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Government competition, corruption and green total factor energy efficiency: An empirical analysis from china

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Currently, global warming and resource and environmental constraints are becoming formidable. Improving green total factor energy efficiency (GTFEE) is an effective tactic to alleviate carbon emissions and resource scarcity, and also a practical demand for the sustainable and healthy development of China's economy. This study applies the super efficiency SBM model to calculate GTFEE of China's 30 provinces over the period from 2006 to 2020, and then the dynamic spatial Durbin model (SDM) is employed to investigate the impact of government competition on GTFEE. Furthermore, the influence path between government competition and GTFEE is identified by the intermediary effect model. The findings reveal that as a whole, local government competition has undermined GTFEE both in local and adjacent areas, but significant differences exist in different regions. After the robustness tests, the conclusions remain valid. The intermediary effect results show that government competition indirectly inhibits GTFEE by triggering corruption. Based on this, policymakers should establish an effective performance appraising for local governments to spark a cycle of virtuous competition and cooperation among regions. Meanwhile, the anti-corruption system should be improved so as to shape a favorable institutional atmosphere for the improvement of GTFEE, and ultimately promote the sustainable development of China's economy.

KEYWORDS

local government competition, GTFEE, corruption, sustainable development, spatial durbin model

1 Introduction

In recent decades, as a result of the drastic advancement of China's urbanization and industrialization, the surge in energy consumption is awfully daunting (Hussain et al., 2020; Zhao et al., 2021). The report on China's energy supply and demand reveals that 40% of the global energy consumption growth in 2020 is contributed by China. To make matters worse, China's energy consumption demand has been skyrocketing as yet (Hao, et al., 2021; Zhao et al., 2022). Massive energy consumption is driving economic and social progress, but the ecosystem has been unavoidably thrown out of whack (Wang et al., 2020a). Severely ecological problems such as resource depletion, environmental pollution, and extreme weather are emerging one after another, which is heavily affecting the well-being and sustainable development of the Chinese nation. In the face of the current grim situation, the fifth Plenary Session of the 19th Central Committee of the Communist Party of China proposed the green development concept of "lucid waters and lush mountains are invaluable assets ", and the development goal of accelerating green and low-carbon transformation. In September 2020, Chinese President Xi Jinping claimed that China would adopt more effective to early achieve the goal of "carbon peak and carbon neutrality". Under such goals and commitment, the contradiction between energy consumption and economic development becomes more prominent. Improving GTFEE becomes an imperative tactic to alleviate resource scarcity and carbon emissions so as to fuel economic green transformation and healthy development.

Government competition may substantially affect China's economy and is regarded as a crucial impetus for its rapid rise and transformation. However, government competition may also trigger rent-seeking corruption in promoting economic development (Lee et al., 2020). Corruption, in turn, curbs economic development by hindering technological innovation (Wang and Wang, 2020) and distorting investment (Hao et al., 2020) and resource allocation (Wang S. et al., 2020). Meanwhile, corruption may aggravate environmental pollution by relaxing environmental regulations and frustrating the enthusiasm for energy innovation. Therefore, corruption has a grave impact on GTFEE. Pitifully, little concern is drawn to the research on the internal relationship between government competition, corruption and GTFEE.

Therefore, this study incorporates government competition, corruption, and GTFEE into a unified analysis framework, and explores the logical relationship between government competition, corruption, and GTFEE. This provides the theoretical basis and practical suggestions for optimizing economic structure, building a green ecological society, and coordinating economic and environmental development.

The remainder of the paper is developed as follows. Section 2 provides the literature review. Section 3 presents mechanism analysis and theoretical hypothesis. Section 4 demonstrates the research design. Section 5 provides the empirical analysis, while Section 6 gives the conclusions, policy implications, and further research directions.

2 Literature review

2.1 Government competition

Internationally, "local government competition" is also called "inter Jurisdictional Competition" (Brennan and Buchanan, 1980; Pan et al., 2017), "inter-regional competition" (Fawn, 2021), or "competitive government" (Breton, 1996; Zakari et al., 2022), and "competitive federalism" (Buchanan, 1995; Vanberg, 2016). The research on local government competition is thought to date back to Adam Smith, who pointed out in the *wealth of nations* that local governments compete essentially for capital. Tiebout (1956) put forward the famous theory of "voting with feet"[1] in his article "*A pure Theory on Local Expenditure*", which is called the Tiebout model. Breton (1989) completed the concept of "local government competition". He stressed that "governments are naturally competitive and will compete with each other for the distributions of the resources and controlling rights, along with public goods and services ". Afterward, foreign scholars conducted in-depth research on local government competition, and the theme extended to a variety of competitions among local governments such as capital tax competition (Eichner and Pethig, 2019; Tamai and Myles, 2022), scale competition (Handley and Mathew, 2020), infrastructure competition (Asturias et al., 2019; Álvarez-SanJaime et al., 2021), financial competition (Grout, 2021), and regulatory competition (Gersbach et al., 2020; Haselmann and Tröger, 2021).

The theoretical analysis of the impact of local government competition on GTFEE consists of the following aspects: 1) the behaviors between local governments are strategic interaction, and there is a "spillover effect", which is representatively manifested in three ways: competing to reduce tax rate (Eichner and Pethig, 2019), to increase financial expenditure (Xie et al., 2021), and to reduce the level of environmental regulation (Woods, 2006); 2) The purpose of local government's strategic interaction behavior is to obtain the entry of liquidity factors such as capital and labor force (Hong et al., 2020); 3) Under the unified jurisdiction, the motivation of local government strategic interaction is also "yardstick competition" (Shen and Zhou, 2020). Different from the spillover effect and the mechanism of obtaining liquid resources, "yardstick competition" focuses on using the

1 Voting with your feet refers to the flow of capital, talent and technology to areas that can provide better public services after barriers are removed.

"relative performance" to settle information asymmetry in the principal-agent framework (Căpraru, et al., 2022).

2.2 Energy efficiency

With the increasingly tight resource constraints, the research on energy efficiency has attracted much attention from scholars. The research mainly focuses on energy efficiency calculation and its influencing factors.

The measurement of energy efficiency mainly includes two methods: single factor energy efficiency (SFEE) and total factor energy efficiency (TFEE). The former is measured by the proportion of economic output to energy input or the ratio of energy input to economic output. Compared with SFEE, TFEE means energy efficiency, which can better reflect the relationship between energy and economy, and has been popularized in the academic circle (Arabi et al., 2014; Zhao et al., 2014; Zhang et al., 2020).

