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IMPACT OF HETEROGENEOUS LOCAL GOVERNMENT COMPETITION AND GREEN TECHNOLOGY INNOVATION ON ECONOMIC LOW-CARBON TRANSITION: NEW INSIGHTS FROM CHINA

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Abstract. Low-carbon transformation of the economy is the inevitable orientation of socialism with Chinese characteristics to high-quality development in the new era, while the Chinese decentralized development model determines that the competition of local governments in China is an important factor influencing the green technological innovation on low-carbon transformation of the economy. How to achieve coordinated economic growth and ecological environment has become a prob-lem for local governments. Data from a Chinese provincial panel covering the years 2007–2019 is used to investigate the effects of heterogeneous local government competition (Comp), namely, economic, ecological and service competitions on economic low-carbon transition, and moderating effects of heterogeneous government competition and green technology innovation (GTECH) on the low-carbon economic transition (LCT). The results reveal that there are substantial disparities in the consequences of heterogeneous government competition on low-carbon economic transition (LCT). Among them, economic competition significantly dampens economic low-carbon transition (LCT), and ecological competition and service competition significantly boost economic low-carbon transi-tion (LCT). After performing robustness checks, these results continue to be strongly convincing. The study of moderating effects shows that economic competition can dampen the positive influence of green technology innovation (GTECH) to the economic low-carbon transition (LCT). However, ecological competition and service competition facilitate the promoting effect of green technology innovation on economic low-carbon transition (LCT).

Keywords: low-carbon economic transition, green technology innovation, heterogeneous, local government.

JEL Classification: L51, O11, O32, Q51, Q55.

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1. Introduction

The tremendous rise of the world population and economy since the industrial revolution has prompted the quick development of minerals and energy. In contrast, the rapid increase of greenhouse gas emissions, such as carbon dioxide generated by massive fossil energy consumption has aggravated global warming and caused irreversible damage to the ecological environment (Ran et al., 2023a; Wang et al., 2023). At present, global warming has become

a non-traditional security threat faced by human society, and implementing the concept of low-carbon development has serve as a new path for the future development of the global economy. The 6th IPCC report reveals that globally averaged surface temperature from 2011 to 2020 increased by 1.09 °C from 1850 to 1900[1]. There will be a significant increase in temperature in the future; that is, carbon dioxide emissions will still be an essential factor affecting climate change. How to deal with complex climate change and solve the problem of environmental degradation has become an issue of the times for countries all over the world to deal with (Li et al., 2023a; Yang et al., 2021a).

Since 1978, the Chinese economy has increased and created a "Chinese miracle" (Chen & Golley, 2014). At the same time, the rapid expansion of China's economy has given rise to a great number of challenges, including resource depletion, ecological destruction, environmental pollution, and climate change (Li et al., 2018; Yang et al., 2021a; Du et al., 2023). President Xi Jinping said on September 22, 2020, that China's carbon dioxide emissions would peak in 2030 and that the nation would become carbon neutral in 2060, demonstrating China's determination and attitude towards emission reduction. To properly handle the relationship between ecological governance and economic development, the government has elevated the construction of ecological civilization and green growth to a national strategy in China, actively formulating various procedures and policies about climate change and cooperating with global climate governance (Miao et al., 2023).

Local government competitiveness is essential, and allowing local governments to express their initiative and passion fully is the foundation and assurance of success to achieve low-carbon economic transformation. Therefore, local government competition (Comp) is bound to profoundly impact China's current low-carbon change and development (Boyne, 1996; Hatfield & Kosec, 2013; Razzaq & Yang, 2023). The way local government competition is multidimensional. Local government competition as a specific government behavior depends on the incentive and constraint mechanisms it faces (Xu et al., 2023a; Yang et al., 2021b; Ran et al., 2023b). Under the incentives and pressures of macro-performance appraisal, local government competition exhibits a multi-dimensional approach to competition. Under the incentive of "economic decentralization", economic competition is the outstanding dimension of competition. With economic growth and increasing industrialization, environmental and ecological problems have gradually entered the government's field of vision, and the public goods attributes of the environment and ecology require the government to strengthen environmental governance and ecological construction (Reed et al., 2021; Li et al., 2023c; Liu et al., 2023a). At the same time, providing quality public services is the basic duty of local governments (Bel & Fageda, 2007). Thus, the study of the impact of heterogeneous local government competition also has profound theoretical and practical significance.

China's economic development cannot be achieved without actively promoting government departments, where Comp based on performance appraisal mechanism plays an important role. Scholars generally consider Comp an effective economic development incentive mechanism. However, under the performance appraisal mechanism emphasizing GDP growth rate indicators, local governments' competition for growth has led to problems such as economic inefficiency, little fiscal expenditure, and an imbalanced economic structure.

[1] See: https://baijiahao.baidu.com/s?id=1707658492439659236&wfr=spider&for=pc

In addition, the traditional competition model of "competition for growth" is one of the institutional root causes of China's crude and distorted economic growth, directly leading to serious carbon emissions and energy consumption. Correspondingly, local governments have achieved long-term stable economic development by improving human capital level, introducing innovation investment, and strengthening technology (Yang et al., 2022b; Xu et al., 2023b; Li et al., 2023b). Government industrial policies, technology policies, environmental management policies, and environmental protection laws and regulations profoundly impact the progress of green technology (Razzaq et al., 2023). Thus, significant variability exists in the impact of different competitive models of local governments on economic low-carbon transition (LCT). So, is there differentiation in the impact of heterogeneous government competition (economic, ecological, and service competitions) on the LCT? What are the reasons for these differences? How does heterogeneous government competition affect LCT by influencing green technology innovation (GTECH)? Against the background of ecological civilization construction, the issues of government competition, ecological, environmental protection, and collaborative socio-economic development are complex problems encountered in China's development practice and essential points that many scholars urgently need to investigate and solve. By exploring the role mechanism of heterogeneous government competition behavior on LCT development from GTECH, a scientific and rational formulation of government competition strategy has significant theoretical and practical implications for achieving economic low-carbon development.

