cost, environmental accountability, and public participation. The decrease in inspection cost when the central government inspects thoroughly, the central government's increase of actual penalties when the local government fails to fully execute, and the public paying more attention to regional environmental issues encourage the central government to inspect the implementation of the local government thoroughly.

Case study

If the actualizing mechanism of haze collaborative governance among central government and local governments is not clear in the actual circumstance, and the evolutionary mechanism derived from the tripartite evolutionary game analysis has not been verified, further empirical research will be required to confirm the validity of the tripartite evolutionary game results. The evolutionary mechanism involves many factors. It is difficult to carry out the quantitative measurement and empirical analysis of the complex interrelationships between different factors based on a large sample. Therefore, the evolutionary mechanism derived from the tripartite evolutionary game analysis can be verified through case studies (Zhang et al., 2016). This paper selects typical cases of haze collaborative governance and attempts a systematic investigation of the collaborative governance behaviours between local governments and the central government in Beijing–Tianjin–Hebei and surrounding (BTHS) regions against the background of CEPI.

Case selection. This paper takes APCP in the BTHS regions against the background of CEPI as the case study object. This paper mainly considers the following two reasons for this case selection. The first is that the case is relatively typical because of the realistic background of the continuous large-scale haze in the BTHS regions in recent years. The second reason is that the case has a higher theoretical match. CEPI is empowered by the central government to conduct the inspection and feedback. The local government is responsible for the implementation of rectification and follow-up accountability, which provides an excellent scenario for the central government to collaborate. Table A4 in the Appendix summarizes the start and end dates of Round 1, the Round 1 evaluation, and Round 2 of CEPI programmes in the BTHS regions.

Data sources. The data sources of this case study include official statistical yearbooks, policy documents, and authoritative news reports. Specifically, this paper takes the 2006 and 2017 economic and environmental indicators of the BTHS regions as a background, summarizing the data in Table 5.

This paper collects and sorts the relevant information on CEPI for air pollution in the BTHS regions from existing policy documents and news reports. First, this paper summarizes the operation mode of the CEPI system based on policy documents, which includes seven aspects: Preparation, Inspection Stationed, Report, Feedback, Handover, Rectification, and Archive, as shown in Fig. 2. Second, based on the feedback from CEPI on air pollution, this paper summarizes the practical problems of haze control in the BTHS regions, which include insufficient work implementation, lack of assessment and accountability, serious problems of slow inaction, weak links in atmospheric environmental governance, prominent problems in launching projects in violation of laws and regulations, insufficient promotion of