Improving energy efficiency is so imperative for the sustainable development of China's economy that a large number of scholars have carried out abundant studies on its influencing factors. Most of them maintain that industrial structure, technological progress, ownership reform, and R&D expenditure are dominant contributing factors to energy efficiency (Li and Lin, 2018; Xiong et al., 2019; Wang et al., 2020b; Zhao and Lin, 2020; Zhang and Fu, 2022). Hu & Wang (2006) initially proposed a basic framework to calculate TFEE. Some scholars refer to this framework to calculate TFEE and studied its influencing factors, finding that per energy price, energy consumption structure, capita income, and energy policy would also exert an obvious impact on it (Gamtessa and Olani, 2018; Bertoldi and Mosconi, 2020; Gillingham et al., 2020; Zakari et al., 2022). However, TFEE index of Li et al. (2022) solely includes the desirable output. Wang et al. (2022) ever argued that the pollution emissions from energy consumption must be considered in the calculation of energy efficiency, which is also a social cost and can negate the positive effect of desirable output. Because of this, some scholars began to take consider undesirable output into account in measuring energy efficiency (Hao et al., 2020; Wu et al., 2020a; Wu et al., 2020b).

2.3 Government competition and energy efficiency

Most studies have focused on the impact of industrial structure upgrading (Xiong et al., 2019), technological progress (Saygin et al., 2011; Lee et al., 2022), environmental regulation (Hao et al., 2022), and marketization (Zhao and Hu, 2020) on energy efficiency. However, few studies explore the correlation between local government competition and energy efficiency. For example, the competition in energy tax may have different effects on energy efficiency.

Aguiar and Bils (2015) argue that local governments can promote local economic growth by attracting foreign resource inflows through institutional innovation and tax incentives. However, under resource constraints, in order to prevent the outflow of resources, local governments will adopt local protectionism, which will increase regional transaction costs, thus reducing energy efficiency and hindering regional economic growth (Wang et al., 2022).

Although there is more and more research literature on government competition, corruption and GTFEE, there still exist deficiencies in this field. Firstly, few studies explored how government competition and corruption affect GTFEE. Secondly, the research on government competition and GTFEE needs to be further explored, and the internal mechanism deserves to be further clarified. In addition, government competition, corruption, and GTFEE are spatially dependent, but existing studies ignore the spatial correlation. Accordingly, the possible contributions are the following: 1) The study includes government competition, corruption, and GTFEE into a unified framework to investigate how government competition and corruption impact GTFEE and the transmission mechanism. 2) The dynamic SDM is constructed for econometric analysis, which effectively reflects the spatial correlation of the variables. 3) From the perspective of corruption, the study expands the previous relevant studies on influencing factors of GTFEE and further improves the influence mechanism of government competition and GTFEE.

3 Mechanism analysis

3.1 Impact of government competition on green total factor energy efficiency

Breton once defined "local government competition" more precisely, which means the behavior of local governments to attract funding, labor force, and mobile factors employing taxation, education, medical treatment, social security, environmental policies, and other means to upgrade the advantage in competition (Hao et al., 2022). The factors in the market abide by the law of "voting with their feet" in pursuing profits. Therefore, economic competition is essentially a behavior of local governments to compete for factors by their preferential terms, aiming to achieve economic targets or maintain regional superiorities.

How economic competition affects energy efficiency may depend on what factors local governments need to drive economic development. Economic competition provokes a "race to the bottom" in energy and ecological efficiency. Wu and Lin (2021) and Zakari et al. (2022) deem that local governments may take the strategy of reducing tax revenues or relaxing environmental regulations or both the aforementioned in order to win a competitive edge and

increase the tax base. Local government tax competition aggravates environmental pollution. On the one hand, a low tax rate is detrimental to making up for the negative externalities of environmental pollution; On the other hand, it impels local governments to loosen environmental regulations such as lowering environmental entry barriers (Khan S. U. et al., 2021; Khan S. A. R. et al., 2021). Such a "race to the bottom " forces local governments to spend less time and financial resources on energy savings, environmental governance, and social welfare improvement, causing the deterioration of regional development quality, the aggravation of pollution, and the decline of energy and ecological efficiency.

Wang and Wang (2020) utilized the provincial data to study how fiscal decentralization and government competition affect environmental governance, finding that government competition significantly amplifies the negative effect of fiscal decentralization on environmental governance, so it is responsible for insufficient investment in environmental control. Under the fiscal decentralization system, local governments are enormously enthusiastic about the economic competition by attracting investment to raise their financial and material strength. However, in order to attract more regional investment, the local governments tend to introduce many high-energy-consumption and pollution-intensive enterprises due to the limited local resource endowment and input factors, which is bound to increase the ecological pressure and the loss of social welfare, further decreasing regional energy ecological efficiency.

Under the "Chinese style decentralization", local governments carry out fierce competition due to the financial and political incentives from the central government, including tax competition, expenditure competition, and regulation competition (Lin and Xu, 2019). At the same time, deluded by private interests from enterprises, local governments collude with enterprises, so corruption is triggered, which further stimulates the strategic interaction and incomplete implementation of environmental regulation. What's more, as the demander of environmental public goods, the public has the right and obligation to supervise the central government and enterprises (Hao et al., 2022). Therefore, the public's demand for environmental protection will be a constraint factor for the interaction and incomplete implementation of environmental regulation, driving local governments to strengthen environmental pollution control and supervision (Wu et al., 2020).

Accordingly, Hypothesis 1 is assumed: local government competition hinders the improvement of GTFEE.

3.2 Impact of government competition on corruption

Government competition is apt to trigger corruption (Bliss, and Tella, 1997; Wu et al., 2022). Under the lure of economic gains, local governments will constantly expand their staff to attract investment and scramble for policies and resources from the central or superior departments. The staff increase will lead to difficulties in government supervision. In addition, it will reduce the income of local government officials, which will force them to seek more profitable activities. All of these increase corruption. Secondly, local government competition will promote privatization and marketization, which will make local officials much more concerned with the power of money and weaken the restraint power of traditional morality. Thirdly, under the dual constraints of carbon constraint performance and GDP performance, when local governments meet the assessment requirements of their superiors, they cannot respond to the needs of the market (Lee and Liu, 2022). In fact, to complete the task of attracting investment, some local governments will reduce land prices or taxes, and use local fiscal revenue to "support" or attract enterprises. In order to obtain this priority access, enterprises will use various improper means to lure local governments, which leads local officials to touch corruption. Last but not the least, the political environment is a key factor in whether local government competition will induce corruption. (Ryvkin and Serra, 2020; Ren et al., 2022). By and large, the looser the political environment, the weaker the anti-corruption ability, and more corruption will occur. Therefore, due to the differences in the political environment of various regions, local government competition may have different effects on corruption.