The following is an explanation of this paper's tangential contributions: First, constructing a multi-indicator system of government competition to provide an in-depth portrayal of the heterogeneity of government competition and the heterogeneous government competition framework is developed in terms of the ecological, economic, and service competitions to deeply delineate it, broadening the current research results in the field. Second, it expands the research perspectives of existing fields. We incorporate multidimensional Comp, GTECH, and LCT development into one analytical structure and bring in the interaction term between the two to generate new insights for achievement of the dual carbon goals. Lastly, we fully deliberate the endogeneity issue and employ various methods for robustness testing to make our findings compelling.

The review of the literature can be found in Section 2. Section 3 presents the investigation's theoretical framework and hypotheses. In Section 4, we will discuss the development of the model, as well as the selection of indicators and the data sources. The empirical findings and subsequent discussion are presented in Section 5. The conclusion as well as any suggestions for public policy are presented in Section 6.

2. Literature review

2.1. Local Government competition and economic low-carbon transition development

The investigation and discussion of the theory of Adam Smith was the first person to write on competition in municipal government (Oprea, 2022). In the 1950s, the American economist Tiebout proposed "voting with one's feet." He believed that the supply of public goods would

cause population migration, which would put external pressure on local government governance and force local governments to improve their operational efficiency and the quality and efficiency of public goods supply, thus attracting the inflow of production factors and increasing local tax revenue (Tiebout, 1956; Liu et al., 2022b).

The study on Comp theory may be traced back to Adam Smith's "the wealth of nations", which was published in its first form in 1776; although not formally put forward the concept of Comp, but pointed out that the flow of production factors to influence the intergovernmental tax competition. In the 1950s, the American economist Tiebout proposed the theory of "voting with your feet", believing that the supply of public goods will cause population migration, which will cause external pressure on local government governance, forcing local governments to improve their own operating efficiency and the quality and efficiency of public goods supply, and improve local tax sources by attracting the inflow of production factors.

The connotation of Comp has become more negative due to the continued growth in the amount of attention given to Comp by academics (Jiang et al., 2022; Razzaq et al., 2021). Many scholars believe that Competitors from across the country's administrative regions compete for inflow of production inputs such as money and technology as well as human talent in the areas of investment climates, legal systems, social services, and natural environments (Deng et al., 2019; Hwang, 2022). As a result, many academics have presented the rivalry between local governments from the perspectives of service, ecological, and competitions (Breton, 1998; Zhang et al., 2021; Wang & Lei, 2021). Concerning low-carbon economic development, scholars believe that there are two types of competition mechanisms, "competition for the worse" and "competition for the better", in the role of Comp in low-carbon development (Wu et al., 2020). The "bad competition" means that local governments may relax environmental regulations and create "pollution havens" for investment to attract more investment (Zhang et al., 2021; Ren et al., 2021). The expense of technical innovation and research and development is, in the end, crowded out, and the ability of local economies to make a LCT is weakened. The "competition for good" means that due to public scrutiny, local governments raise the bar on environmental regulations, which spurs technical advancement and optimizes businesses structure, and ultimately promotes low-carbon economic development (Ramanathan et al., 2010; Manello, 2017).

2.2. Green technology innovation and and economic low-carbon transition development

Technological innovation is proposed based on the endogenous growth model. Neoclassical economists have identified technological advancement as a key driver of economic growth in the theory of the endogenous growth model (Oprea, 2022). According to their definition, "green technology" includes any type, product, or technology that helps the environment by using less energy and raw materials and reducing pollution. Many academics have acknowledged the importance of GTECH in achieving long-term economic growth, prevent waste, and maximizing the efficiency of available resources (Norberg-Bohm, 1999).

The meaning of "green technology innovation" has become more nuanced as a result of researchers' unceasing efforts to broaden and deepen their understanding of the topic of GTECH (Wicki & Hansen, 2019; Wang et al., 2019; Du et al., 2021). Green technology is the

new modern specialized system that aims to protect the environment, follow the ecological principles and economic laws, and raise the rate at which resources are used in harmony with the ecological and environmental systems, which many scholars have supported (Zailani et al., 2014; Lv et al., 2021). To accurately, objectively, scientifically, and comprehensively measure GTECH, some scholars quantified its level using R&D investment (Costa-Campi et al., 2017) or patent grants (Cai et al., 2020). In addition, additional academics have also measured green total factor efficiency to indicate green technological progress using the Malmquist-Luenberger index, respectively, with significant results (Kumar, 2006). Most scholars support that green technological progress can contribute to developing a low-carbon economic transition. Green-oriented technological innovations significantly contribute to the green economy and contribute to the low-carbon transformation of the economy by improving resource efficiency and energy utilization (Ghisetti & Quatraro, 2017). Scholars such as Chang (2011) find that green technological innovations promote economic decarbonization while protecting firms' marginal profits. In addition, Some academics believe that innovations in environmentally friendly technology may foster low-carbon transformative growth and that low-carbon transformational development is the basis for green economic development. Moreover, Environmental deterioration may be mitigated, resources conserved, and economic development can be promoted via green economic growth (Bagheri et al., 2018; Musango et al., 2014; Liu et al., 2023b).

By "green" they mean a new contemporary technological system designed to safeguard the environment, adhere to ecological principles and economic laws of ecology, and enhance the efficiency with which resources are used while also better coordinating with the ecological environment system. To accurately, objectively, scientifically and comprehensively measure GTECH, some scholars quantify its level by means of R&D investment (Costa-Campi et al., 2017) or patent authorization (Cai et al., 2020). Some scholars also used Malquist-Luenberger index (Kumar, 2006) to measure green total factor efficiency to indicate the progress of green technology and achieved remarkable results. Most scholars currently support the view that green technological progress can reduce carbon emissions. Ghisetti and Quatraro (2017) also highlight how technological advancement greatly encourages the green economy. Green technological innovation can promote low-carbon economic transformation by improving resource efficiency and energy utilization rate. Chang (2011) found that GTECH can promote the low carbonization of economy and protect the marginal profit of enterprises. An LCT may be aided through green technical innovation, which is the basis of green economic development (Li et al., 2019). Environmental deterioration, resource conservation, and economic development may be achieved via green economic growth (Bagheri et al., 2018; Musango et al., 2014).