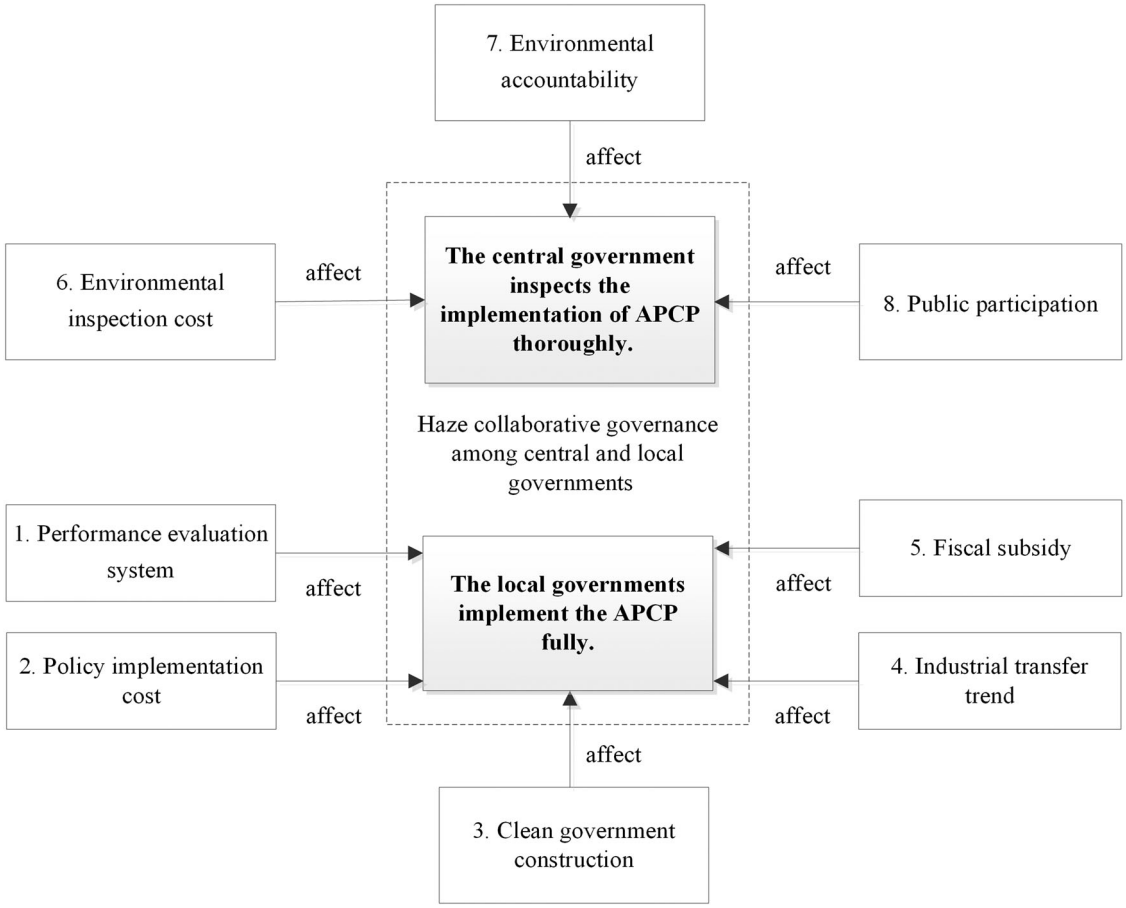

Fig. 1 Evolutionary mechanism of haze collaborative governance among central government and local governments. The performance evaluation system, policy implementation cost, clean government construction, industrial transfer trend, and fiscal subsidy affect whether the local governments implement fully. Environmental inspection cost, environmental accountability, and public participation affect whether the central government inspects thoroughly.

Table 5 Economic and environmental indicators of BTHS regions in 2006 and 2017.

Regions	GDP per capita (ten thousand yuan)		GDP growth rate (percentage)		Proportion of secondary industry (percentage)		SO_2 emissions per capita (kg)		Soot and dust emissions per capita (kg)	
	2006	2017	2006	2017	2006	2017	2006	2017	2006	2017
Beijing	5.07	9.31	12.0	6.7	27	19	10.99	0.93	5.01	0.94
Tianjin	4.15	10.68	14.4	3.6	55	41	23.72	3.57	8.40	4.19
Hebei	1.66	3.99	13.2	6.7	53	46	22.40	8.01	19.84	10.69
Henan	1.32	3.83	14.1	7.8	54	47	17.29	3.00	14.49	2.34
Shandong	2.35	6.39	14.7	7.4	57	45	21.08	7.39	9.75	5.49
Shanxi	1.45	3.26	11.8	7.0	56	44	43.79	15.48	50.48	11.72
Inner Mongolia	2.05	6.64	18.0	4.0	48	40	64.47	21.60	38.54	21.20

Source: The statistical yearbooks in different regions (the base year is 2006).

pollution control, prominent structural pollution problems, and insufficient control of coal and dust.

Case discussion. Combined with the typical case material provided by CEPI regarding air pollution in the BTHS regions, this paper conducts a systematic investigation of the collaborative governance behaviour among central government and local governments in the BTHS regions in the context of CEPI to further verify the evolutionary mechanism of haze collaborative governance among central government and local governments.

Performance evaluation system. Performance evaluation is an incentive system for local governments. Before the implementation of the CEPI system, the performance evaluation system paid more attention to economic growth but did not pay enough attention to environmental protection. This meant the local governments of the BTHS regions persisted in not fully