To this end, Hypothesis 2 is proposed: local government competition may induce local corruption, but the effect may be different in different regions.

3.3 Mediating effect of corruption

Corruption plays a key role when government competition affects GTFEE. Under fiscal decentralization, local governments have a large number of fiscal revenue and expenditure rights. With the discretion of a large number of local affairs, local governments have huge economic and administrative resources, which makes local government officials face many temptations. Some bureaucrats or interest groups get more convenience and political patronage for themselves by tempting local government officials to make use of their huge economic and administrative resources. Moreover, due to the local governments' strong position in China's social structure, their economic and administrative power is less supervised and balanced, leading to corruption such as power and money trading. More and more studies show that corruption exerts a great negative impact on the ecological environment. Corruption affects environmental sustainability and aggravates environmental pollution by relaxing environmental regulations (Leitão, 2010; Yu, 2019; Liu and Dong, 2021). For example, the impact of the "shadow economy" on pollution depends on corruption in the public sector (Sohail et al., 2021). Corruption

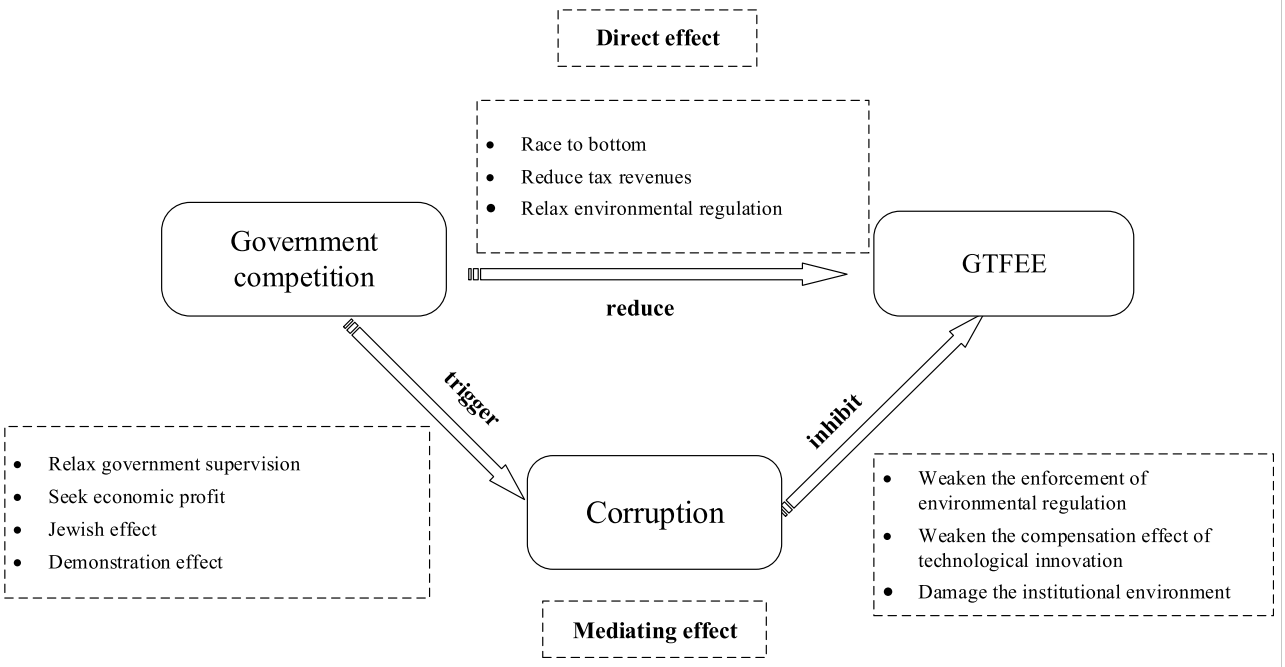

FIGURE 1
The mechanism analysis of government competition, corruption, and GTFEE.

will inhibit GTFEE. Due to government corruption, enterprises gain profits by continuously using outdated technologies, and thus their enthusiasm for the development and utilization of new energy fails to be mobilized. In the context of increasingly tight environmental resource constraints, local government competition exacerbates environmental pollution by triggering corruption and the role of government corruption is more prominent. Generally, the dual incentives of local government economic catch-up and official promotion strengthen the policy preference oriented by growth and promotion, which may lead to environmental corruption, namely, the economic growth mode at the cost of environmental pollution, and GTFEE is reduced in this manner.

Hence, Hypothesis 3 is put forward: Corruption acts as a bridge in the impact of government competition on GTFEE.

Figure 1 is presented to clarify the mechanism of how government competition affects GTFEE through corruption.

4 Research design

4.1 Spatial weight matrix

According to Tobler's First Law of Geography, all things are related, but nearby things are more related than distant things (Tobler, 1970), so it is necessary to set up a spatial weight matrix to represent the spatial correlation and dependence between spatial units. It is very important to choose an appropriate spatial weight matrix to explore the impact of government competition on green total factor productivity. However, in the existing literature on influencing factors of GTFEE, the spatial correlation of influencing factors of energy efficiency is insufficient. Existing research mainly used 0–1 adjacency matrix (Cheng et al., 2020; Wu et al., 2020b; Zhang et al., 2022) or geographic distance matrix (Wu et al., 2020a; Wang et al., 2022; Wang et al., 2022c) to reflect the spatial correlation. These studies only consider the geographical factors but ignoring the influence of economic factors. In fact, due to convenient transportation, the farther the distance between cities, the weaker the correlation degree may be, but they can still have economic exchanges with each other. Therefore, it is inappropriate to simply adopt 0–1 adjacency matrix or geographic distance matrix. In addition, the premise of this kind of matrix is that the mutual influence is equal, which is not consistent with the economic fact. Compared with the existing literature, we construct the nested matrix of economic geography ($W1$) for the benchmark test.

$$W_{ij}^{e} = W_{ij}^{d} \times diag\left(\bar{E}/\bar{E}, \bar{E}_2/\bar{E}, \cdots\cdots \bar{E}_n/\bar{E}\right)$$

$$W_{ij}^{e} = \begin{cases} \dfrac{W_{ij}^{e}}{\sum_i W_{ij}^{e}}, & i \neq j \\ 0, & i = j \end{cases} \tag{1}$$

Where $\bar{E}_i = 1/(t_1 - t_0 + 1)\sum_{t0}^{t1} Eij$ is the average per capita GDP of the city (i) during the observation period,

$\bar{E} = 1/(t_1 - t_0 + 1)\sum_{i=0}^{n}\sum_{t0}^{t1} Eij$ is the average value of per capita GDP of all cities in the observation period, t is the observation period. The above matrix shows that when a city's per capita GDP accounts for a large proportion of the total GDP of all cities ($\overline{E_i}/\bar{E} > \overline{E_j}/\bar{E}$), its impact on surrounding areas is also greater ($W_{ij} > W_{ji}$).