There have been rich investigated on the linkages between Comp, GTECH, and LCT development. Significant outcomes have been achieved in terms of theoretical analysis and empirical evidence. However, there are still weaknesses as follows. First, few scholars have examined the role mechanism of Comp towards economic transformation development of low carbon economy from the perspective of heterogeneity. Secondly, most scholars adopt indicators such as growing competition, fiscal competition, tax competition, and capital attraction competition to characterize Comp, which cannot be comprehensively or scientifically. They properly reflect the extent of competition in municipal government, but their analysis

lacks objectivity and objectivity. Finally, local government rivalry may be broken down into economic, ecological, and service competition. The link between Comp and economic low-carbon transformation growth from the heterogeneity of government competition has only been examined by a small number of research to this point. Based on this information, they investigate the effect of diverse Comp on the LCT growth from economic, ecological, and service competition perspectives. Competition between municipal governments and the development of green technologies is also intertwined, as is the word "interaction" used to describe this relationship. The mechanism of heterogeneous local government rivalry on LCT development is examined for the theoretical guiding of local government LCT development.

3. Mechanism analysis and research hypothesis

Competition between different local government levels is an essential component of LCT development. Local governments can be categorized into three types of rivalry: Combining the findings of earlier academics, this study examines economic competition, ecological competition, and service competition (Zhang et al., 2021). Economic competition refers to local governments competing with surrounding areas for production factor resources by taking advantage of their policy advantages in taxation, investment attraction, and investment to promote local economic growth (Deng et al., 2019). Economic competition exists two kinds of effect of low carbon transformation; To realize high-speed economic development, an excessive amount of interference by the local government might have a negative impact on the market's ability to efficiently allocate resources (Jiang et al., 2022; Liang et al., 2022), which already has a negative impact on the natural development of the ecological environment and is unfavorable to the transformation to a low-carbon society and the growth of the local economy (Hwang, 2022). That is, the government competition behavior has the effect of "bottom-by-bottom competition" (Zhang et al., 2021). On the one hand, economic competition in the local government can augment that of the area's economic development. While the economic development level is the basis for the social security and development. Economic growth can simultaneously foster industrial restructuring, advancing technology and boosting its capital stock to fulfill LCT, in which the government has been "bottom-up competition" (Wu et al., 2020; Bridge et al., 2013; Sharif et al., 2023).

Moreover, ecological competition implies that when local governments are confronted with rising resource limits, severe environmental pollution, and ecosystem degradation restrictions, they push businesses to participate in corporate innovation to increase the efficiency of natural resource usage (Zhang et al., 2020). Ecological competition forces enterprises to invest more resources to improve production technology under the constraints of environmental regulations through adjusting environmental regulations, which can drive production and utilization efficiency of natural resources to fulfill low-carbon economic transition development. Meanwhile, service competition denotes the competition for the inflow of human resources by local governments through improving the quality of public services, creating a favorable business environment, and perfecting the talent introduction policy (Deng et al., 2019). Furthermore, service competition attracts the inflow of human capital by improving the public service guarantee system and increasing the supply of public products. The inflow of

human capital can accelerate the dissemination and sharing of information and knowledge among innovation subjects. In addition, the widespread adoption of new technologies has the potential to greatly boost the utilization rate of available resources and pave the way for the creation of low-carbon economies.The following hypothese are presented:

H1. *The role of economic competition for LCT development is uncertain under the dual constraints of "bottom-up competition" and "top-down competition".*

H2. *Ecological competition serves an important role of fostering the LCT.*

H3. *Service competition serves an important role of fostering the LCT.*

Competition between local governments encourages incorporating essential innovation elements into green development. This is accomplished by attracting the influx of production factors such as money, technological advances, and talented individuals. It then improves production efficiency and the level of green technological progress. Renewable and clean energy growth may be boosted through GTECH, which re-optimizes the allocation of diverse technologies and knowledge, and stimulates LCT development (He et al., 2018). That is, LCT development directly linked to Comp and green technological innovation. Specifically, The primary focus of economic competition is expansion of existing economies. Local governments loosen the stringency of environmental restrictions to attract additional financial support, which not only squeezes out the cost of technological innovation and R&D but also tops up green technological innovation (Nie et al., 2021).

Meanwhile, economic competition can improve the vitality of regional economic development, quicken green innovation technology migration, and stimulate GTECH development (Liu et al., 2022a). Economic competition has an impact on the LCT through green technological innovation. The government's investment in environmental management and pollutant treatment rate primarily reflects ecological competition. In order to improve regional environmental quality, local governments have expanded their operations in environmental governance and tightened environmental legislation. This constraint compels businesses to use renewable energy and GTECH, improving enterprise productivity and promoting low-carbon economic transition (Yang et al., 2018; Jin et al., 2019; Porter & van der Linde, 1995). Service competition provides higher service levels and attracts human capital for firms and residents. Human capital is the basis for GTECH. Integrating human resources with the original human resources of enterprises facilitates the unfolding of green innovation and accelerates the dissemination and sharing of information and knowledge among innovation agents. The flow of human capital may make enterprises' green innovation more efficient and thus drive low-carbon economic transformation (Brueckner, 2003). Following the analysis presented above, the following possibilities are proposed:

H4. *GTECH can positively moderate the results of economic competition on LCT development.*

H5. *GTECH can positively moderate the results of ecological competition on LCT development.*

H6. *GTECH can positively regulate the results of service competition on LCT development.*

4. Model construction, variable selection and data description

4.1. Model construction

The generalized method of moments (GMM) approach is advantageous for resolving difficulties of panel data including personal effects, autocorrelation, heteroskedasticity, and endogeneity, enabling more accurate estimation of parameters. Furthermore, the system GMM (SYS-GMM) can solve the weak instrumental variables problem, which has been more widely used. Referring to Wu et al. (2021) and Yang et al. (2022b), the relationship between Comp, GTECH and LCT is quantified using a two-stage SYS-GMM. The specific model is set as follows:

$$LTC_{it} = a_0 + a_1 LTC_{it-1} + a_2 \mathrm{Comp}_{\mathrm{it}} + \beta_i X_{it} + \varepsilon_{it}, \quad (1)$$

where i and t respectively denote year and area; β represents the coefficient vector; ε is the error term. *LTC* is the Economic low-carbon transition development. The core explanatory variable is *Comp*, which represents Comp. X is the set composed of control variables.

