

Impact of China's Environmental Decentralization on Carbon Emissions From Energy Consumption: An Empirical Study Based on the Dynamic Spatial Econometric Model

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1 **Impact of China's environmental decentralization on carbon**
2 **emissions from energy consumption: An empirical study based on**
3 **the dynamic spatial econometric model**

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14

15 **Abstract**

16 Facing the growing problem of carbon emission pollution, the scientific and reasonable division of
17 environmental management power between governments is the premise and institutional foundation for
18 realizing China's carbon emission reduction target in 2030. Although existing studies have focused on the
19 relationship between Chinese decentralization and carbon emissions, most of them are based on fiscal
20 decentralization indicators to depict China's environmental decentralization, lacking of systematic analysis
21 and empirical test of institutional factors affecting carbon emissions from the perspective of environmental
22 management. In this paper, we directly assess the environmental decentralization degree according to the
23 allocation of environmental management personnel among different levels of government. By incorporating
24 fiscal decentralization indicators, the provincial panel data and dynamic spatial econometric model are used
25 to empirically test the impact of environmental decentralization on carbon emissions from spatial
26 perspective. The study found that: (1) China's provincial carbon emissions have a significant positive
27 spatial autocorrelation, showing a clear trend of high-high, low-low aggregation, and the carbon emissions
28 of the previous period and the current have an obvious positive relationship. (2) At the national level,
29 environmental decentralization, environmental administrative decentralization and environmental
30 monitoring decentralization significantly reduce China's carbon emissions, while environmental
31 supervision decentralization and fiscal decentralization significantly aggravate carbon emissions, which
32 means that China's current environmental decentralization systems are generally conducive to carbon
33 emission governance. The interaction between fiscal decentralization and environmental decentralization
34 with its decomposition indicators significantly promotes carbon emissions, and its impact is related to the
35 category of environmental decentralization, indicating that when local governments have greater
36 environmental management power and fiscal autonomy, the combination of the two will push up carbon
37 emissions. (3) The carbon emission effects of environmental decentralization in different regions are
38 spatially heterogeneous. In the central region, environmental decentralization, environmental administrative
39 decentralization and environmental supervision decentralization can promote carbon emissions apart from
40 environmental monitoring decentralization. In the western region, the carbon emission suppression effect of
41 environmental decentralization, environmental administrative decentralization and environmental
42 monitoring decentralization is stronger than the eastern region, but the inhibitory effect of fiscal

43 decentralization and environmental decentralization with its decomposition index interaction on carbon
44 emissions in the eastern region is significantly better than the central and western regions. The above
45 results provide policy ideas and theoretical support for the construction of the environmental management
46 system with long-term carbon emission control in China in terms of regional differences and categories of
47 environmental management power.

48 **Keywords** Environmental decentralization; Fiscal decentralization; Carbon emission; Spatial perspective;
49 Dynamic spatial econometric model

50 **Introduction**

51 With the rapid development of social economy and the increasing energy consumption, the
52 environmental pollution problems in the world have become increasingly prominent. In particular, as the
53 important part of environmental pollution, carbon dioxide emissions (hereinafter referred to as carbon
54 emissions) lead to greenhouse effect and global warming is an indisputable fact. Under such circumstances,
55 reducing greenhouse gas emissions and developing low-carbon economy have become important measures
56 taken by governments to deal with climate change and solve the environmental pollution problem (Zhang et
57 al. 2011). According to BP World Energy Statistics, carbon emissions in China have been on a rapid upward
58 trend since 2000 and reached 9.258 billion tons in 2017, accounting for 27.3% of total carbon emissions in
59 the world. To improve environmental quality, Chinese government has made a great deal of effective efforts
60 to fulfill national commitments on carbon emission reduction (to reduce carbon dioxide emissions per unit
61 of GDP in 2030 by 60%—65% compared to 2005, and the proportion of non-fossil energy in total primary
62 energy consumption will reach to 20%), especially in the "13th Five-Year Plan", China has taken the
63 environmental governance institution reformation, local governments' environmental responsibility
64 implement, and modern environmental management system construction as a basic task. At the same time,
65 several reform initiatives also have been proposed, including the establishment of clear responsibilities and
66 powers, environmental protection supervision and accountability for environmental damage. In recent years,
67 with the reformation of environmental decentralization management institution at different government
68 levels in recent years, local governments, in order to pursue the GDP growth and promotion incentives,
69 often choose to loosen environmental regulations to launch a "bottom-up competition", which in exchange
70 for economic growth at the expense of the environment, and ultimately lead to increase pollution (Lu and
71 Zhang 2016; Bai et al. 2017). At present, research on carbon emissions mainly focuses on measurement,
72 regional differences, influencing factors, and carbon reduction countermeasures. In terms of the factors
73 influencing carbon emissions, most scholars have conducted extensive research on the effects of economic
74 growth, population density, energy structure, industrial structure, technology level, and trade openness on
75 carbon emissions (Zhang et al. 2017; Feng et al. 2017), while less research has been conducted specifically
76 on the institutional factors. And it is undeniable that regional environmental quality (carbon emissions)
77 cannot be independent of institutional factors. If institutional factors, which are closely related to carbon
78 emission reductions, are ignored, it may be difficult to effectively curb the current carbon emissions at high
79 level. Environmental decentralization, as an important part of the environmental management system in
80 central and local governments, is bound to have a significant impact on regional carbon emissions to some
81 extent. However, most of the existing studies (Zhang et al. 2017; Ran et al. 2020; Peng 2016; He 2015; Tian
82 et al. 2018; Xue et al. 2012; Yan 2012; Wang et al. 2014; Ben et al. 2017; Huang 2017; Zhang et al. 2017)
83 concluded that environmental decentralization distorted the supply mode of environmental public goods

84 and intensifies competition among local governments, thus creating a significant positive boost to carbon
85 emissions and environmental pollution. It is noteworthy that most of the above-mentioned studies simply
86 characterize environmental decentralization among governments using fiscal decentralization indicators,
87 ignoring the differences between environmental decentralization and fiscal decentralization. In fact, fiscal
88 decentralization reflects more about the economic or political rights divided from central and local
89 governments, while environmental decentralization, with basic public services as its core, mainly reflects
90 the division of powers over environmental management. If we confuse the essential difference between the
91 two and using fiscal decentralization indicators as an approximate substitute for intergovernmental
92 environmental decentralization may lead to a measurement deviation on environmental decentralization,
93 making it difficult to determine the direction and extent of the impact of environmental decentralization on
94 carbon emissions. Furthermore, does the current environmental decentralization have a positive effect
95 (increasing carbon emissions) or a negative effect (decreasing carbon emissions) on carbon emissions in
96 China? Does the existing fiscal decentralization have an impact on this? Should central and local
97 governments centralize or decentralize powers over carbon emission reduction and environmental
98 management? And how to determine the appropriate level of decentralization, all of the above questions
99 need to be answered, but the current research on these issues has not given definite answers, unfortunately.
100 A few scholars have explored the relationship between environmental decentralization and carbon
101 emissions from an empirical perspective (Lu and Zhang 2016; Zhang et al. 2017; Ran et al. 2020) and
102 found that environmental decentralization can significantly increase carbon emissions indirectly through
103 political and economic incentives (Halkos et al. 2013; Xiao et al. 2014), however, they have neglected that
104 both carbon emissions and environmental governance have spillover effects and spatial correlations, and
105 the importance of geospatial correlations in environmental issues has been confirmed by many scholars
106 (Anselin 2001; Maddison 2006; Poon et al. 2006; Hossein et al. 2013). At the same time, the studies
107 mentioned above also ignore the fact that the impact of environmental decentralization on carbon emissions
108 may be spatially heterogeneous across regions with different economic development levels, which is related
109 to the energy consumption structure, economic development level, geographic location and environmental
110 policies. In addition, existing static panel models are less likely to take into account the dynamics and
111 continuity of the explained variables, thus affecting the consistent estimation of the impact of
112 environmental decentralization on carbon emissions. As a result, there is considerable room for
113 improvement in both logic and accuracy of existing studies.