In addition, we construct the inverse distance space weight matrix ($W2$) to test the robustness of the empirical results.

$$W_{ij} = \begin{cases} \frac{1}{d}, & i \neq j \\ 0, & i = j \end{cases} \tag{2}$$

Where, d is the Euclidean distance between the two provinces.

4.2 Empirical model setting

The theory of spatial econometrics suggests that almost all spatial data have the characteristics of spatial dependence or spatial autocorrelation (Anselin, L., 2013), which has been confirmed in the research of Hao and Wu (2020).

Anselin (2013) further pointed out that the spatial econometric model mainly involves three models: spatial Lag model (SLM), spatial Error model (SEM), and spatial Durbin model (SDM). SDM takes the spatial autocorrelation of variables into account and can test the spillover effect of variables. Therefore, this paper constructs the dynamic SDM to fully investigate how government competition and corruption affect GTFEE, as shown in formula Eq. 1:

$$GTFEE_{it} = \alpha_0 + \rho\sum_{j=1}^{n} W_{ij}GTFEE_{it} + \alpha_1 GTFEE_{i,t-1} + \alpha_2 COM_{it} + \alpha_3 W_{ij}COM_{it} + W_{ij}\sum_{k=1}^{6}\alpha_k X_{it} + \varepsilon_{it} \tag{3}$$

In formula Eq. 1, i and t denote province and year, respectively. $GTFEEit$ refers to green total factor energy efficiency; $GTFEE_{i,t-1}$ means GTFEE lags behind the first phase; $COMit$ for government competition; X stands for control variables; ρ is the spatial spillover coefficient of GTFEE, $\alpha 0$, $\alpha 1$, $\alpha 2\ldots$, αk are the parameters to be estimated; W for spatial weight matrix; ε_{it} is a random perturbation term; All indexes are treated with natural logarithm.

Based on the research of Baron and Kenny (1986), this paper further constructs mediating effect model to judge the potential impact of local government competition on GTFEE. To alleviate the endogeneity, this paper utilizes the system generalized moment estimation (SYS-GMM) for regression.

$$GTFEE_{it} = \beta_0 + \beta_1 COM_{it} + \sum_{k=1}^{6}\beta_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \tag{4}$$

$$MED_{it} = \eta_0 + \eta_1 COM_{it} + \sum_{k=3}^{6}\eta_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \tag{5}$$

$$GTFEE_{it} = \omega_0 + \omega_1 COM_{it} + \omega_2 MED_{it} + \sum_{k=3}^{6}\omega_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \tag{6}$$

Where, $MEDit$ is an intermediary variable, representing corruption (COR_{it}). Eq. 2 tests the impact of local government competition on GTFEE, Eq. 3 tests the impact of local government competition on corruption, and Eq. 4 tests the impact of local government competition and corruption on GTFEE. When Eq. 2 is significant, local government competition significantly impacts GTFEE, and then observe the significance in Eqs. 3 and 4. If they are significant simultaneously, local government competition will affect GTFEE through corruption, in which the mediating effect is $\eta 1 \times \omega_2$. At this time, if ω_1 is also significant, it suggests that COR_{it} is a partial intermediary variable. If ω_1 is not significant, COR_{it} is a complete intermediary variable.

4.3 Variables and data

4.3.1 Explanatory variable

Green total factor energy efficiency ($GTFEE$). The global climate continues to deteriorate, so energy efficiency has attracted the great attention of governments and academia. However, most of the existing research on the measurement of energy efficiency fails to take undesired outputs into accounts such as wastewater, gases, and residues. The measurement of GTFEE is similar to that of total factor productivity. Referring to Khan et al. (2021), we use super-efficiency SBM of undesirable output to calculate GTFEE.

In calculating GTFEE, input variables, intentional output, and unintended output variables are included. Among them, the input variables are capital input, labor input, and energy input. Capital input (k) is calculated by the perpetual inventory method (Shan, 2008) which calculates the total fixed-asset investment and fixed asset price index of provinces. The formula is as follows

$$K_{it} = I_{it}/P_{it} + (1 - \sigma)K_{i,t-1} \tag{7}$$

In formula Eq. 7, K_{it}, I_{it}, P_{it} and σ represent the capital stock, total fixed capital, fixed asset price deflator, and asset depreciation rate of the province, respectively, in which the depreciation rate of fixed assets is 10.96%. Labor input is measured by the total number of employed people in each province. Energy input (E) is measured by the total energy consumption of each province. The intentional output index (GDP)is reflected by GDP. The paper deals with the constant price of GDP in 2006 to eliminate the interference of inflation

TABLE 1 Variables description.

Variable	Obs	Mean	Std. Dev	Min	Max
GTFEE	450	−0.6270	0.3357	−1.5196	0.2,955
COM	450	−1.1021	0.7945	−7.4486	0
COR	450	2.9521	0.7457	−4.6877	4.0148
FISCAL	450	0.4001	0.1285	0.1258	0.6683
PGDP	450	1.3590	0.6140	−0.45591	2.8394
INDUS	450	0.3249	0.0992	0.1136	0.5752
ER	450	1.9521	0.7457	−5.6877	3.0148
FDI	450	0.3059	0.2873	−0.2747	2.1098
URBAN	450	0.4364	0.0850	0.2426	0.6397

and other factors. Unintended output indicators include waste gas, solid waste, and wastewater. Assuming that there are K DMUs in the production system, and each DMU includes input vector X, intentional output vector Y^d, and unintended output Y^u, the production possibility set can be defined, as shown in Eq. 8:

$$\begin{aligned} P &= \{(x,\ y^d,\ y^u) | x \geq X\lambda,\ y^d \leq Y^d\lambda,\ y^u \geq Y^u,\ \lambda \geq 0\} \\ & x \in R^m, y^d \in R^{s1}, y^u \in R^{s2} \\ X &= (x_{i,j}) \in R^{m\times k}, Y^d = (yi, j) \in R^{s1\times k}, Y^u = (yi, j) \in R^{s2\times k} \\ & X > 0, Y^d > 0, Y^u > 0 \end{aligned} \tag{8}$$