To determine the influence of the combined roles of Comp and GTECH on the LCT development, the interaction term of the two is added into the Eq. (2) to further test the moderating effect of Comp. The specific model is set as follows:

$$LTC_{it} = a_0 + a_1 LTC_{it-1} + a_2 GTECH_{it} + a_3 Comp_{it} + a_4 Inter_{it} + \beta_i X_{it} + \varepsilon_{it}, \quad (2)$$

where *LTC* is the economic low-carbon transformation, LTC_{it-1} represents the lagged one-term for the *LCT* development. $GTECH_{it}$ is the GTECH. $Inter_{it}$ is the interaction term of *GTECH* and Comp The rest of the parameters are set as in Eq. (1).

4.2. Variables selection

4.2.1. Dependent variable

Economic low-carbon transition development (LCT). The comprehensive system known as LCT development includes a wide range of economic and social development factors. The comprehensive system known as LCT development includes a wide range of economic and social development factors. 16 indicators from energy consumption are chosen based on research on the traits of low-carbon economic transition development (Xu et al., 2023b; Xue et al., 2023). The emission, ecological, environmental, socio-economic, and technological support subsystems, respectively, and an indicator system for low-carbon economic transition development in China is constructed concerning the 2009 carbon dioxide report of the International Energy Agency (see Table 1) (Shi et al., 2022). The entropy method is an objective weighting approach that effectively eliminates biases arising from artificial factors. We apply the entropy method to measure low-carbon transformation in various provinces from 2007 to 2019.

Overall, the distribution of China's low-carbon economic transition across provinces has not changed significantly from 2007–2019 (Figure 1). The LCT is faster in the eastern coastal cities, while the central and western regions are relatively lagging behind in economic development and have relatively slow LCT despite their relative abundance of energy resources and other productive resources.

Table 1. Economic low-carbon transition development indicator system

System Indicators	Stratification Indicators	Measurements	Variable Name	Properties
Economic low carbon transition indicator system	Energy consumption and emission subsystem	Energy consumption per unit of GDP (tons of standard coal/yuan)	x1	–
		The proportion of coal in energy consumption (%)	x2	–
		Carbon emission per unit of GDP (tons / 100 million yuan)	x3	–
	Ecosystem subsystem	SO_2 emissions per unit of GDP (tons / 100 million yuan)	x4	–
		Forest coverage rate (%)	x5	+
		Number of national-level nature reserves (pieces)	x6	+
	Socio-economic Sub-system	GDP per capita (yuan)	x7	+
		Tertiary industry share (%)	x8	+
		Per capita disposable income of urban residents (yuan)	x9	+
		Urbanization rate (%)	x10	+
		Engel coefficient (%)	x11	–
		Book ownership per unit of personnel (book)	x12	+
	Technology Support Subsystem	R&D personnel full time equivalent (10,000 person-years)	x13	+
		R&D funding intensity (%)	x14	+
		Harmless treatment rate of domestic waste (%)	x15	+
		Energy processing and conversion efficiency (%)	x16	+

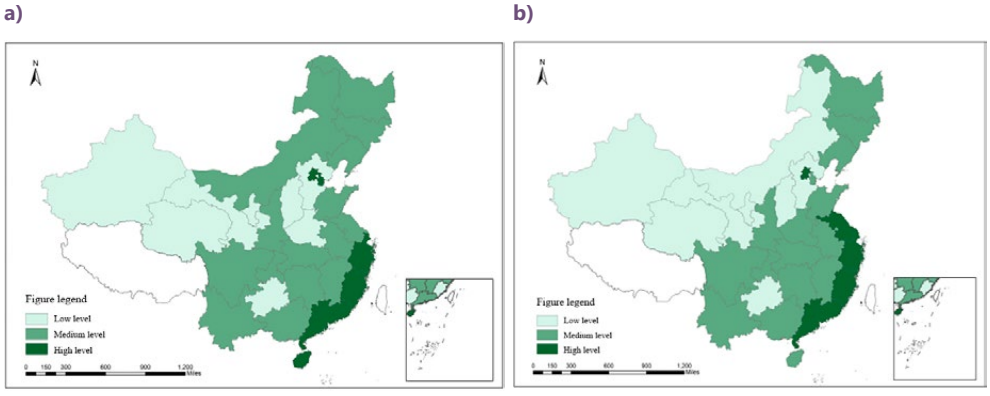

Figure 1. a) Low carbon transition in 2007; b) Low carbon transition in 2019

4.2.2. Core explanatory variables

Local government competition (*Comp*): It covers many dimensions, including economic and ecological social development. Incorporating existing scholars' research on Comp, this paper selects 15 measurement indicators from economic, ecological and service perspectives to construct an indicator system of heterogeneous government competition (see Table 2). Real GDP growth rate, the ratio of fiscal expenditure to local fiscal revenue; FDI to GDP; the total regional tax revenue to GDP; and the proportion of local fixed asset investment to national fixed asset investment are the five dimensions of economic competition that can be expressed in terms of these five metrics, respectively (Zhang et al., 2020). According to Zhang et al. (2020), ecological competition mainly includes five dimensions: competition for the greening environment, competition for pollution treatment capacity, competition for investment in pollution treatment, competition for investment in greening, and competition for ecological water use, and the greening coverage rate of built-up areas, daily treatment capacity of urban sewage, the ratio of investment in industrial pollution treatment to industrial value added, the ratio of investment in forestry to GDP, respectively, are selected (Zhang et al., 2021; Wu et al., 2020). The competition for services includes five dimensions: competition for primary conditions, competition for medical services, competition for commuting, competition for employment, and competition for income, which are represented by the ratio of fiscal expenditure on people's livelihood, the number of beds in medical and health institutions, the number of public vehicles per 10,000 people, the unemployment rate, and the growth rate of employees' wages (Zhang et al., 2021). This paper uses the entropy value method to measure the degree of Comp in heterogeneity.