114 Based on previous studies, this paper constructs various indicators for measuring environmental
115 decentralization from the inherent logic of intergovernmental environmental management power in China,
116 and uses a dynamic spatial measurement model to fully explore and analyze the impact of environmental
117 decentralization on carbon emissions from a spatial perspective, and reveals the environmental institutional
118 mechanisms affecting carbon emissions, so as to find out whether the current environmental management

119 in China is indeed aggravating local carbon emissions, and to provide a scientific basis for the Chinese
120 government to improve environmental decentralization management system and promote the realization of
121 carbon emission reduction target in 2030.

122 **Literature review**

123 With the increasing severity of environmental problems around the world, scholars have begun to
124 focus on the role of local governments in implementing environmental policies and controlling
125 environmental pollution (Zhang et al. 2017; Luo et al. 2020; Li 2018). Since environmental management as
126 an institutional factor directly affects the environmental quality, it has been a hotspot of research, especially
127 the distribution of power among governmental levels regarding environmental management. As for the
128 environmental management system for carbon emission, it can be traced back to the classic environmental
129 federalism theory (a branch of fiscal federalism) in the 1970s (Zhang et al. 2017), which can be understood
130 as the de facto decentralization of environmental management, that is, the decentralization of
131 environmental management from the central government to local governments so that local governments
132 have autonomy and decision-making power in environmental management affairs. Central to this theory is
133 whether environmental management in a country should be centralized or decentralized, and how
134 responsibility for environmental management should be divided between central and local governments
135 (Cole et al. 2013). At present, the debate over the impact of environmental decentralization on
136 environmental quality or carbon emissions is dominated by three different perspectives: the suppression,
137 the facilitation and the uncertainty theories. The suppression theory, represented by Huang (2017) and
138 Oyono (2005), argues that environmental decentralization management is not conducive to environmental
139 protection, but rather tends to exacerbate environmental pollution in local and neighboring areas, ultimately
140 inhibiting the improvement of environmental quality. Zhang (2011) also concluded that fiscal
141 decentralization is detrimental to reducing environmental pollution from the perspective of carbon
142 emissions. Most scholars who hold this view describe the negative environmental effects of
143 decentralization from the perspective of jurisdictional competition. There are three main reasons for this: (1)
144 Environmental decentralization will give local governments greater autonomy in environmental governance.
145 Local officials, in their unilateral pursuit of economic growth and job promotion, choose to loosen
146 environmental regulations and engage in "bottom-up competition", or even divert environmental
147 expenditures to the development of local economies, resulting in "free-riding" phenomenon in exchange for
148 economic growth and environmental governance by sacrificing environmental resources, which ultimately
149 lead to environmental pollution or increase carbon emissions (Gray et al. 2004; Kuncze et al. 2007; Dijkstra
150 et al. 2010). while centralized environmental management would enable central governments to provide
151 better environmental public services, thereby avoiding the "free-riding" of local governments and the
152 insufficient supply of environmental public goods resulting from decentralization. (2) Under a

153 decentralized environmental management system, local governments, in order to obtain sufficient economic
154 benefits, may form political collusion with local enterprises, or even cooperate with enterprises to conceal
155 the facts of environmental pollution, leading to inefficient environmental policies and thus aggravating
156 environmental pollution (Burgess et al. 2012; Long et al. 2014). (3) Environmental public services usually
157 have economy scale, and the provision of environmental public services by the central government may
158 reduce supply costs (Liu et al. 2015), plus the spillover effect of environmental public goods also
159 determines that socially optimal provision and environmental governance by local governments are
160 unlikely to be achieved (due to a lack of cooperation from local governments). On the contrary, facilitation
161 theory scholars (decentralization supporters) argue that environmental decentralization helps local
162 governments to target and implement environmental regulations that are more responsive to local needs and
163 interests, which is conducive to controlling environmental pollution and improving environmental
164 standards (Fslleth et al. 2009; Tan et al. 2015). From the perspective of fiscal decentralization and haze
165 management, Li and Han (2015) have confirmed that decentralization has a favorable effect on
166 environmental quality improvement. The reason for this is that, first of all, the regional heterogeneity in
167 environmental pollution and demand for environmental public goods gives local governments a greater
168 information advantage (local governments are closer to the public and have a better understanding of the
169 real state of the environment and the environmental preferences of residents in their jurisdictions) than the
170 central government in the provision of public goods, thus enabling local governments to provide better
171 environmental governance services to residents in an efficient and low-cost manner (Zou et al. 2019; Lu et
172 al. 2019; Banzhaf et al. 2012). If environmental centralization is adopted, heterogeneity between regions
173 will be ignored and public services provided by the central government will struggle to meet real local
174 needs. Secondly, the lack of clarity of responsibility for environmental governance is the root cause of the
175 ineffective implementation of environmental policies (Lopez et al. 2000). The decentralization of
176 environmental power, on the one hand, makes the responsibility of local governments in environmental
177 management matters more clear and governmental behavior more transparent, and on the other hand, helps
178 to mobilize residents to exercise environmental supervision power, thus helping to promote the
179 transformation and upgrading of industrial structure and ultimately improve environmental quality (Li 2018;
180 Goel et al. 2017). Oates and Schwab (Oates et al. 1988), representatives of uncertainty theory, argue that in
181 the context of jurisdictional competition for resource mobility, local governments seek to maximize
182 self-interest rather than social welfare. Therefore, the environmental impact of decentralization can be
183 either negative or positive, or even insignificant (He 2015). Fredriksson and Wollscheid's (2014) study
184 found that different forms of environmental decentralization have different impacts. Environmental
185 administrative decentralization usually has a positive drive on the local environment, while environmental
186 monitoring decentralization has a negative effect on the local environment. Similarly, Ferrara (2014)
187 supports the uncertainty theory, arguing that environmental decentralization can result in both "bottom-up

188 competition" and "top-up competition", with the direction of influence depending on the extent of
189 transboundary pollution of public goods (e.g. CO₂) and the heterogeneity of preferences among local
190 governments (Besley et al. 2003). He's (2015) study found that fiscal decentralization has no significant
191 effect on the "three wastes" of industry. Some scholars have also confirmed that decentralization has a
192 significant nonlinear effect on environmental pollution. For example, Peng (2016) and Qi (2014) showed
193 that there is a significant inverted U-shaped relationship between environmental decentralization and
194 industrial green transition or environmental pollution, and this inverted U-shaped relationship depends on
195 three factors, such as per capita income, foreign direct investment and industrial structure (Li et al. 2016).