Assuming that each DMU has l input, $s1$ expected output, and $s2$ unexpected output, the relaxation of input, expected output, and unexpected output is expressed in S^-, S^d and S^u, respectively, λ is the weight vector, and the SBM undesirable model is established as Eq. 9:

$$s.t = \begin{cases} x_0 = X\lambda + S^- \\ y_0^d = Y^d\lambda - S^d \\ y_0^u = Y^u\lambda - S^u \\ \lambda \geq 0, S^- \geq 0, S^d \geq 0, S^u \geq 0 \end{cases} \tag{9}$$

Many scholars have found that when the efficiency of DMU is 1, the optimal efficiency DMU becomes meaningless to compare horizontally. In order to overcome the disadvantage, Tone (2004) came up with a super-efficiency SBM of undesirable output. Use (X, Y) the removable point to define the possible $P^{'}$, $\bar{P}^{'}$, as shown in formula Eq. 10:

$$\begin{aligned} & P^{'}\backslash(x_0, y_0^d, y_0^u) = \{\bar{x}, \bar{y}_0^d, \bar{y}_0^u | \bar{x} \geq X\lambda, \bar{y}_0^d \leq Y^d\lambda, \bar{y}_0^u \geq Y^u\lambda, \bar{y} \geq 0, \lambda \geq 0\} \\ & \bar{P}^{'}\backslash(x_0, y_0^d, y_0^u) \subseteq P^{'}\backslash(x_0, y_0^d, y_0^u) \\ & \bar{P}^{'}\backslash(x_0, y_0) = P\backslash(x_0, y_0) = \cap\{\bar{x} \geq x_0\ and\ \bar{y} \leq y_0\} \end{aligned} \tag{10}$$

Finally, an improved SBM undesirable model is established, as shown in Eq. 11:

$$gtfee^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{l}\frac{\bar{s_i}}{x_{i,0}}}{1 + \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^d}{y_{r,0}^d} + \sum_{r=1}^{s2}\frac{s_r^u}{y_{r,0}^u}\right)}$$
$$s.t = \begin{cases} \bar{x} \geq X\lambda \\ \bar{y}^d \leq Y^d\lambda \\ \bar{y}^u \geq Yu\lambda \\ \bar{x} \geq x_0, \bar{y}^d \leq y_0, \bar{y}^u \geq y_0^u, \lambda > 0 \end{cases} \tag{11}$$

4.3.2 Explanatory variable

Local government competition (COM_{it}). There still exist some disputes in the academic circle about the measurement of government competition. Most of the existing literature

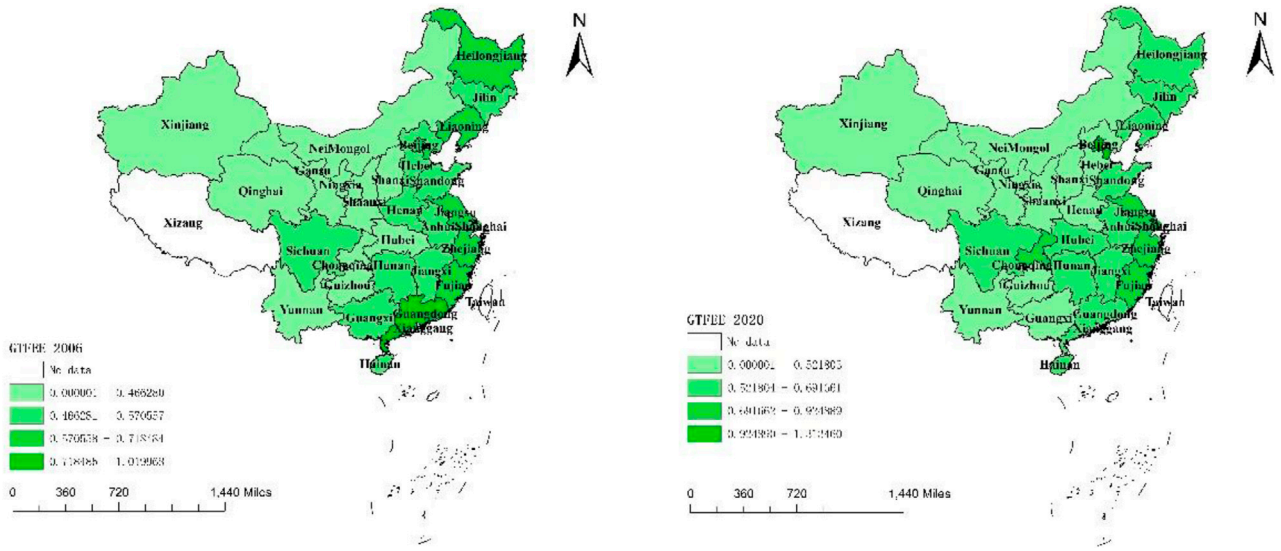

FIGURE 2
The distribution map of GTFEE in 2006 and 2020.

TABLE 2 Moran's I index of GTFEE.

Year	I	z	*p*-value*	Year	I	z	*p*-value*
2006	0.058	2.720	0.003	2014	0.086	3.356	0.000
2007	0.065	2.872	0.002	2015	0.080	3.193	0.001
2008	0.065	2.837	0.002	2016	0.113	4.117	0.000
2009	0.060	2.690	0.004	2017	0.110	4.024	0.000
2010	0.066	2.854	0.002	2018	0.138	4.831	0.000
2011	0.067	2.878	0.002	2019	0.138	4.869	0.000
2012	0.074	3.064	0.001	2020	0.136	4.851	0.000
2013	0.072	2.990	0.001				

takes foreign direct investment as the proxy variable. Foreign direct investment has the dual attributes of means and objectives of competition among local governments. In fact, economic development is the most important competitive goal of Chinese local governments under the dual incentive of "political championship" and "economic championship". Referring to Miao et al. (2017), this paper takes the GDP index to construct the local government competition index. The calculation formula is shown in formula Eq. 2:

$$COM_{it} = \frac{GDP_2}{GDP_1} \times \frac{GDP_3}{GDP_1} \quad (12)$$

Where GDP1 is the per capita GDP of a province. GDP2 represents the highest per capita GDP of its neighboring provinces, and GDP3 denotes the highest per capita GDP of the country.

4.3.3 Mediating variable

The above theoretical analysis suggests that local government competition may affect GTFEE by triggering correction. This paper takes corruption (COR_{it}) as the intermediary variable to test the indirect impact. Currently, two main methods are used to measure the degree of corruption: one is the subjective evaluation index based on the questionnaire survey. The other is to use the number of corruption cases filed by local judicial or procuratorial organs to measure the degree of corruption. Considering the subjectivity of the evaluation index of corruption, the deviation of evaluation, and the availability of data, this study, referring to the practice of Zhou and Tao (2009), adopts corruption cases filed by procuratorial organs in regions to express corruption degree. Specifically, job-related crimes per 10,000 public officials and job-related crimes per 10,000 regional total population are used to measure the degree of corruption in regions.