Table 2. Heterogeneous local government competition indicator system

	First-level indicator	Second-level indicator	Variable name	Attribute
Heterogeneous local government competition indicator system	Economic competition	Growth Competition	x1	+
		Fiscal Competition	x2	+
		Competition for investment	x3	+
		Tax Competition	x4	+
		Investment competition	x5	+
	Ecological competition	Green environment competition	x6	+
		Competition for pollution control capacity	x7	+
		Competition for investment in pollution control	x8	+
		Competition for greening investment	x9	+
		Competition for ecological water use	x10	+
	Service competition	Competition for Basic Conditions	x11	+
		Competition for medical services	x12	+
		Commuting Competition	x13	+
		Competition for jobs	x14	+
		Income competition	x15	+

Regarding the spatial distribution of Comp (Figure 2), economic competition and service competition are higher for local governments in the eastern regions than in the central and western regions. And ecological competition is significantly higher in the central and western regions than in the eastern regions. This is because the eastern region has a good business environment and a dynamic market mechanism, and thus has more economic development

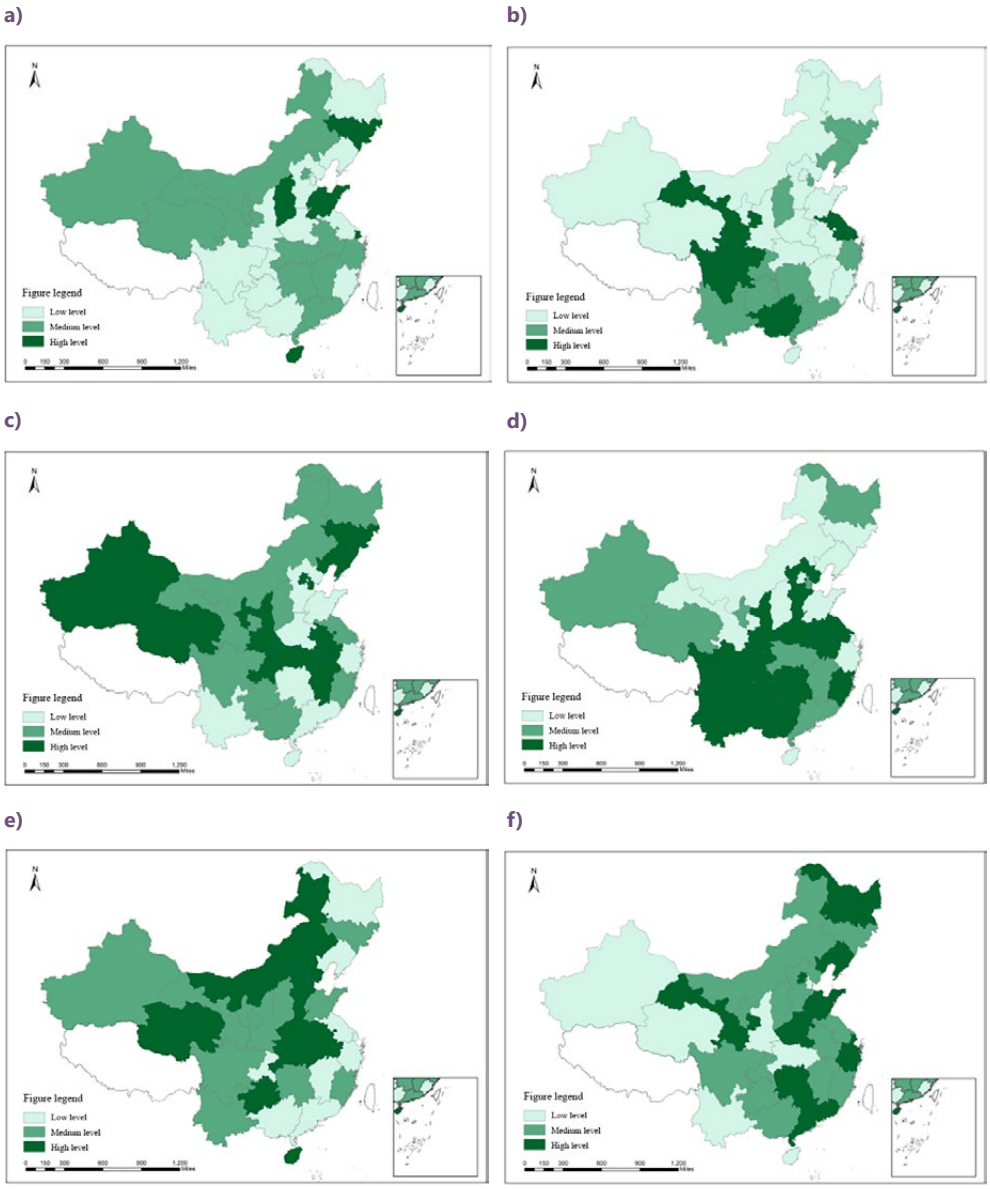

Figure 2. a) Economic competition in 2007; b) Ecological competition in 2007; c) Service competition in 2007; d) Economic competition in 2019; e) Ecological competition in 2019; f) Service competition in 2019

and service provision advantages. In contrast, the climate in the central and western regions is mostly arid and semi-arid, with a fragile ecological environment. Along with strengthening environmental protection, local governments in the central and western regions are more eager to protect the ecological environment, leading to increased ecological competition.