196 In recent years, with the increasing prominent environmental problems in China, carbon emissions
197 have gradually become an important factor plaguing socio-economic development, and more and more
198 scholars have begun to focus on the impact of Chinese decentralization on carbon emissions. Existing
199 studies have shown that in addition to the impact of decentralization on the growth of carbon emissions
200 presents an inverted U-shaped relationship (Zhang et al. 2017; Halkos et al. 2013), most of the findings
201 are consistent with the first view above, which suggests that decentralization will increase the level of
202 carbon emissions in the region and the surrounding areas, thus making it more difficult to reduce carbon
203 emissions (Zhang et al. 2011; Lu and Zhang 2016; Zhang et al. 2017; Ran et al. 2020; Xiao et al. 2014;
204 Tian et al. 2018). Furthermore, most scholars attribute this result to the incentive distortions and inadequate
205 constraints caused by Chinese-style decentralization reforms, that is, local governments and officials are
206 more willing to loosen environmental standards to attract foreign investment in exchange for economic
207 growth and job promotion, while the carbon emissions, as public goods with significant spillovers, are
208 often ignored by local governments, resulting in higher carbon emissions and affecting the quality of local
209 and neighboring environments.

210 In summary, existing studies are divided on the environmental effects of decentralization. Although
211 existing studies conclude that decentralized management increases environmental pollution, this result is
212 still debatable. There are four main reasons: First, on the index depiction of the connotation of
213 environmental decentralization in China, a relatively unified understanding and accurate representation has
214 not yet been formed. Existing studies mainly adopt indirect methods to characterize environmental
215 decentralization, in other words, judging whether the state is decentralized or centralized based on the legal
216 system and factual characteristics, or using fiscal decentralization indicators to approximate environmental
217 decentralization, and then analyzing the environmental decentralization behavior of local governments and
218 its impact on the environment (Jacobsen et al. 2012; Deng et al. 2012). In fact, environmental
219 decentralization is an environmental management institution established by the central government through
220 the delegation of environmental protection functions to different government levels, reflecting the division
221 of environmental powers with basic environmental public services at the core, and is a dynamic process of
222 evolution and interaction. However, fiscal decentralization emphasizes an incentive mechanism that

223 combines "political centralization and economic decentralization", which hardly reflects the division of
224 responsibility for environmental protection between the central government and local governments.
225 Therefore, the relative independence and uniqueness of environmental protection determine that fiscal
226 decentralization cannot replace environmental decentralization, and if fiscal decentralization is used to
227 approximate the environmental decentralization of local governments, it will lead to deviations in the
228 measurement of environmental decentralization, thus affecting the investigation of the real relationship
229 between environmental decentralization and environmental pollution. Second, in exploring the
230 environmental (carbon emission) effects of decentralization, most existing studies assume that provinces
231 and regions are independent of each other, that is to say, carbon emissions do not affect each other and
232 ignore the spatially correlated effects of environmental pollution between regions, while spatial spillover
233 effects of environmental pollution (carbon emissions) have become a common problem in many federal
234 countries as well as in developing countries. It also ignores the possible impact of spatial heterogeneity in
235 the level of environmental decentralization on regional estimation results, making it difficult for
236 environmental federalism, which is rooted in the theory of fiscal decentralization, to comprehensively
237 explain the underlying mechanisms of local pollutant changes from the perspective of environmental
238 decentralized management. Third, previous studies have not considered the interaction between
239 environmental and fiscal decentralization when analyzing the effects of environmental decentralization on
240 environmental pollution. In fact, in the context of fiscal decentralization reform and environmental
241 protection "compartmentalization", fiscal decentralization gives local governments greater economic
242 autonomy, but also to a certain extent affects the implementation of local environmental management
243 power. Therefore, in order to more accurately investigate the impact of environmental decentralization on
244 local carbon emissions, it is necessary to focus on the synergy between environmental decentralization and
245 fiscal decentralization on carbon emissions under the circumstance of Chinese-style decentralization.
246 Fourthly, there is little literature on the relationship between environmental decentralization and carbon
247 emissions, with relevant studies mainly focusing on the impact of fiscal decentralization on environmental
248 pollution, and the pollutants involved are mainly industrial "three wastes", sulfur dioxide and smog (Bai et
249 al. 2017; Xue et al. 2012; Qi et al. 2014), while the influence mechanism of decentralization on different
250 environmental pollutants are different. Compared with previous research, this study may make three
251 contributions: (1) From the perspective of the environmental management institution, it constructed
252 decentralized indicators that fit the actual functions of environmental protection, discussed the impact of
253 different types of environmental decentralization on carbon emissions and their effect mechanisms, and
254 provided a basis for improving the division of environmental responsibilities in China. (2) Based on the
255 spatial perspective, the spatial dynamic panel model between environmental decentralization and carbon
256 emissions was constructed, which expands the research thinking in the field of environmental
257 decentralization and carbon emissions, and enriches the connotation of Chinese-style environmental

258 federalism theory. (3) From the regional level, the study analyzed the differences of the impact of
 259 environmental decentralization on carbon emissions, and the direction and degree of the interaction effect
 260 of environmental decentralization and fiscal decentralization on carbon emissions under the background of
 261 fiscal decentralization at the regional level, so as to provide a policy reference for the formulation of
 262 differentiated environmental decentralization strategies to reduce emissions.

263 **Model and methodologies**

264 **Model building**

265 In order to empirically investigate the impact of Chinese-style environmental decentralization and
 266 other socio-economic factors on carbon emissions, this study built a benchmark model to investigate the
 267 impact of environmental decentralization on carbon emissions in China, based on the models of the
 268 relationship between decentralization and environmental pollution by He (2015), and Ran (2020), as
 269 follows.

$$270 \quad \ln PCO_{2it} = \beta_0 + \beta_1 ED_{it} + \beta_2 FD_{it} + \sum \alpha_j X_{ijt} + \varepsilon_{it} \quad (1)$$

271 where i denotes the province, $i = 1, 2, \dots, 30$; t represents time; $\ln PCO_{2it}$ is the explained variable,
 272 expressed as the logarithm of the provincial per capita carbon emissions; ED_{it} and FD_{it} are the core
 273 explanatory variables, respectively representing the level of environmental decentralization and fiscal
 274 decentralization in each province (municipality directly under the central government, autonomous region,
 275 hereinafter collectively referred to as provinces). X_{ijt} indicates other control variables affecting carbon
 276 emissions, including the level of economic development ($\ln PGDP_{it}$) and its squared term ($\ln PGDP_{it}$)²,
 277 population size ($\ln PD_{it}$), R&D intensity (RD_{it}), foreign direct investment (FDI_{it}), industrial structure
 278 ($INDUS_{it}$) and trade openness ($OPEN_{it}$). ε_{it} is random error and is assumed to follow a normal
 279 distribution. β and α_j are model estimation coefficients.