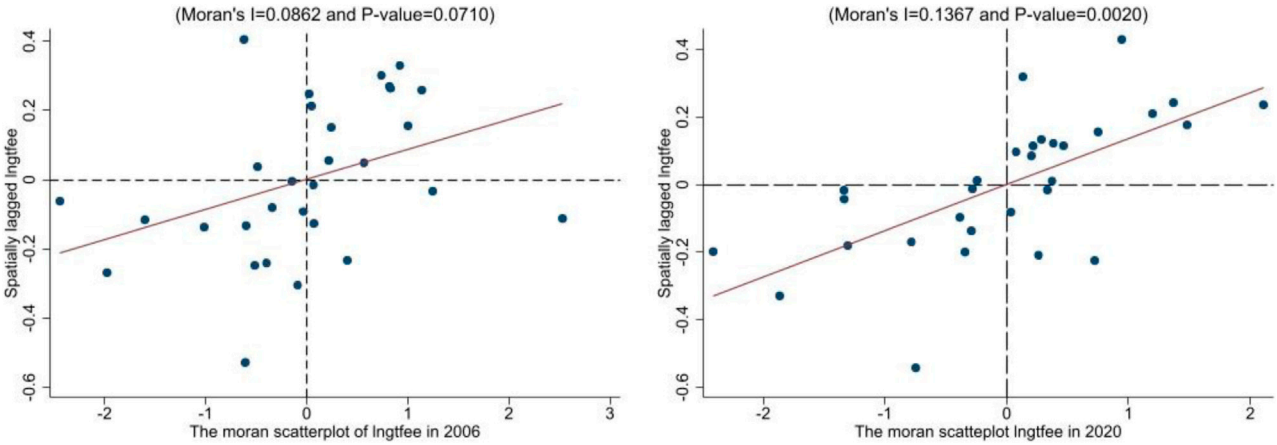

FIGURE 3
The local Moran scatter diagram of GTFEE in 2006 and 2020.

TABLE 3 Test results of the model applicability.

Index	Value	*p*-value	Index	Value	*p*-value
LM-lag	5.962	0.015	LM-error	5.655	0.017
Robust LM-lag	15.999	0.009	Robust LM-error	20.692	0.000
LR-lag	52.14	0.000	LR-error	85.22	0.000
WALD-SAR	93.50	0.000	WALD-SEM	92.65	0.000
Hausman	−60.40	0.000			

TABLE 4 Benchmark regression.

Variable	(1)	(2)	(3)	(4)
	Pool OLS	FE	SysGMM	SDM
L.GTFEE			0.9684***	1.3369***
			(29.64)	(76.17)
COM	−0.0689***	−0.0445***	−0.0041**	−0.0271***
	(−3.64)	(−5.12)	(−2.16)	(−8.31)
FISCAL	0.6066***	−0.5274***	0.0042	−0.0586
	(6.59)	(−3.76)	(0.15)	(−1.00)
PGDP	−0.0687**	0.0922***	−0.0015	−0.1055***
	(−2.24)	(3.71)	(−0.46)	(−6.21)
INDUS	−1.3085***	−0.6470***	−0.0661	0.3154***
	(−9.41)	(−4.71)	(−1.21)	(6.59)
FDI	0.2245***	0.0559*	0.0043	−0.0027
	(7.07)	(1.80)	(0.43)	(−0.29)
ER	0.0024	0.0069	0.0076***	0.0167***
	(0.14)	(0.91)	(2.70)	(6.69)
URBAN	0.8860***	−0.9233***	0.1762***	1.0835***
	(3.36)	(-3.08)	(4.33)	(8.90)
*W1*COM*				−0.0818***
				(−4.61)
*W1*PGDP*				−0.0243**
				(−2.55)
*W1*ER*				−1.8771***
				(−24.25)
*W1*URBAN*				8.9346***
				(36.59)
AR(1)			2.32 [0.023]	
AR(2)			0.97 [0.330]	
Hausman test			0.47 [0.926]	
Two-way fixed	NO	YES	YES	YES
ρ				1.0165***
				(11.04)
sigma2_e				0.0005***
				(16.68)
N	450	450	420	420
R^2	0.754	0.273		0.311

Note: the significances at 1, 5, and 10% levels are symbolized by ***, **, and *, respectively. Figures in () are Z-values. Figures in [] are *p*-values. The following is as above.

TABLE 5 Regional heterogeneity.

Variable	(1)	(2)
	East	Central & West
L.GTFEE	1.2128***	0.9644***
	(28.04)	(48.50)
COM	−0.0352***	−0.0430*
	(−5.60)	(−1.89)
FISCAL	−0.0215	−0.0361
	(−0.17)	(−0.66)
PGDP	−0.0446	−0.0201
	(−0.94)	(−1.51)
INDUS	0.3427***	−0.1373***
	(2.60)	(−3.14)
FDI	0.0173	−0.0718***
	(1.13)	(−3.27)
ER	−0.0241***	−0.0023
	(−3.44)	(−1.03)
URBAN	5.1038***	−0.0967
	(15.34)	(−0.90)
*W1*COM*	0.0154	−0.1983***
	(0.64)	(−4.06)
Two-way fixed	YES	YES
ρ	0.0194**	0.0737**
	(2.15)	(2.31)
sigma2_e	0.0009***	0.0002***
	(10.03)	(12.38)
N	165	285
R^2	0.528	0.952

4.3.4 Control variables

To control other factors that may affect GTFEE, industrial structure ($INDUS_{it}$), urbanization level ($URBAN_{it}$), economic development level ($PGDP_{it}$), fiscal decentralization ($FISCAL_{it}$), environmental regulation (ER_{it}), and opening-up level (FDI_{it}) are selected as control variables. Fiscal decentralization ($FISCAL_{it}$). Referring to Wu et al. (2020a), fiscal decentralization is measured by provincial per capita local fiscal expenditure/(provincial per capita local fiscal expenditure + per capita central fiscal expenditure at the same level). The level of economic development ($PGDP_{it}$) is expressed by the per capita GDP of each province. The industrial structure ($INDUS_{it}$) is measured by the ratio of the GDP of the secondary industry to the GDP of the tertiary industry. Environmental regulation (ER_{it}) refers to the provincial environmental investment in pollution control. The opening-up level (FDI_{it}) is denoted by provincial foreign direct investment. The urbanization level ($URBAN_{it}$) is measured by the ratio of the urban population to the year-end total population in each province.