4.2.3. Moderating variable

This paper selects green technology innovation (GTECH) as the moderating variable. Academics mostly utilize patents, including the number of patent applications and authorisation, to gauge green technological advancement. An area's real degree of technical innovation may be gauged by looking at the number of patents that have been granted in that area. For this article, the number of green patents granted from 2007 to 2019 is used as a proxy for green technological innovation in each province, based on the International Patent Classification (IPC) code published by WIPO and information supplied by the State Intellectual Property Office.

4.2.4. Control variables

To consider robustness, this paper uses the following variables as control variables. Government administrative capacity (*GA*), number of years of education (*Human*), industrial structure (*IND*), and environmental regulation intensity (*ER*). General public budget revenue to spending ratio indicates the administrative capacity of the government (*GA*)'s status. The number of years of education (*Human*) represents the number of college students per 1,000 people enrolled. Industrial structure (*Ind*) is chosen to represent the share of secondary industry in GDP. It has been decided that the symbol of environmental regulation intensity (*ER*) will be used to indicate the ratio of overall investment in industrial pollution control to GDP.

4.3. Data

Chinese statistical yearbooks (2008–2020), environmental statistical yearbooks (2008–2020), the Chinese environmental yearbook (2008–2020), and local statistical yearbooks (2008–2020) provided the bulk of the information used in this study. In addition, certain data are logarithmically transformed to remove the influence of heteroscedasticity and dimensional issues. According to Table 3, the major variables' definitions and descriptive statistics are provided.

Table 3. Descriptive statistics

Data Type	Symbols	Obs	Mean	Std.Dev	Min	Max
Dependent variable	LTC	390	0.401	0.102	0.175	0.713
Core explanatory variables	Econ	390	0.403	0.152	0.077	0.852
	Ecol	390	0.410	0.188	0.034	0.927
	Serv	390	0.454	0.143	0.133	0.828
Moderating variables	GT	390	6.800	1.532	2.197	10.257
Control variables	GA	390	8.829	0.985	6.594	12.675
	Human	390	0.115	0.070	0.027	0.487
	Ind	390	45.502	8.540	18.287	64.177
	ER	390	0.135	0.121	0.002	0.986

5. Empirical results and discussion

5.1. Baseline regression results and discussion

Columns (1)–(3) in Table 4 are OLS model results, columns (4)–(6) are fixed effect regression results, and columns (7)–(9) are SYS- GMM model regression results. Since explanatory and explained variables are composite indicators, endogenous problems are inevitable. In addition, local governments' LCT and development may lag in policies, systems and other aspects. This paper includes the lag phase of the explained variables in the model analysis, in which the SYS- GMM model can effectively solve the endogenous problems (Harris & Mátyás, 2004). To do this, this piece of writing uses the estimated outcomes of the OLS model and the fixed effect model as a point of reference, and it focuses mostly on analyzing the estimation outcomes of the SYS-GMM approach. The AR (2) and the Hansen tests' findings indicate that SYS-GMM is likely genuine.

Table 4 implies that the coefficients of *L.lnc* are all positive (P-value < 0.01), suggesting that LCT suffers from considerable inertia dependence, i.e., the degree of economic development that occurred in the year before is having a negative impact on the level of development that will occur in the current year. LCT development is bound to suffer from policy, institutional and other aspects of backwardness. Moreover, Because of limited financial resources, it is difficult to implement significant changes in the near term, market entry and exit barriers, and it takes a certain period for enterprises to innovate their production equipment and technologies and for the public to develop environmental awareness. Furthermore, Furthermore, LCT development is a sophisticated system that includes social, economic and ecological aspects. Each system influences and interacts with the other. Also, economic development is significantly cyclical, and the development of low-carbon economic transformation is influenced by the long-term planning guidance of local governments and the process of market mechanisms gradually playing a regulatory role.

The regression coefficient of economic competition on economic low-carbon transition is insignificant, thus verifying Hypothesis (1). Local government economic competition operates through two mechanisms: "competition to the top" and "competition to the bottom". The insignificant regression coefficients of economic competition can be attributed to the opposing effects of these two mechanisms on low-carbon transition (LCT) development. "Competition to the bottom" suggests that local governments, in pursuing economic growth through competition, may relax environmental regulations to attract capital, inadvertently turning the region into a "pollution haven" to some extent. Furthermore, the loosening of environmental regulations by local governments hinders the internalization of pollution externalities, leading to a lack of incentives for enterprises to invest in technological innovation and hinder the promotion of low-carbon economic transformation.

Furthermore, excessive pursuit of economic growth by local governments can rapidly increase GDP growth, resulting in an economic model that emphasizes scale expansion and high output with high emissions. This model hinders technological progress and industrial upgrading, thus impeding the promotion of economic low-carbon transition (LCT). On the other hand, "competition to the top" refers to the use of growth competition and financial competition in economic competition to stimulate regional development. This approach pro-

vides regional infrastructure construction, technology development, and technology transfer opportunities. Enterprises can still achieve increased profits through technological innovation while pursuing low-carbon economic transformation. However, despite the presence of both "competition to the top" and "competition to the bottom", economic competition has shown no significant impact on LCT development."

The coefficient of ecological competition on low-carbon economic transformation (LCT) is 0.008, indicating that ecological competition plays a significant role in promoting LCT. This result verifies hypothesis (2). Local governments enhance ecological competition by improving the overall greenery level, increasing the per capita green area, implementing stricter environmental regulations, and improving pollutant treatment efficiency. This form of competition falls under the "competition to the top" category. As China implements its ecological civilization strategy, local governments have increasingly engaged in competition focused on environmental protection. They have strengthened ecological regulations, phased out high-pollution backward production capacities, and reduced pollution emissions. Furthermore, stringent ecological regulations help internalize the external effects of environmental pollution, stimulate technological innovation in enterprises, promote the adoption of cleaner and more environmentally friendly technologies and equipment, and ultimately drive LCT. One of the most noticeable features of ecological competition is the competition for flow factors. By pursuing rapid regional economic development, provincial governments engage in "competition to the top", effectively preventing the entry of highly polluting industries into the local area. Therefore, ecological competition plays a significant role in promoting LCT.