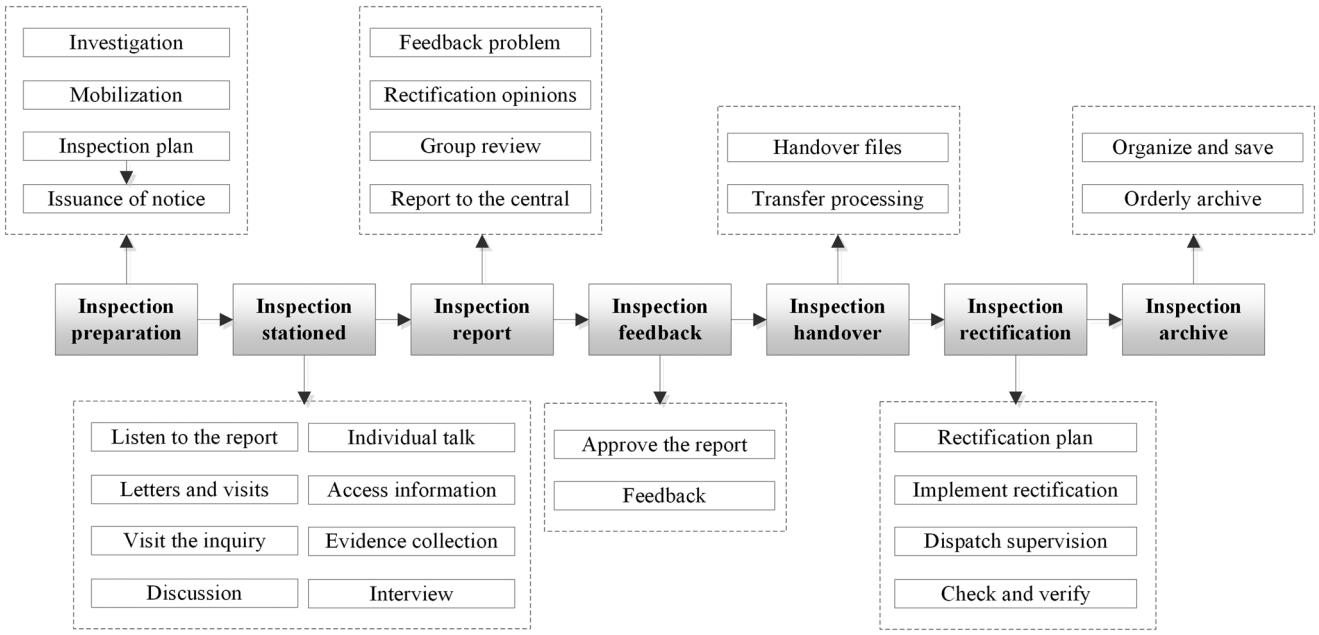

Fig. 2 Operation mode of the CEPI system. This figure summarizes the operation mode of the CEPI system which includes seven aspects: Preparation, Inspection Stationed, Report, Feedback, Handover, Rectification, and Archive.

implementing APCP. Table 5 shows that, in 2006, the per capita SO_2 emissions in the BTHS regions ranged from 10.99 to 64.47 kg, and the per capita soot and dust emissions ranged from 5.01 to 50.48 kg. In 2006, the per capita SO_2 emissions and per capita soot and dust emissions in all provinces were still relatively high.

Table 5 shows that, in 2017 and after the implementation of the CEPI system, the per capita SO_2 emissions in BTHS regions ranged from 0.93 to 21.60 kg, and the per capita soot and dust emissions ranged from 0.94 to 21.20 kg. In 2017, the per capita SO_2 emissions and per capita soot and dust emissions decreased in all regions. Compared with 2006, the high-intensity and high-standard CEPI had reduced the weight of economic indicators in the performance evaluation system, and the importance of environmental indicators became more prominent (Peng et al., 2019). Therefore, the evolutionary trend of the proportion of economic and environmental indicators in the performance evaluation system made the local governments of the BTHS regions move gradually towards fully implementing APCP in 2017.

Policy implementation cost. Table 5 shows that, in 2006, the per capita GDP of the BTHS regions ranged from 13,200 yuan to 50,700 yuan, and the proportion of secondary industry ranged from 27% to 57%. In general, the overall economic development level of each province was much lower compared with 2017, and the proportion of the secondary industry was much larger compared with that in 2017. As the development of secondary industry has a great impact on haze pollution, the cost of implementing APCP during this period remained high, which made the full implementation of APCP costly and difficult to promote pollution control.