4.4 Data description

This paper samples China's 30 provinces from 2006 to 2020, excluding Hong Kong, Macao, Taiwan, and Tibet due to the data missing. The interpolation method is employed to supplement the missing data. The relevant data except for GTFEE are from China's statistical yearbook of all kinds and China's statistical

TABLE 6 Intermediary effect test.

Variable	(1)	(2)	(3)
	GTFEE	*COR*	*GTFEE*
COM	−0.0622***	0.0098*	−0.0566***
	(-4.82)	(1.87)	(−4.48)
COR			−0.5727***
			(−4.48)
FISCAL	0.3182***	−0.0166	0.3,087***
	(3.33)	(−0.43)	(3.32)
PGDP	−0.0648**	0.0134	−0.0,571**
	(−2.45)	(−1.26)	(−2.21)
INDUS	−1.0321***	0.1669***	−0.9364***
	(−7.97)	(3.18)	(−7.32)
FDI	0.1777***	−0.0032	0.1759**
	(5.17)	(−0.23)	(5.25)
URBAN	1.4810***	−0.0619**	1.4456**
	(6.64)	(−1.98)	(6.65)
N	450	450	450
Sober test	Z- value = −1.724*		
Mediatory effect test	mediatory effect = −0.0056***		
	The proportion of total effect that is mediated: 9.02%		

database. The descriptive statistical results of relevant variables are shown in Table 1.

5 Empirical analysis

5.1 Analysis of spatial correlation

This paper uses arcgis10.6 to draw a quadrant map of GTFEE to intuitively reflect the regional differences and dynamic changes of GTFEE in China. On account of confined space, the distribution maps of GTFEE in 2006 and 2020 are presented in Figure 2. It can be seen that economically developed regions such as Beijing, and Tianjin are dominant in the dark green regions with the highest GTFEE. Additionally, the dark green areas increased from 2006 to 2020, implying that China's GTFEE is being gradually improved. The reason is that the governments have changed the promotion and incentive objectives, taking the intensive use of resources and the restriction of pollutant emission as binding indicators, which has strengthened the environmental governance of local governments. In this manner, energy efficiency has been greatly improved.

Table 2 shows the Moran's I index of China's GTFEE from 2006 to 2020. It can be found that Moran's I index of GTFEE is positive at the significance level of 1% from 2006 to 2020, suggesting that in the whole region, China's GTFEE has obvious spatial positive correlation and spatial agglomeration.

The local Moran scatter diagram (Figure 3) is used to vividly demonstrate the spatial agglomeration of GTFEE. We can see that the scatter points are mainly located in the first quadrant (high-low agglomeration), the third quadrant (low-low agglomeration), and the fourth quadrant (low-high agglomeration), and as time goes on, the agglomeration trend of environmental pollution moves to the first quadrant (high-high agglomeration).

5.2 Spatial econometric model selection test

Considering the spatial correlation, this paper preliminarily sets SDM and then conducts the model applicability test. The test results in Table 3 show that all tests pass the significance test, indicating the dynamic SDM with spatiotemporal double fixed effect is appropriate for the empirical test.

5.3 Analysis of estimation results of spatial durbin model

5.3.1 National sample analysis

This paper mainly uses the dynamic SDM model for parameter estimation. For better comparative study, the estimations of the non-spatial panel OLS model 1), panel fixed effect model 2), system Gaussian Mixed Model 3), and dynamic Spatial Dubin Model (SDM) 4) are also listed in Table 4.

It can be seen from Table 4 that the lag term of GTFEE is significant at the level of 1%, indicating that there is an obvious "time inertia" (Yang C. et al., 2021; Yan et al., 2022). If the GTFEE is at a high level at this moment, it may continuously be rising in the following days, thus showing the "snowball effect".

Additionally, both in the non-spatial panel model and spatial panel model, the estimation coefficients of government competition on GTFEE are negative, indicating that as a whole, government competition hinders the improvement of GTFEE. The possible reason is that local governments intend to adopt the competitive strategy of the low tax burden or relax environmental regulations or both to gain an economic competitive edge (Liu and Dong, 2021; Ren et al., 2021). This distorted behavior will cause the "contagion" effect among regions, resulting in the same direction chain change of regional environmental supervision behavior (Hao et al., 2022). The "race to the bottom" of government competition and the "adverse selection" of the market have caused the withdrawal of enterprises with high environmental standards and high production efficiency from the market. Under the factor curse trap and the "pollution paradise" effect, the path dependence of the regional economy on the extensive

TABLE 7 Robustness test.

	(1)	(2)	(3)
	Replace the explained variable (*GTFEE*1)	**Replace the explanatory variable (*TI*)**	**Replace the matrix (*W*2)**
*L.GTFEE*1	1.3392***	1.3492***	1.2386***
	(76.35)	(76.81)	(70.61)
COM	−0.0238***	−0.0227***	−0.0276***
	(−8.12)	(−8.92)	(−8.46)
FISCAL	−0.0812	−0.0995*	−0.1498**
	(−1.55)	(−1.71)	(−2.56)
PGDP	−0.0897***	−0.1059***	−0.1008***
	(−5.87)	(−6.24)	(−5.94)
INDUS	0.2616***	0.3131***	0.2905***
	(6.08)	(6.55)	(6.08)
FDI	−0.0037	−0.0040	−0.0034
	(−0.45)	(−0.43)	(−0.37)
ER	0.0162***	0.0199***	0.0219***
	(7.23)	(7.99)	(8.79)
URBAN	0.8140***	0.8900***	0.7946***
	(7.43)	(7.32)	(6.53)
W* *COM*	−0.0777***	−0.0743***	−0.1166***
	(−4.06)	(−4.48)	(−5.48)
ρ	1.3274***	1.5309***	2.0955***
	(12.02)	(13.83)	(18.98)
sigma2_e	0.0004***	0.0005***	0.0005***
	(16.70)	(16.75)	(16.88)
N	420	420	420
R^2	0.439	0.521	0.460

development model has become stronger and stronger (Candau and Dienesch, 2017; Yang X. et al., 2021), thus hindering the improvement of GTFEE. Hypothesis 1 was tested.

The estimation coefficient $W*COM$ is significantly negative at the 10% significance level, indicating that under the official promotion mechanism with economic growth as the main target, local governments compete fiercely for high-quality production factors to obtain political interests at the expense of the environment. This not only inhibits the improvement of GTFEE within the jurisdiction but also produces a negative spillover effect on adjacent areas, showing the behavior of a "race to the bottom".