Column 9 of Table 4 presents the coefficient of service competition on low-carbon economic transformation (LCT), which is 0.007. This value indicates that service competition significantly impacts LCT, thereby verifying hypothesis (3). By expanding the number of public transport vehicles and improving the quality of medical facilities, local governments can enhance their capacity to provide public services. Concurrently, they intensify competition among service offerings. High-quality public services are crucial in attracting human resources inflow. As the competition for local government services intensifies, it steadily becomes more appealing to talented individuals. Recruiting skilled workers is vital in promoting the transition to a low-carbon economy.

Human capital and technological innovation are the fundamental guarantees for the transformation of industrial structure, which can significantly affect the optimization of the industrial system, realize the transformation of enterprises into industries with a higher degree of innovation, and then change the development mode, improve total factor productivity and promote LCT. On the other hand, upgrading the industrial structure driven by human capital and technological innovation usually has high production efficiency. The development of firms' human capital can potentially increase their labor production efficiency, contributing to the rationalization and upgrading of industrial structure. The upgrading of industrial design can drive technological progress, improving the ability of energy intensity and environmental governance; local government service competition can significantly promote LCT.

Table 4. Baseline regression results

Variables	OLS			FE	GMM				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
L.LTC							0.856***	0.845***	0.841***
							(0.041)	(0.029)	(0.040)
Econ	–0.014			–0.021*			0.005		
	(0.018)			(0.013)			(0.004)		
Ecol		0.112***			0.026**			0.008*	
		(0.013)			(0.011)			(0.004)	
Serv			0.090***			0.059***			0.007**
			(0.017)			(0.012)			(0.003)
GA	0.390***	0.378***	0.390***	–0.046	–0.014	0.020	0.098***	0.113***	0.106***
	(0.017)	(0.015)	(0.016)	(0.050)	(0.045)	(0.044)	(0.024)	(0.011)	(0.026)
Human	–0.418***	–0.317***	–0.405***	–1.147***	–1.097***	–1.204***	–0.178***	–0.149**	–0.189***
	(0.047)	(0.044)	(0.044)	(0.070)	(0.075)	(0.064)	(0.062)	(0.059)	(0.047)
Ind	–0.005***	–0.004***	–0.005***	–0.002***	–0.002***	–0.001***	–0.001**	–0.001***	–0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ER	–0.219***	–0.254***	–0.214***	–0.074***	–0.084***	–0.072***	–0.024**	–0.031***	–0.024**
	(0.023)	(0.021)	(0.022)	(0.019)	(0.020)	(0.019)	(0.011)	(0.010)	(0.011)
_Cons	0.516***	0.433***	0.466***	0.670***	0.634***	0.587***	0.071***	0.068***	0.071***
	(0.017)	(0.017)	(0.018)	(0.025)	(0.023)	(0.025)	(0.023)	(0.018)	(0.026)
N	390	390	390	390	390	390	360	360	360
R-squared	0.769	0.805	0.784	0.741	0.744	0.756			
AR(2)-P							0.115	0.104	0.129
Hansen-P							1.000	1.000	1.000

Note: ***, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively; standard errors are indicated in () below the coefficients. Same as below.

5.2. Moderating effect results and discussion

Table 5 to test the moderating effect of heterogeneous government competition on GTECH and LCT. The fixed-effects model considers individual variability relative to the OLS regression model and can respond more accurately to the relationship between variables. The OLS results are similar to those of the fixed-effects model, so the OLS regression results are used as a reference to focus on the analysis of the fixed panel regression model.

Table 5's items (1)–(6) make it clear that developing environmentally friendly technologies is important in fostering the transition to a low-carbon economy. First, enterprises may enhance the efficiency of raw materials and energy, realize the reproduction and reuse of production components, lower the cost of resource use, and minimize environmental costs to support a low-carbon economic transition by deploying green technological innovations. Second, GTECH can not only reduce costs, increase market share and expand the scale of enterprises but also transfer their green technology and obtain the benefits of technology transfer, which is also one of the essential sources of sustainable development of enterprises and provides technical support for low-carbon economic transition. Third, with the depletion

of resources and the continuous deterioration of the environment, the consumption concept of consumers has also changed from traditional consumption to green consumption and sustainable consumption. In order to meet market demand and expand market share, enterprises promote low-carbon development by developing green products that are harmless or less harmful to low-carbon economic transition.

As shown in column 4 of Table 5, the regression coefficient of the interaction term between economic competition and GTECH is significantly negative, which verifies hypothesis (4). The results indicate that local government economic competition tends to be "competition to bottom" and is prone to self-interest in emphasizing production-oriented technology over innovative technology. The economic development is still driven by the chain of "expanding production scale → increasing business profit → expanding tax base → increasing income level". Under the influence of economic competition, local governments have a GDP-oriented viewpoint and neglect the construction of the ecological environment. To further encourage investment in high energy-consuming businesses, local governments may compete to lower environmental regulatory requirements. This might limit the ability of GTECH to promote a low-carbon economic revolution. Therefore, the interaction between local government economic competition and GTECH hurts the LCT.

From columns 5–6 of Table 5, we can see that the regression coefficient of the interaction term between eco-competition, service competition and GTECH is significantly positive,