Table 5 shows, that in 2017, the per capita GDP of the BTHS regions ranged from 32,600 yuan to 106,800 yuan, and the proportion of secondary industry ranged from 19% to 47%. The overall economic development level of each province had made considerable progress, and the weight of secondary industries had declined. Although GDP growth in 2017 in the BTHS regions slowed down compared to 2006, regional GDP was still growing at a steady rate of between 4% and 7.8%. Combined with the data on per capita GDP and the proportion of the secondary industry, it is not difficult to see that, after the implementation of CEPI, the economic growth of the BTHS regions was of high quality. The implementing cost of APCP during this period was reduced compared with 2006, giving local governments of the BTHS regions more motivation to move towards fully implementing APCP gradually.

However, with high-quality economic growth and improved ecological environment requirements, the pollution discharge fee standards in the BTHS regions in 2019 (after Round 1 and the Round 1 evaluation of CEPI) were more stringent than for the corresponding regions in 2016, as shown in Table A5 in the Appendix. This shows that all regions increased their resource investment in haze control over time and were able to afford greater haze control costs (Ali and de Oliveira, 2018). Therefore, the reduction in implementation costs encouraged local governments to implement APCP fully.

Clean government construction. During the process of air pollution management, the CEPI team pointed out problems relating to slowness or inaction in implementing policy in the BTHS regions. To a large extent, inaction in the field of environmental protection may cause government officials to act as an "umbrella" for polluting companies, and may even cause rent-seeking corruption in the environmental protection field. Existing studies have shown that such corruption aggravates the degree of environmental pollution by weakening the effectiveness of environmental regulation (Zhou et al., 2020). Because of the huge harm this causes, the CEPI team transferred suspected crimes to the relevant state departments for legal processing during the Inspection Handover phase. This pressure from CEPI can promptly correct the inaction and slowness of the local government in the environmental protection field, which helps the local government establish a clean government, thereby encouraging the local government to fully implement APCP.

Industrial transfer trend. Table 5 shows that in 2006, the per capita GDP of Beijing and Tianjin reached the level of moderately

developed countries, while other regions still have a large gap compared with that of Beijing and Tianjin. From the perspective of industrial structure, Beijing is dominated by the tertiary industry and has entered the post-industrialization stage. The high-end trend of industrial structure in Beijing is obvious, while the surrounding six regions are still in the industrialization stage. The actual situation from each dimension shows a vast regional gap among BTHS regions (Chen et al., 2019). In the case of different development levels in different regions, it is difficult for BTHS regions to achieve the goal of collaborative governance of haze.

In addition, Table 5 illustrates that the proportion of the secondary industry in Beijing, Tianjin, Hebei, Henan, Shandong, Shanxi, and Inner Mongolia in 2017 decreased by 29.62%, 25.45%, 13.21%, 13.21%, 21.05%, 21.43%, and 16.67%, respectively compared with 2006. Beijing and Tianjin have the largest proportion of the decline in the secondary industry, which shows that BTHS regions are optimizing and upgrading industries at different levels. Among them, Beijing and Tianjin have the highest level of industrial optimization and upgrading. With the continuous decline of the proportion of secondary industry in BTHS regions, the loss of industrial transfer borne by the local government fully implementing APCP will continue to decrease. Accordingly, the proportion of industrial transfer from the local to the neighbouring regions will also decrease. This also helps to some extent that after the implementation of the CEPI, the local governments of BTHS regions gradually tend to implement APCP fully, achieving horizontal collaborative governance (Amirkhanyan, 2009; Calanni et al., 2015).

Fiscal subsidy. Fiscal subsidy or special fund from the central government plays a discretionary and stabilizing role in the governance of poverty alleviation (Yang et al., 2022) and environmental protection (Fan et al., 2021). The central government subsidizes and motivates local governments to fully implement APCP, which is conducive to enhancing the enthusiasm of local governments to control air pollution. The central government reasonably allocates fiscal funds, and fully considers the balance between different regions, different industries, and different eras. Fiscal subsidy coordinates the inconsistency of central and local government objectives. They compensate for the loss of interest caused by externalities through the construction of ecological compensation and transfer payment.

The incentive and compensation effects of fiscal subsidy are conducive to the central government coordinating different local governments fully implement APCP. Currently, China's fiscal investment in APCP continues to increase, and the range of investments expands rapidly. The air pollution control funds issued in advance by the central government from 2020 to 2023 are 17.90, 10.78, 10.71, and 10.69 billion yuan in BTHS regions (Table A6 in the Appendix). The fiscal subsidy of the central government is conducive to promoting local governments fully implement APCP.