280 Given the potential endogeneity of the model itself and the time lag effect of the explained variables,
 281 this article incorporated a lagged phase one of the explained variables into the model and set up a dynamic
 282 panel model to tackle the risk of estimation bias due to omitted variables and the potential endogeneity of
 283 the model, so as to fully investigate the impact of factors other than the explained variables on carbon
 284 emissions in the model. At the same time, considering the path-dependence (spatial correlation) problem
 285 caused by carbon emission externalities and spillover effects (Liu et al. 2018), the impact of carbon
 286 emissions, we included the spatial lag term $W \times \ln PCO_{2it}$ as an explanatory variable in the regression
 287 model to examine how the level of carbon emissions in a certain region is affected by the carbon emissions
 288 of the neighboring provinces. Based on the above analysis, the original benchmark model was extended to
 289 a dynamic spatial panel data model, that is

$$290 \quad \ln PCO_{2it} = \beta_0 + \tau L. \ln PCO_{2it} + \rho W \times \ln PCO_{2it} + \beta_1 ED_{it} + \beta_2 FD_{it} + \sum \alpha_j X_{ijt} + \delta_i + \mu_t + \varepsilon_{it} \quad (2)$$

291 In the formula, τ is a time lag coefficient indicating the effect of the previous period carbon emission
 292 level on the current period; ρ is the spatial hysteresis coefficient, which reflects the extent to which carbon
 293 emissions from neighboring provinces affect carbon emissions in the region; W is a geospatial adjacency
 294 weights matrix, the value of which is determined according to the Queen's principle of geographic
 295 proximity, that is, the weight (w_{ij}) is set at 1 when two regions are adjacent and share a common border
 296 and vertex, and 0 otherwise (Hainan Province is assumed to be adjacent to Guangdong Province, given its
 297 closest geographical location and strong economic ties with that province, although it is not geographically
 298 adjacent to any province); δ_i and μ_t are respectively individual fixed effects and time fixed effects; the

299 remaining variables are interpreted in the same way as in Eq. (1).

300 In addition, to test the joint effect of environmental and fiscal decentralization on carbon emissions,
 301 the empirical model included an interaction term for environmental and fiscal decentralization to reflect the
 302 synergistic effect of environmental and fiscal resource allocation on carbon emissions. The model with an
 303 interaction term for the variables is:

$$304 \quad \ln PCO_{2it} = \beta_0 + \tau L \ln PCO_{2it} + \rho W \ln PCO_{2it} + \beta_1 ED_{it} + \beta_2 FD_{it} + \sum \alpha_j X_{ijt} + \beta_3 ED_{it} \times FD_{it} +$$

$$305 \quad \delta_i + \mu_t + \varepsilon_{it} \quad (3)$$

306 Variable measurement

307 In this paper, we used 30 provinces in mainland China (Considering the availability and completeness
 308 of data, Hong Kong, Macau, Taiwan and Tibet were not involved in this study) in 2003–2017 as the study
 309 sample and referred to the research results on carbon emissions both at home and abroad, and selected eight
 310 major factors affecting carbon emissions as the independent variables for empirical analysis. The definition
 311 and measurement of each variable are as follows.

312 Explained variable

313 For the explained variables, carbon emissions per capita for each province in China are used here.
 314 Since the purpose of the study is to explore the impact of environmental decentralization on carbon
 315 emissions, it is important to estimate carbon emissions accurately. This paper referred to the reference
 316 method provided by the Intergovernmental Panel on Climate Change (IPCC) of the United Nations, and
 317 estimated the per capita carbon emissions in each province based on the consumption of eight major fossil
 318 energy sources (raw coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, and natural gas). The
 319 formula is as follows.

$$320 \quad PCO_{2it} = (\sum_{j=1}^8 E_j \times SCC_j \times CEC_j \times 44/12) / POP_{it} \quad (4)$$

321 In the formula, i and t respectively stand for province and year, j stands for energy type, E stands for
 322 fossil energy consumption, SCC stands for standard coal conversion factor for fossil energy, CEC stands
 323 for carbon emission coefficient for fossil energy, $44/12$ stands for the ratio of molecular weight of CO_2 to
 324 molecular weight of carbon, POP is the population at the end of the year, and other variables or letters have
 325 the same meaning as in equation (1). The energy standard coal conversion coefficient and carbon emission
 326 coefficient used to calculate carbon emissions are from the Guidelines for National Greenhouse Gas
 327 Emissions Inventories, as shown in table 1.

328 **Table 1** The conversion coefficient of standard coal and carbon emission coefficient for eight fossil energy sources

Coefficient	Raw coal	Coke	Crude oil	Gasoline	Kerosene	Diesel oil	Fuel oil	Natural gas
SCC (kg tce/kg)	0.7143	0.9714	1.4286	1.4714	1.4714	1.4571	1.4286	1.3300*
CEC (kg/kg tce)	0.7559	0.8550	0.5857	0.5538	0.5714	0.5921	0.6185	0.4483

329 Note: the unit of conversion coefficient of natural gas is kg standard coal·m⁻³.

330 Core explanatory variables

331 Environmental decentralization and fiscal decentralization are the core explanatory variables in this
 332 paper, and thus it is extremely important to correctly understand their connotations and accurately measure
 333 the indicators. The environmental decentralization involved here refers to the central government's
 334 delegation of environmental management and powers to local governments, and gives local governments a
 335 certain degree of autonomy in environmental governance, which regulates the division of environmental
 336 protection powers and governance responsibilities between the central and local governments through
 337 decentralization. The aim is to achieve compatibility of incentives between central and local environmental

338 management and effective provision of public services for environmental protection through gradual
339 adjustment and optimization of environmental powers between governments. Unlike western
340 environmental federalism, Chinese environmental decentralization is holistic in nature, and gives greater
341 freedom to local governments to delegate environmental management. In addition, China has a relatively
342 detailed division of environmental powers, including environmental policymaking, environmental
343 monitoring, environmental supervision, investment in environmental facilities and environmental
344 information services (Qi et al. 2014). Due to the difficulty of constructing a comprehensive measure of
345 environmental decentralization that is self-consistent between practice and theory, previous studies have
346 mostly measured environmental decentralization using fiscal decentralization indicators through an indirect
347 approach. However, the special nature of environmental management power means that fiscal
348 decentralization cannot and will not replace environmental decentralization. Only by directly constructing
349 indicators for measuring environmental decentralization based on the internal logic of environmental
350 decentralization can we objectively and accurately reflect the content of environmental decentralization in
351 China. Considering the essential connotation of environmental decentralization, this paper used the
352 distribution of personnel in environmental protection agencies at different levels of government to portray
353 the overall Chinese environmental decentralization (ED_{it}), which was subdivided into three types of
354 environmental administrative decentralization (EAD_{it}), environmental supervision decentralization (ESD_{it})
355 and environmental monitoring decentralization (EMD_{it}). The distribution of personnel in environmental
356 protection departments at different levels of government is used to measure the degree of decentralization
357 of the environmental management institution for the following four reasons: (1) the personnel of
358 environmental protection agencies, as executors for exercising environmental protection powers, can reflect
359 the specific division of environmental powers among different levels of government to a certain extent; (2)
360 The change in the distribution of personnel in environmental protection agencies can reflect the change in
361 the environmental management system with the division of environmental responsibility as the core. (3)
362 The essence of environmental decentralization is management decentralization, and the distribution of
363 personnel better reflects the essence of environmental decentralization. (4) The use of personnel
364 distribution to measure decentralization is also a common international practice. Therefore, the ratio
365 between the number of local and national personnel per capita in environmental protection agencies is of
366 strong scientific validity and applicability to characterize the level of environmental decentralization in
367 China. This article discusses the impact of environmental decentralization on carbon emissions in terms of
368 the overall effect, environmental administrative power, environmental monitoring power and
369 environmental supervision power. The specific formulas for calculating each type of environmental
370 decentralization are as follows.