Table 5. Moderating effects results

Variable	OLS			FE		
	(1)	(2)	(3)	(4)	(5)	(6)
Econ	–0.004			–0.007		
	(0.015)			(0.010)		
Ecol		0.046***			–0.022**	
		(0.013)			(0.009)	
Serv			0.033**			0.045***
			(0.015)			(0.010)
Moderating effects	–0.005	0.019**	0.035***	–0.021***	0.024***	0.017***
	(0.009)	(0.007)	(0.009)	(0.005)	(0.005)	(0.006)
GT	0.029***	0.026***	0.027***	0.037***	0.041***	0.034***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
GA	0.210***	0.227***	0.208***	–0.072*	–0.041	–0.030
	(0.020)	(0.019)	(0.019)	(0.039)	(0.035)	(0.035)
Human	–0.123***	–0.113***	–0.074	–0.456***	–0.421***	–0.477***
	(0.045)	(0.043)	(0.045)	(0.072)	(0.071)	(0.069)
Ind	–0.004***	–0.004***	–0.004***	–0.001***	–0.001***	–0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ER	–0.137***	–0.151***	–0.141***	–0.021	0.004	–0.030**
	(0.020)	(0.021)	(0.019)	(0.015)	(0.016)	(0.015)
_Cons	0.336***	0.311***	0.309***	0.305***	0.270***	0.273***
	(0.019)	(0.019)	(0.019)	(0.030)	(0.029)	(0.028)
N	390	390	390	390	390	390
R-squared	0.843	0.851	0.851	0.848	0.852	0.855

further verifying that local government eco-competition and service competition belong to "competition to top". According to Porter's hypothesis, when the government's eco-competition improves the level of environmental regulation, environmental regulation can reduce compliance costs, promote technological innovation, and realize effective resource allocation as long as the scientific and reasonable setting of environmental regulation can improve the productivity and competitiveness of enterprises. GTECH's role in driving a low-carbon economic transformation may be further thwarted if local governments seek to lessen environmental regulatory requirements to entice investment in high energy consumption businesses. At the same time, the government's environmental management promotes enterprise GTECH by employing pollution charges, emission-suitable trading and taxation. Therefore, the objective regulation of national industrial and technology policy significantly drives GTECH. Furthermore, local government service competition can attract the inflow of human capital. Industrial structure transformation is guaranteed by human capital and technological innovation, which can significantly influence economic structure optimization, realize the transformation of businesses into industries, encourage the emergence of numerous emerging industries, boost technological innovation, and then alter the LCT model.

5.3. Robustness checks

Two ways are used to test the samples' robustness to ensure the results are reliable. They were first, excluding the year and changing the study period. The emergence of the financial crisis in 2008 led to structural mutations in the data, so the data from 2008 are excluded (See columns (1)–(3) of Table 6). Second, changing the sample size. There are differences in

Table 6. Robustness checks

Variable	FE			FE		
	(1)	(2)	(3)	(4)	(5)	(6)
Econ	–0.020			–0.020		
	(0.013)			(0.013)		
Ecol		0.025**			0.028**	
		(0.011)			(0.011)	
Serv			0.059***			0.043***
			(0.013)			(0.014)
GA	–0.033	–0.000	0.032	–0.077	–0.057	–0.015
	(0.051)	(0.046)	(0.045)	(0.053)	(0.049)	(0.049)
Human	–1.139***	–1.085***	–1.173***	–1.345***	–1.273***	–1.379***
	(0.073)	(0.079)	(0.067)	(0.082)	(0.090)	(0.076)
Ind	–0.002***	–0.002***	–0.002***	–0.001***	–0.001***	–0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ER	–0.065***	–0.077***	–0.064***	–0.066***	–0.078***	–0.064***
	(0.020)	(0.021)	(0.020)	(0.020)	(0.020)	(0.020)
_Cons	0.669***	0.633***	0.585***	0.639***	0.606***	0.572***
	(0.025)	(0.024)	(0.026)	(0.026)	(0.023)	(0.027)
N	360	360	360	338	338	338
R-squared	0.732	0.734	0.747	0.742	0.745	0.748

development environment and development mode between municipalities directly under the central government and other provinces and cities, so they are deleted and re-estimated for the remaining 26 areas, cities and autonomous regions in columns (4)–(6) of Table 6. The results are consistent with the previous section. Table 6 shows that the coefficients of the main variables remain broadly consistent with the original model in terms of directionality and significance, proving the robustness of results.

6. Conclusions and policy recommendations

Data from a Chinese provincial panel covering the years 2007–2019 is used to investigate the effects of heterogeneous Comp, namely, economic, ecological, and service competitions on LCT, and moderating effects of heterogeneous government competition and GTECH on the low-carbon economic transition. The findings reveal a substantial amount of variety in how diverse government competition influences the shift toward low-carbon economic transition. Also, economic competition has a significant inhibitory effect on LCT, and ecological competition and service competition have a significant facilitating effect on LCT. Furthermore, After robustness checks, these results are strongly convincing. Economic competition can dampen the contribution of GTECH to the LCT. Yet, ecological competition and service competition facilitate the promoting effect of GTECH on LCT.

Based on the above findings, some essential policy recommendations are as follows.

To begin, decision-makers at all levels should work to enhance the performance rating index system by considering local governments' roles. Ast the same time, the assessment is used as a guide to enhance the competitive ability of local governments in all aspects. Further, policymakers should optimize the comprehensive assessment index system that includes economic, ecological, and service objectives and incorporate economic, environmental, and service competition into a unified assessment. Based on maintaining the central government's economic and social development goals, policymakers should increase the proportion of the assessment of ecological and service plans, keep the rationalization of economic growth rate, and realize the multidimensional assessment of political performance.

In addition, a long-term mechanism for fostering green innovation should be established by policymakers. GTECH is a vital tool for accelerating the transition of regional economies to low-carbon economies. Government officials should aggressively boost R&D spending, actively support green technologies, and develop new production techniques. While enhancing their production efficiency, they should realize the economy's low-carbon transformation and effectively play the engine of green technological progress for developing low-carbon economic change. Finally, national research institutions and energy enterprises should strengthen communication and cooperation to speed up renewable energy development and utilization.

Although this paper has explored the links between local government competition and green technology innovation as thoroughly as possible, it has some deficiencies. First, because of data availability, this paper only covers data in the province. Still, it fails to perform an in-depth analysis on a city level, which causes inadequate coverage of the results. Thus, future scholars can be further broadened in terms of sample comprehensiveness. Secondly, a government competition indicator framework can be developed and elaborated, which

can be discussed in depth in future research. Finally, in addition to green technology innovation, financial development and marketization, economic uncertainty can influence the nexus between local government competition and green technology innovation; therefore, these influencing factors deserve further consideration in future research.

Disclosure statement

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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