Environmental inspection cost. With the assistance of the national authority, CEPI has overturned the original fixed structure of the bureaucratic organization in the environmental protection field to a certain degree. Therefore, it is necessary for the central government to fully mobilize various human, financial, and material resources and to bear huge inspection costs in advancing the environmental inspection objectives (Xiang and van Gevelt, 2020). According to the inspection process of the CEPI system in Fig. 2, the costs of CEPI consist of four aspects:

1. Inspection and training costs of the CEPI team during the Inspection Preparation process, the investigation and evidence collection cost during the inspection process, and the dispatch supervision and random inspection verification cost during the Inspection Rectification process.
2. Costs related to various expenses borne by local party committees and local governments in the process of receiving and responding to environmental protection inspections.
3. Costs related to various expenses borne by the inspected enterprises during the CEPI process and subsequent pollution transformation costs.
4. Costs related to various CEPI fees for the public, environmental non-governmental organizations (NGOs), news media, and other third-party participants: the full implementation of CEPI not only requires the mobilization of the human, material, and financial resources of the party committees and governments at every level, but also the costs of publicity and mobilization throughout the country, as well as the participation costs of different stakeholders. Therefore, the administrative cost incurred by CEPI has far exceeded the original environmental administrative cost of governments at all levels.

The cost of human resources spent during the CEPI process is huge. For example, the CEPI team stationed in the BTHS regions includes various staff members who have transferred from the relevant departments of the Party Central Committee and the State Council. After the inspection team has been stationed, the work also requires strong cooperation from local party committees and government staff at every level, as well as from relevant personnel of the supervised enterprise. Additionally, the supervision process requires the full participation of the public, environmental NGOs, news media, and other third-party participants. It can be found that, if CEPI is to be thoroughly promoted, the various human, financial, and material resource costs are huge (Xiang and van Gevelt, 2020). Reducing CEPI costs during the inspection process is conducive to the advancement of CEPI.

Environmental accountability. In comparison to the REPS centres implemented in 2002, the CEPI system has gradually improved since 2015, with stronger environmental accountability (Wu and Hu, 2019). The REPS centres, which were public institutions, were adjusted and upgraded to inspection bureaus for ecological and environmental protection with the status of administrative entities, which enabled them to have higher accountability and more power to implement environmental penalties. By promulgating a series of high-level CEPI laws and regulations and by appointing provincial or ministerial officials as the head of the CEPI team, the legal status of CEPI has been strengthened, and the authority and independence of CEPI have been guaranteed. The environmental accountability of CEPI has been improved at the national authority level. In addition, the "supervision of enterprises" has changed to "supervision of governments". The main responsibility of local party committees and local governments has been reinforced through the party and government equal responsibility system, which provides a more effective guarantee for the accountability of CEPI for the haze control of local governments.

By summarizing the feedback from Round 1 and the Round 1 evaluation of CEPI, this paper finds problems of haze governance in the BTHS regions, such as insufficient work implementation, lack of assessment and accountability, and prominent problems of inaction and slowness. Existing studies have shown that CEPI is effective in the short-term control of haze pollution, but the long-term control effect is not clear (Wang et al., 2021). The research shows that local governments may still face practical problems, such as trying to deal with the problem of haze

pollution during the CEPI period but showing long-term poor implementation after that period is over. Handling the weak environmental awareness of local governments and strengthening the accountability of local governments and leading cadres are important parts of the CEPI process conducive to the thorough implementation of CEPI.

Public participation. Public participation in environmental governance is a policy tool to reduce information asymmetry, which has rapidly evolved over the years (Mahajan et al., 2022). From the feedback of CEPI and the feedback of the Round 1 evaluation on Inspection Rectification, this paper also finds that there is widespread public concern regarding air pollution in the BTHS regions. For example, launching environmental protection projects such as waste incineration could easily lead to petitions related to air pollution (Li et al., 2012). The "letters and visits" process of CEPI is the main way to collect information on environmental issues during the Inspection Stationed. It not only avoids public petitions related to air pollution but also solves the problems that the public is particularly concerned about (Li et al., 2020).