$$371 \quad ED_{it} = \left[\frac{SYS_{it}/POP_{it}}{SYS_t/POP_t} \right] \times \left[1 - \frac{GDP_{it}}{GDP_t} \right] \quad (5)$$

$$372 \quad EAD_{it} = \left[\frac{SYSA_{it}/POP_{it}}{SYSA_t/POP_t} \right] \times \left[1 - \frac{GDP_{it}}{GDP_t} \right] \quad (6)$$

$$373 \quad EMD_{it} = \left[\frac{SYSM_{it}/POP_{it}}{SYSM_t/POP_t} \right] \times \left[1 - \frac{GDP_{it}}{GDP_t} \right] \quad (7)$$

$$374 \quad ESD_{it} = \left[\frac{SYSS_{it}/POP_{it}}{SYSS_t/POP_t} \right] \times \left[1 - \frac{GDP_{it}}{GDP_t} \right] \quad (8)$$

375 where i and t denote province and year respectively; SYS_{it} , $SYSA_{it}$, $SYSM_{it}$ and $SYSS_{it}$ represent the
376 number of personnel in the environmental protection system, the number of environmental protection
377 administrative personnel, the number of environmental protection monitoring personnel and the number of
378 environmental protection supervising personnel respectively. SYS_t , $SYSA_t$, $SYSM_t$ and $SYSS_t$ are

379 respectively the number of personnel in the environmental protection system, the number of environmental
380 protection administrative personnel, the number of environmental protection monitoring personnel and the
381 number of environmental protection supervising personnel at the national (including central and local) level.
382 POP_{it} and POP_t respectively indicate the size of the population of each province and in the country as a
383 whole, both expressed in terms of population at the end of the year. GDP_{it} is the GDP of each province,
384 GDP_t is the national GDP, and $[1 - (GDP_{it}/GDP_t)]$ is an economic size reduction factor used to deflate
385 the impact of economic size on the actual degree of environmental decentralization (the higher the degree
386 of economic development, the more local environmentalists are set up) to reduce possible endogenous risks.
387 The greater the value of ED_{it} above, the higher the degree of environmental weighting, and other
388 weighting values (e.g., EAD_{it} , ESD_{it} , and EMD_{it}) have a similar relationship.

389 Since fiscal decentralization is the basis of environmental decentralization and there is interaction
390 between the two, fiscal decentralization is also taken as the core explanatory variable affecting carbon
391 emissions. Based on the availability of data, this paper adopted the fiscal autonomy index to characterize
392 the fiscal decentralization of each province with reference to the research method of Zou (2019) to
393 compensate for the inability of the existing index to reflect the differences in the degree of fiscal
394 decentralization among local governments. The specific formula is $FD_{it} = FE_{it}/FI_{it}$, in which FD_{it}
395 indicates the degree of fiscal decentralization in local governments, and FE_{it} and FI_{it} are the fiscal
396 expenditures in the provincial budgets and fiscal revenues in the regional budgets respectively.

397 **Control variables**

398 There are many factors influencing carbon emissions, and for robustness reasons, this study also
399 selected other factors affecting carbon emissions as control variables for the model. ① The level of
400 economic development ($\ln PGDP_{it}$) is measured by the logarithm of the per capita gross domestic product
401 ($PGDP$) in each province, and the GDP deflator is used to eliminate the impact of price fluctuations; the
402 squared term of the level of economic development ($\ln PGDP_{it}$)² is also introduced to examine the
403 existence of a Kuznets curve for carbon emissions. ② Population size ($\ln PD_{it}$) is expressed as the
404 logarithm of the ratio of the end-of-year population to the area of administrative divisions in each province.
405 ③ R&D intensity (RD_{it}) is measured as the share of GDP spent on R&D in each province. ④ Foreign
406 Direct Investment (FDI_{it}) is expressed by the proportion of the actual foreign direct investment (converted
407 by the average exchange rate of RMB against the US dollar) in each province to GDP. ⑤ The industrial
408 structure ($\ln INDUS_{it}$) is measured using the value-added of the secondary sector as a share of GDP. ⑥
409 Trade openness ($OPEN_{it}$) choose a measure of the total import and export trade in each province as a share
410 of GDP.

411 **Data sources and variable descriptive statistics**

412 The raw data used to estimate provincial carbon emissions, environmental decentralization (including
413 environmental system decentralization, environmental administration decentralization, environmental
414 supervision decentralization and environmental monitoring decentralization), fiscal decentralization,
415 economic development, population size and research and development intensity were taken from
416 successive China Energy Statistical Yearbooks, China Environment Yearbook, China Finance Yearbook,
417 China Statistical Yearbook and China Science and Technology Statistical Yearbook. As the data on the
418 personnel of environmental protection agencies at all levels compiled by the China Environmental
419 Yearbook ended in 2015, the number of environmental protection system personnel, environmental
420 protection administrative personnel, environmental protection monitoring personnel and environmental
421 supervision personnel in each province in 2016-2017 was calculated from the sub-data in the China

422 Environmental Yearbook, and the missing numbers of environmental protection system personnel and
 423 environmental protection administrative personnel in individual provinces were made up by consulting the
 424 statistical yearbooks and statistical bulletins of the corresponding provinces. Data on the output value of
 425 secondary industries needed to measure the industrial structure, the total import and export volume needed
 426 to open up trade, and FDI come from the statistical yearbooks of each province (Hebei' s and Gansu's FDI
 427 were respectively taken from the Hebei Economic Yearbook and Gansu Development Yearbook). All
 428 indicators in the text expressed in monetary units were deflated using the 2000 price index as the base
 429 period (FDI data were first converted using the average exchange rate of the RMB against the USD for
 430 each year and then deflated using the 2000 price index). The definitions of the variables and the results of
 431 their descriptive statistics are shown in table 2. Table 2 shows that, except for the large standard deviation
 432 of the squared term of the logarithm of GDP per capita, the standard deviations of the other variables are
 433 generally small, indicating that the selected sample is stable overall. However, there is obvious
 434 heterogeneity among the provinces for each variable, taking the core explanatory variable environmental
 435 decentralization as an example, the maximum value of environmental decentralization is 2.347 and the
 436 minimum value of environmental decentralization is 0.059, the former is 39.8 times of the latter; similarly,
 437 environmental administrative decentralization, environmental monitoring decentralization and
 438 environmental supervision decentralization also show similar difference characteristics.