5.3.2 Regional heterogeneity analysis

To further explore the regional differential impact of government competition on GTFEE, the samples are divided into Eastern, and Central & Western regions, and the dynamic SDM is used to estimate the regional differential impact. The estimations are presented in Table 5.

Table 5 shows that the impact of local government competition on GTFEE has not only characteristics in common but also regional differences. In terms of the main effect, for all regions, the coefficients *COM* are negative, which means that local government competition reduces regional GTFEE. The conclusion agrees with the estimations at the national level. However, the absolute value of the government competition coefficient (−0.0352) in the eastern region is smaller than that (−0.0430) in the central and western regions, where local government competition has a greater inhibitory effect on GTFEE (Lin and Xu, 2019). As for the spatial effect, it is not statistically significant, but the impact is different. The local government competition in the eastern region promotes GTFEE, whereas hinders GTFEE in the central and western regions. In the eastern region, there are sounder mechanisms, better management skills, and a higher technical level. The local governments are more inclined to benign competition for high-quality development, which is conducive to improving the GTFEE. In the central and western regions, the economic

strength is weak and the industrial structure is abnormal. In order to develop the economy, local governments adopt preferential policies and other illegal means to attract "three high" industries to settle down, thus reducing the regional GTFEE (Hao et al., 2020).

5.3.3 Mechanism test

Generally, the local government competition can reduce GTFEE. In the following, the mechanism will be further analyzed. In this paper, a step-by-step test (Baron and Kenny, 1986) is applied to verify whether the intermediary effect exists. Equations 2–4 are the intermediary effect test models. What's more, the bootstrap method has a high statistical effect and is recognized as a method that can replace the Sobel method and directly test the coefficient product (Yan et al., 2021).

Table 6 shows that $\beta 1$ in Eq. 2 is significant, indicating that local government competition inhibits GTFE, which further verifies hypothesis 1. The local governments compete for economic growth by relying more on the consumption of traditional energy without considering environmental problems, unavoidably damaging the improvement of GTFEE. Both $\eta 1$ in Eq. 3 and ω_2 in Eq. 4 are significant, showing that local government competition may affect GTFEE through corruption, in which the mediating effect is $\eta 1 \times \omega_2$. $\omega 1$ is significant implying that corruption is a partial intermediary variable, and the intermediary effect accounting for 9.02%. This suggests that local government competition not only directly weakens GTFEE but also indirectly inhibits GTFEE through corruption (Leitão, 2010). Hypothesis 3 is verified.

5.3.4 Robustness test

To further verify the reliability of the estimations, the following tests are carried out by using SDM, and the results are shown in Table 7.

1) Recalculate the explained variable. Non-radial distance function (NDDF)is employed to remeasure GTFEE by taking capital, labor, and energy as input factors, GDP as desirable output, and pollution emission as undesirable output (Lin and Xu, 2019). 2) Recalculate the explanatory variable. Tax intensity (TI) is denoting local government competition, that is, the ratio of the annual total tax revenue of a province (city) to the GDP of the province (city). 3) Replace the matrix. The inverse distance matrix is used to replace the nested matrix of economic geography. It can be found that the estimations direction and significance of the three methods are highly consistent with the basic regression results, verifying that the model setting and regression estimations are scientific and robust.

6 Conclusion and policy implication

Based on the data of 30 provinces in China excluding Hong Kong, Macao, Taiwan, and Tibet from 2006 to 2020, this study empirically tests the relationship and internal mechanism between government competition, corruption, and GTFEE by using SDM and intermediary effect model. The findings show that: 1) In general, local government competition considerably reduces the regional GTFEE. After the robustness test, the conclusion is still valid. 2) Regional heterogeneity shows that local government competition in the western region has a greater inhibitory effect on GTFEE than that in the eastern region. As for the spatial spillover effect, the local government competition in the eastern region promotes GTFEE, whereas hinders GTFEE in the central and western regions. 3) Government competition indirectly inhibits the improvement of regional GTFEE by triggering corruption and the mediating effect accounts for 9.02%.

Accordingly, in order to achieve sustainable and healthy development of China's economy, policymakers should take government competition as the starting point to improve regional GTFEE. Firstly, scientifically guide and regular the horizontal competition among local governments. When local economic development is backward and the government's financial resources are insufficient, local government competition fails to play its positive role. Therefore, tax competition has necessarily become the main means of horizontal competition among regions. However, as China's economic development enters the middle stage of industrialization and the new era of people's livelihood, it is urgent to guide local governments to carry out the benign and orderly competition by reforming the performance evaluation system of local government officials, to reduce local governments' excessive dependence on tax competition, and realize the transformation from tax competition to expenditure competition Meanwhile, make full use of the positive effects of expenditure competition on resource allocation to alleviate the negative effects of tax competition and promote high-quality economic development.

Secondly, adopt differentiated local competition strategies. According to local conditions, the primary and secondary competitive motives should be distinguished in line with the actual needs of local governments. The local government should choose the different game objects and strategies according to competitive motivation. When adopting the strategy of "Race to the bottom" to attract economic interests, it is necessary to avoid the occurrence of collective irrational vicious competition caused by individual rationality. For most local governments, they should carry out benign competition (such as moderate race-to-top competition) and cooperation to deal with the contradiction of environmental regulation among local governments, getting out of the dilemma of short-term interests and long-term returns, and gradually improving GTFEE.

Thirdly, the local government should improve the anti-corruption system to curb corruption among local officials so as to reduce the negative effect of corruption on GTFEE (Hao et al., 2020). Specifically, they should carry out warning

education to build a strong defense line against corruption ideologically. In this manner, corruption is nipped in the bud. On the other hand, they should strengthen supervision over rights, improve the supervision system of law, democracy, public opinion, and the masses, exposing the behavior of local government officials to the public so as to provide a good institutional environment for the improvement of green energy efficiency.

Although this study has conducted an in-depth discussion on the relationship between government competition, corruption, and GTFEE, the exploration is insufficient. Firstly, this study is made by using provincial data due to data availability, and prefecture-level city data should be used for further research, which can reduce the errors caused by large spatial scale and internal differences. Secondly, this study has verified that corruption is a partial intermediary variable of government competition affecting GTFEE, indicating that there are other transmission paths, which deserve to be further explored in future research.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

JZ: Conceptualization, Project administration, Writing - review and editing, Writing original draft, Funding acquisition. JY: Writing - review and editing, Software, Visualization, Formal analysis. XY: Writing - review and editing, Validation, Formal analysis. CN: Methodology, Formal analysis, Funding acquisition, Supervision. QR: Writing - review and editing, Validation, Funding acquisition, Supervision. HS: Writing - review and editing, Formal analysis, Funding acquisition.

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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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