During the CEPI period, the CEPI team accepts environmental report information all day through the establishment of a reporting mailbox and a reporting phone. After receiving information from the public, the CEPI team forwards it to the relevant departments of the provincial government. Through the principle of territorial administration, the responsibility for dealing with petitions has gradually shifted to the municipal party committee and government, as well as to the county's party committee and government, due to the initial promotion of provincial party committees and governments. Depending on the requirements of "rectification during supervision", the environmental protection department of the grassroots government needs to conduct detailed field investigations and seek out specific opinions on how to rectify problems. After the grassroots government departments form rectification opinions, they need to report to the municipal governments, provincial governments, and the CEPI team step by step. After the inspection team examines the rectification opinions carefully, the provincial governments are required to respond publicly on provincial TV stations, party newspapers, and government websites (Fig. 3). For issues related to the violation of laws and discipline and the dereliction of duty involved in a petition report, the CEPI team transfers the investigation files of ecological environment damage to the relevant state ministries and transfers the people connected with ecological compensation, public interest litigation, and suspected crimes to the relevant state departments for legal treatment.

According to statistics, more than 80,000 environmental concerns raised by the public have been resolved during Round 1 of CEPI. Through the broad participation of the general population, environmental information asymmetry between the national and local governments has been relieved to some extent, enhancing the diversified participation and process transparency of CEPI. The central government has strengthened the supervision of local governments through the petition information provided by the public, and the public has made their own environmental demands through the full participation of the central government (Kostka and Mol, 2013). Therefore, through the CEPI procedure, the central government and the public have formed an "information alliance", strengthening the constraints of local governments' environmental protection behaviours through the internal and external supervision of the administrative system (Wang et al., 2021). The enhancement of public participation is conducive to the thorough advancement of CEPI.

Conclusions and policy recommendations

Based on the limited rationality of game participants and the repeatability of game strategy, a TEGM has been used in this paper to investigate the law of countermeasures and their influencing factors on haze collaborative governance between central and local governments in the BTHS regions. The evolutionary mechanism of haze collaborative governance among central government and local governments has been elaborated at length, and the evolutionary mechanism has been verified based on a case

Fig. 3 The handling process of letters and visits during CEPI for air pollution. The CEPI team, the public, the party committees, and governments at different levels are important factors in the handling process of letters and visits.

study carried out in the BTHS regions. From the perspective of the central government, the environmental inspection cost, environmental accountability, and public participation are the main factors affecting the action strategy. From the perspective of the local governments, the main factors affecting their action strategies are the performance evaluation system, policy implementation cost, clean government construction, industrial transfer trend, and fiscal subsidy. Changes in the corresponding factors will affect the choice of countermeasures for haze collaborative governance between the two levels of government. Continuously optimizing the performance evaluation system, policy implementation cost, clean government construction, industrial transfer trend, and fiscal subsidy at the local government level, as well as environmental inspection cost, environmental accountability, and public participation at the central government level, are conducive to promoting haze collaborative governance between central and local governments. It makes sense for the central and local governments to strengthen their collaboration and deal with cross-regional haze pollution problems more effectively.

In the process of haze collaborative governance in the BTHS regions, it is necessary to pay attention to the following recommendations.