439 **Table 2** Definitions and descriptive statistics of all variables (2003-2017)

Variable name	Variable definition	Mean	Std. D	Max.	Min.	Obs.
<i>lnPCO₂</i>	Logarithm of per capita carbon emissions	1.711	0.551	3.516	0.269	450
<i>L.lnPCO₂</i>	Logarithm of per capita carbon emissions lagging by one period	1.661	0.546	3.289	0.138	450
<i>ED</i>	Environmental decentralization	1.008	0.365	2.347	0.059	450
<i>EAD</i>	Decentralization of environmental administration	1.027	0.582	10.612	0.186	450
<i>EMD</i>	Decentralization of environmental monitoring	1.033	0.725	14.203	0.069	450
<i>ESD</i>	Decentralization of environmental supervision	0.972	0.545	3.503	0.185	450
<i>FD</i>	Fiscal decentralization	2.248	0.980	7.426	0.197	450
<i>lnPGDP</i>	Logarithm of GDP per capita	3.031	0.650	4.586	1.246	450
<i>(lnPGDP)²</i>	Square of per capita GDP logarithm	9.607	3.9705	21.031	1.551	450
<i>lnPD</i>	Logarithm of population density	5.429	1.266	8.249	2.036	450
<i>RD</i>	Proportion of R & D expenditure in GDP	1.871	1.535	9.844	0.172	450
<i>FDI</i>	Proportion of foreign direct investment in GDP	3.197	2.376	10.941	0.054	450
<i>lnINDUS</i>	Logarithm of the proportion of industrial production in GDP	3.812	0.207	2.944	4.202	450
<i>OPEN</i>	Proportion of total export-import volume in GDP	0.394	0.424	1.891	0.018	450

440 **Results and discussions**

441 **Spatial correlation test for carbon emissions**

442 Testing the existence of spatial correlation of variables is a prerequisite for the empirical analysis of
 443 the effect of environmental decentralization on the spatial impact of carbon emissions using dynamic
 444 spatial panel models. At present, most scholars adopt Moran's *I* index to characterize the spatial
 445 autocorrelation of regional variables (the correlation between a certain geographical phenomenon in one
 446 spatial unit and that in the neighboring spatial unit), which is calculated as follows.

$$448 \quad = \left[\sum_{i=1}^n \sum_{j=1}^n w_{ij} (Y_i - \bar{Y})(Y_j - \bar{Y}) \right] / \left(S^2 \sum_{i=1}^n \sum_{j=1}^n w_{ij} \right) \quad (9)$$

449 in the formula, $S^2 = \frac{1}{n} \sum_{i=1}^n (Y_i - \bar{Y})^2$, $\bar{Y} = \frac{1}{n} \sum_{i=1}^n Y_i$, Y_i is the observed value for province i (i.e. carbon
 450 emissions per capita); n is the number of provinces. w_{ij} is the spatial weight of inter-provincial neighbors
 451 (considering that the Queen spatial weight matrix better reflects the real spatial relationship than the Rook
 452 spatial weight matrix, this paper adopted the Queen proximity principle to construct the spatial weight
 453 matrix to test the spatial correlation of carbon emissions). Moran index I indicates the global spatial
 454 autocorrelation of provincial per capita carbon emissions in China, and its value range is $-1 \leq I \leq 1$. When I
 455 is close to -1, it means that per capita carbon emissions are spatially negatively correlated among provinces;
 456 when I is close to 1, it means that per capita carbon emissions are spatially positively correlated; and when
 457 I is equal to 0, it means that there is no spatial autocorrelation of carbon emissions. Table 3 shows the
 458 global Moran's I index of carbon emissions per capita for provincial areas in China from 2003 to 2017
 459 obtained using GeoDa1.10 software processing.

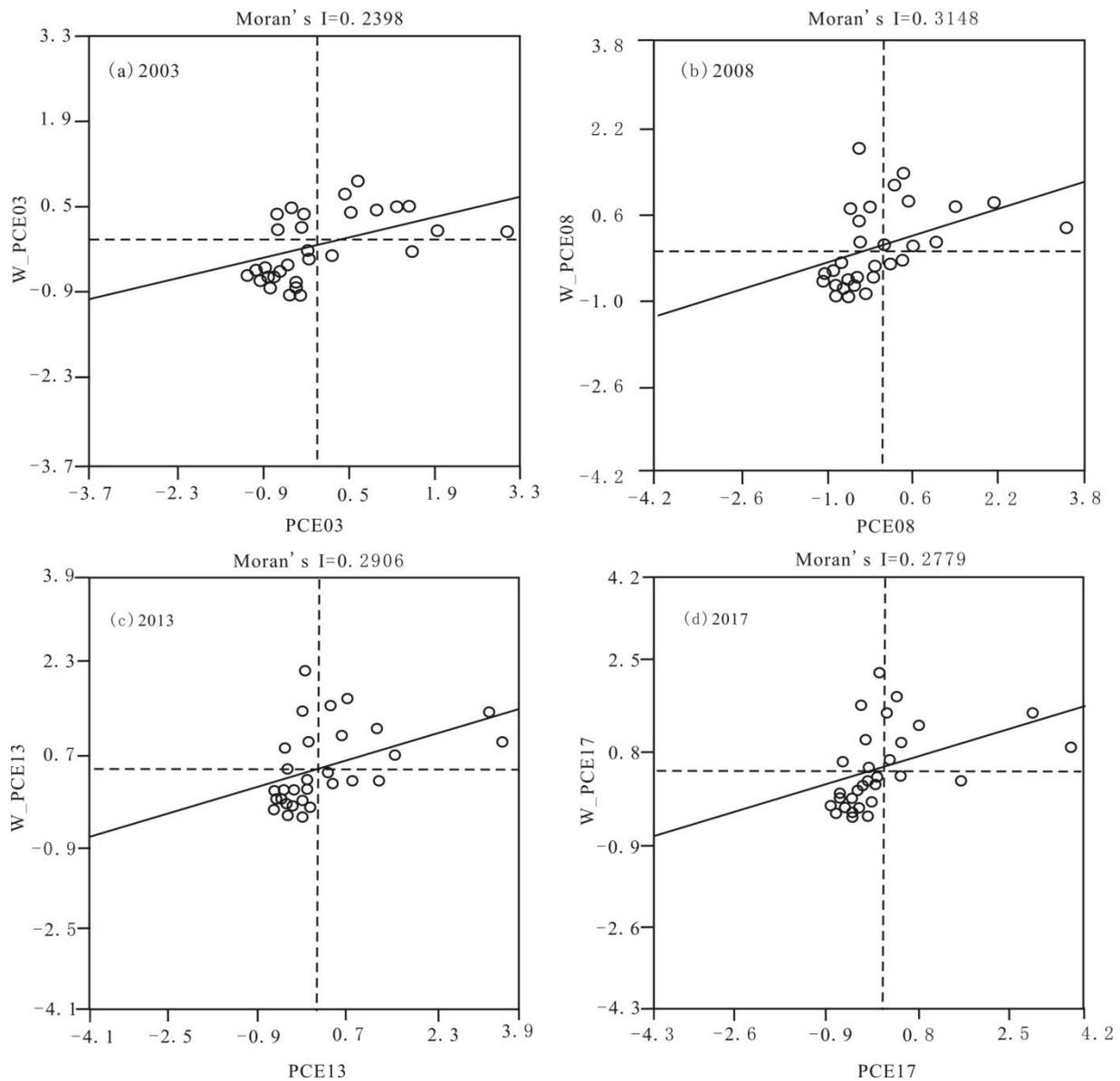
460 **Table 3** Global Moran's I of China's provincial carbon emissions per capita from 2003 to 2017

Year	Moran's I	$E(I)$	$SD(I)$	$Z(I)$ -value	P -value
2003	0.2398	-0.0357	0.1173	2.5023	0.02
2004	0.3680	-0.0357	0.1280	3.2772	0.01
2005	0.3340	-0.0357	0.1223	3.1516	0.01
2006	0.3450	-0.0357	0.1175	3.3837	0.01
2007	0.3359	-0.0357	0.1114	3.4869	0.01
2008	0.3148	-0.0357	0.1015	3.5903	0.01
2009	0.2853	-0.0357	0.0989	3.3854	0.02
2010	0.3186	-0.0357	0.0969	3.7912	0.01
2011	0.2836	-0.0357	0.0911	3.6169	0.01
2012	0.2874	-0.0357	0.0935	3.5556	0.01
2013	0.2906	-0.0357	0.0985	3.4022	0.01
2014	0.2930	-0.0357	0.1004	3.3597	0.01
2015	0.2840	-0.0357	0.1012	3.2446	0.02
2016	0.2786	-0.0357	0.1020	3.1502	0.03
2017	0.2779	-0.0357	0.1001	3.1992	0.02

461 Note: $E(I)$ is the expected value, $E(I) = -1/(n - 1)$; $SD(I)$ is the standard deviation; $Z(I)$ is the standardized statistic,
 462 $Z(I) = [I - E(I)]/\sqrt{var(I)}$; P is the level of significance of I , obtained by Monte Carlo simulation 1000 times. In this study,
 463 if the P -value is less than the given significance level ($\alpha = 0.05$) and $|Z| > 1.96$, it means that the provincial per capita
 464 carbon emissions have significant spatial correlation; otherwise, the spatial correlation is not significant; when the Z -value is
 465 0, it means that the provincial per capita carbon emissions are randomly distributed.

466 From Table 3, it can be seen that the global Moran's I index of carbon emissions per capita in China's
 467 provinces all passed the 5% level of significance test, with Z -values above 2.5 (> 1.96) and Moran's I values

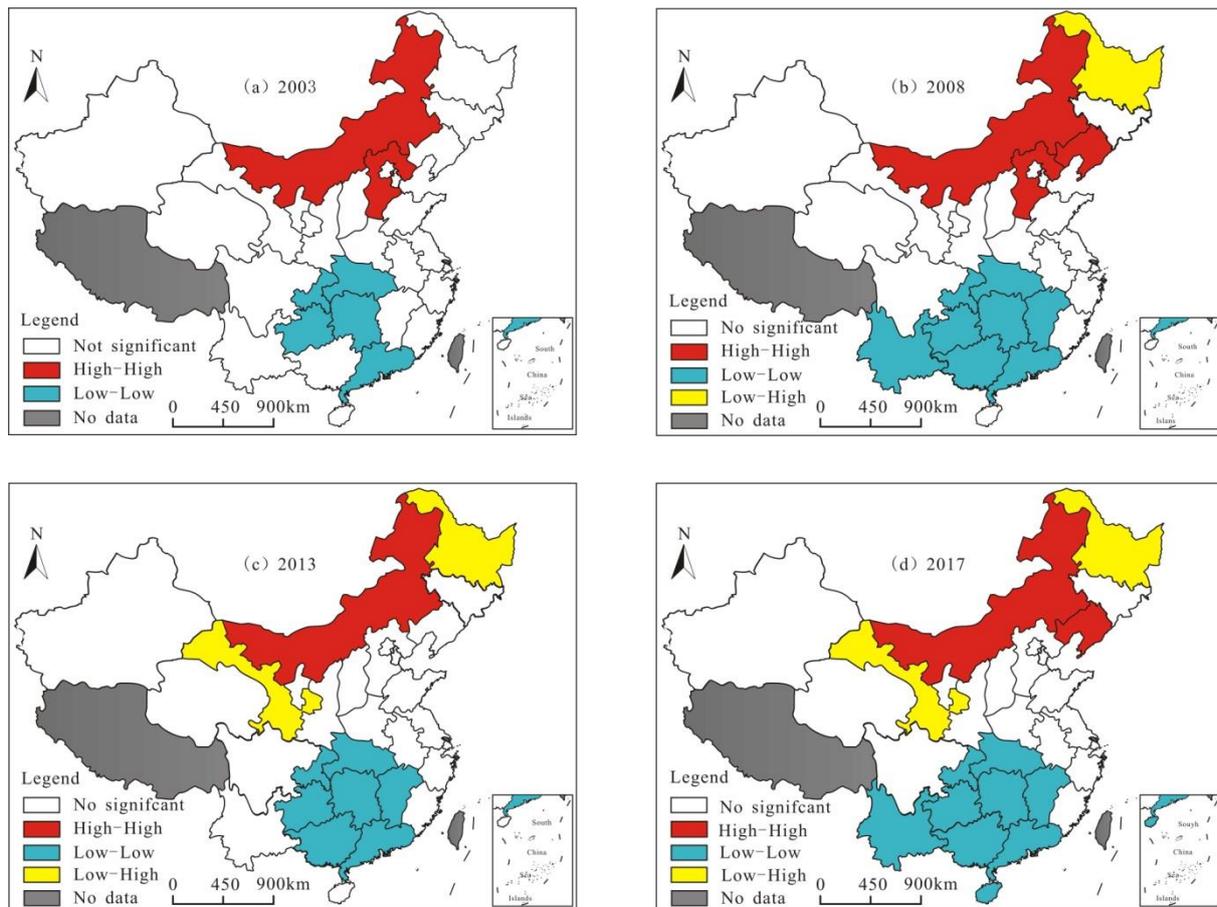
468 around 0.3, which indicates that carbon emissions per capita in China's provinces are not completely
469 random, but show a significant positive spatial correlation. Although Moran's I index shows a gradual
470 downward trend over time, provinces with similar per capita carbon emissions over the study period still
471 show a clear clustering and strong spatial dependence (Table 3). In order to further explore the similar
472 clustering characteristics of provincial carbon emissions per capita in local space, this paper adopted the
473 local Moran scatter plot and LISA (Local Indicators of Spatial Association) clustering plot to analyze the
474 clustering among provincial carbon emissions per capita and its significance. Figure 1 shows the local
475 Moran scatter plot of China's provincial carbon emissions per capita based on the Queen's spatial adjacency
476 matrix. In Figure 1, the quadrant I indicates that areas with high per capita carbon emissions are surrounded
477 by areas with high per capita carbon emissions, referred to as "High-High" (H-H) agglomeration areas;
478 quadrant II indicates that areas with low per capita carbon emissions are surrounded by areas with high per
479 capita carbon emissions, i.e. "Low-High" (L-H) agglomeration areas; quadrant III indicates areas with low
480 per capita carbon emissions and low per capita carbon emissions in the surrounding area, that is, "Low-
481 Low" (L-L) agglomeration areas; Quadrant IV indicates that areas with high per capita carbon emissions
482 are surrounded by areas with low per capita carbon emissions, known as " High-Low" (H-L) agglomeration
483 areas. The H-H and L-L clusters represent the positive spatial correlation of carbon emissions per capita at
484 the provincial level, while the L-H and H-L clusters represent the strong negative spatial correlation of
485 carbon emissions per capita at the provincial level.



486

487 Fig. 1 Moran scatter plot of China's provincial carbon emission per capita in typical years (2003, 2008, 2013 and 2017)

488 Figure 1 shows that the majority of Chinese provinces are located in quadrants I and III. The
 489 proportion of provinces in quadrants I (H-H) and III (L-L) reached 70.0%, 73.3%, 70.0% and 76.7% in
 490 2003, 2008, 2013 and 2017 respectively, while the corresponding percentages of provinces in quadrants II
 491 (L-H) and IV (H-L) were only 30.0%, 26.7%, 30.0%, and 23.3% respectively. This indicates that the per
 492 capita carbon emissions of most Chinese provinces have a strong spatial correlation on a local scale during
 493 the study period, especially the spatial clustering features of H-H and L-L are very obvious, which shows
 494 that there is a strong spatial synergy (or positive correlation), in other words, an increase or decrease in the
 495 per capita carbon emissions of the surrounding provinces will lead to an increase or decrease in the per
 496 capita carbon emissions of the region.