- The performance evaluation system of local governments should be optimized, considering economic development as well as environmental protection. The BTHS regions need to continue adjusting the weight of atmospheric environmental quality indicators and economic growth indicators in the performance evaluation system, encouraging local economic development and emphasizing the necessity of haze pollution control. The local governments of all provinces and municipalities in the BTHS regions should continuously improve the green and diversified performance evaluation system of leading cadres, and leading cadres should deeply implement the audit system of natural resources assets, as well as the evaluation method of environmental protection effectiveness of local government departments.
- The policy implementation costs of local governments should be reduced with cost-sharing measures. The BTHS regions need to strengthen cooperation between industry, universities, and research and measure the haze pollution transmission pathways, as well as the external effects of haze governance, accurately. By determining the mutual influence between haze pollution and haze governance, the two basic issues of haze control benefits and approved compensation costs are confirmed, internalizing the external environmental impact among regions. Moreover, transferring part of the responsibility and cost of policy implementation to a higher level of government will be conducive to further encouraging grassroots governments to participate actively in the process of haze governance.
- Clean government construction should be strengthened and rent-seeking corruption relating to environmental protection should be eliminated. The party committees and administrations of the BTHS regions must continuously strengthen the effectiveness of supervision in key positions that are prone to environmental corruption, such as environmental project approval, pollutant discharge permit, environmental law enforcement, and environmental protection tax collection. Besides, the disruptive personal power of leading cadres to interfere in environmental protection enforcement should be restrained effectively by means of environmental protection information disclosure, as well as through diversified engagement in environmental protection evaluation. By strengthening the backward investigation system of environmental corruption cases, environmental corruption behaviours could be constantly restrained and deterred. Furthermore, when local governments do not fully implement APCP, the central government should resolutely punish the rent-seeking corruption that might be undertaken by local government officials and should try their best to eliminate the impact of the rent-seeking corruption that may occur among local government officials on the haze control of local governments.
- Although there is a huge regional gap, the BTHS regions are undergoing industrial optimization and upgrading to varying degrees. With the continuous decline of the proportion of secondary industry in the BTHS regions, the loss of industrial transfer borne by the local government fully implementing APCP will continue to decrease. Therefore, it is necessary to strengthen the coordinated development of cross-regional industries further and advance the development of different industrial types among regions. By vigorously developing the tertiary industry and reducing the proportion of labour-intensive and resource-intensive industries, the loss of industrial transfer caused by regional differences in APCP will be gradually reduced.
- The incentive and compensation effects of fiscal subsidy are conducive to the central government coordinating different local governments fully implement APCP. Therefore, it is necessary to reasonably allocate fiscal subsidies or special funds, and consider the balance between different regions, different industries, and different eras, to compensate for the interest loss caused by externalities through the construction of ecological compensation and transfer payment.
- The accountability mechanism for haze governance should be strengthened and the normalization of supervision and accountability should be maintained. On one hand, the supervision and accountability mechanism of the environmental protection inspection and law enforcement team should be strengthened to prevent the creation of false environmental monitoring data, virtual environmental inspections, and ineffective environmental accountability measures (such as non-compliance, lax law enforcement, and failure to investigate problems). On the other hand, when the central government thoroughly inspects local governments and finds they have not fully implemented APCP, the central government must intensify its oversight and punishment by raising the number of penalties imposed on local governments.
- An integrated assessment framework of cost-benefit analysis should be utilized to reduce the cost of CEPI. The administrative cost of CEPI work has far exceeded the original environmental administrative cost of governments at all levels (Ali and de Oliveira, 2018). To solve this problem, it is necessary to establish an integrated assessment framework for the cost-benefit analysis of CEPI. By evaluating the costs and benefits of supervision objectively, the goal of gradually reducing the cost of CEPI could be achieved.
- External supervision channels for the public and promote the participation of third parties should be promoted in the haze of collaborative governance among central government and local governments. On one hand, traditional media such as radio and newspapers should strengthen the process supervision of haze pollution governance, legally disclosing and reporting on enterprises that illegally discharge waste gas and on local governments that do

not act (or act indiscriminately). Social media, such as Weibo and WeChat, should reasonably play a guiding role in public opinion, popularizing the knowledge of APCP and leading the public to deal with haze pollution emergencies rationally. On the other hand, the BTHS regions should give inspection responsibility to various environmental NGOs through laws, regulations, and policy documents, standardizing the behaviours of environmental NGOs. APCP should be supervised by improving the environmental supervision committee and encouraging environmental protection social organizations to behave as environmental inspectors.

There are still limitations to this study. First, in the study of intergovernmental collaborative haze control, this paper does not fully discuss the evolutionary mechanism of the policy combinations due to limited space and feasibility. It will be of great significance to explore the evolutionary mechanism of different policy combinations in the future. Second, the local governments analysed in this study are mainly provincial governments, and this paper does not examine local governments at lower levels. Future research could be based on municipal or county-level governments to conduct more in-depth research.

Data availability

All data in this article are from the official website of the National Bureau of Statistics of China. The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

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Competing interests

The authors declare no competing interests.

Ethical approval

Ethical assessment is not required prior to conducting the research reported in this article, as the present study does not have experiments on human subjects and animals, and does not contain any sensitive and private information.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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