497
498 Fig. 2 LISA cluster map of China's provincial carbon emission per capita in typical years (2003, 2008, 2013 and 2017)

499 In order to better reflect the spatial clustering of carbon emissions and its significance, this paper
500 plotted the Moran's I scatter plots for the above four years directly on the map of China, and then obtains
501 the LISA clustering map of provincial carbon emissions per capita in China. Figure 2 shows that the spatial
502 pattern of provincial per capita carbon emissions in China has remained relatively stable over the period
503 2003-2017. In addition to the increasing trend of provinces with significant L-L and L-H agglomerations,
504 the number of provinces with significant H-H agglomerations did not change significantly, especially the
505 number of provinces with H-L agglomerations (higher per capita carbon emissions than the surrounding
506 provinces) did not pass the significance test throughout the study period, which indicates the likelihood of a
507 significant "bump" in per capita carbon emissions nationwide is extremely low. Nevertheless, there are
508 certain differences in the spatial clustering pattern of carbon emissions per capita in China's provinces and
509 regions in different years. In 2008, for example, the spatial clustering of provincial carbon emissions per
510 capita in China is very obvious as shown in Figure 2(b). H-H clustering was mainly located in the coastal
511 area and yellow economic belt in northern China, but the only provinces that passed the significance test
512 are Inner Mongolia, Hebei and Liaoning. The reason is that these provinces are important energy
513 production and heavy industry bases in China, with a high proportion of energy development and
514 consumption, and the high energy consumption and high emission industries represented by coal,

515 petrochemicals, iron and steel, and metallurgy have produced a large amount of carbon emissions to the
516 local environment. In particular, in recent years, Inner Mongolia has been increasingly developing its coal
517 resources, while at the same time undertaking a large number of backward production capacity elimination
518 from developed areas, coupled with the slow population growth in the region, which has pushed up per
519 capita carbon emissions and has always shown high-value clustering characteristics in the study period
520 (Figure 2). In 2008, the clustering of L-L provincial per capita carbon emissions in China was mainly
521 concentrated in the middle reaches of the Yangtze River, southwest China and south China, with significant
522 spatial correlation in Hubei, Hunan, Jiangxi, Yunnan, Chongqing, Guizhou, Guangxi and Guangdong
523 (Figure 2b). However, the reasons for the low per capita carbon emission clustering pattern in these
524 provinces are different. The decrease in per capita carbon emissions in Hunan, Hubei and Jiangxi provinces
525 is due to the implementation of the central rise strategy in 2006, which accelerated the structural
526 transformation of traditional industries in these provinces, while the impact of technological advances
527 contributed to a reduction in their total carbon emissions, which in turn led to a decrease in per capita
528 carbon emissions; while in Yunnan, Guizhou and Guangxi, were affected by the financial crisis in 2008,
529 which slowed down their economic growth, resulting in a smaller increase in the demand for energy from
530 economic activities, which led to a decrease in their per capita carbon emissions. The decrease in per capita
531 carbon emissions in Chongqing and Guangdong is mainly due to the gradual shift of their traditional
532 energy-intensive industries to the inland northwest and the gradual development of capital-intensive and
533 knowledge innovation-driven high-tech industries in the original regions, which has reduced their reliance
534 on primary energy and improved their energy efficiency. The influx eventually led to a decline in per capita
535 carbon emissions. As for the provinces with significant L-H agglomerations in 2008 (with relatively lower
536 per capita carbon emissions than the surrounding provinces), the presence of Heilongjiang in the northeast
537 may be related to the reduction of its total carbon emissions due to the accelerated transformation of its
538 heavy industry structure and the elimination of a number of backward production capacity by the northeast
539 revitalization policy. The above analysis suggests that it is necessary to consider the spatial spillover effect
540 of carbon emissions in the panel model when exploring the impact of environmental decentralization on
541 carbon emissions.

542 **Empirical analysis of the impact of environmental decentralization on carbon emissions**

543 **The impact of environmental decentralization on carbon emissions at the national level**

544 Based on the aforementioned models and relevant data, this paper explored the impact of
545 environmental decentralization on carbon emissions by double-fixed individual and time effects using Stata
546 14.0 software. The final estimation results for each model are presented in Table 4. In particular, models 5
547 and 6 are respectively the results of dynamic spatial panel regression estimates with environmental
548 decentralization and fiscal decentralization as core explanatory variables and adding geospatial adjacency
549 weight matrices. For robustness reasons, Table 4 also presents the estimated results of ordinary least

550 squares (OLS) and static spatial panel regressions.

551 The estimated effects of environmental decentralization and fiscal decentralization on provincial per
552 capita carbon emissions in China shown in Table 4 show that the estimated coefficients of environmental
553 decentralization are negative and pass the significance test at least at the 5% level in Models 1, 3 and 5,
554 indicating that environmental decentralization is beneficial in reducing provincial carbon emissions in
555 China compared to environmental centralization. This result can be explained in two ways. First,
556 environmental decentralization has given local government greater autonomy in environmental
557 management. Compared with the central government, local governments have greater access to local
558 information, and thus are better able to understand the environmental needs of local residents and achieve
559 rational resource allocation at lower costs and with better information, and to formulate targeted
560 environmental policies in terms of emission reduction and green technology, thereby promoting the
561 coordinated development of the local economy and the environment. Secondly, as the degree of
562 environmental decentralization increases, the number of local environmental protection personnel will
563 increase. While promoting the gradual formation of local environmental regulatory networks, local
564 governments can make environmental policy adjustments in real-time according to local environmental
565 conditions, thus ultimately improving local environmental quality. However, it is surprising that the results
566 of this study on the impact of environmental decentralization on carbon emissions are inconsistent with the
567 results of Lu and Zhang (2016), Zhang et al. (2017) and Qi et al. (2014), that is, environmental
568 decentralization is not conducive to carbon emission control, on the contrary, the higher the degree of
569 environmental decentralization, the greater the carbon emissions. They also interpreted this result from the
570 perspective of jurisdictional competition to mean that environmental decentralization would make local
571 governments blindly pursue economic growth at the expense of the environment, resulting in ineffective
572 environmental regulatory standards, which would lead to a "race to the bottom" phenomenon, thereby
573 aggravating environmental pollution and carbon emissions. Although there is some validity in their
574 explanation of the impact of environmental decentralization on carbon emissions, their conclusions are still
575 open to further debate. First, the previous research period mainly focused on 1992-2010 (Lu and Zhang
576 2016; Zhang et al. 2017; Qi et al. 2014), while this study spanned the period 2000-2017. With the change of
577 time, the era conditions of the impact of environmental decentralization on carbon emissions are changing.
578 In particular, since 2007, the Chinese government has gradually incorporated energy conservation and
579 emission reduction into the local performance appraisal system, and in the context of lifelong
580 accountability and veto system for local officials, local governments' awareness of environmental
581 protection has been strengthened, and local officials can no longer arbitrarily change regional
582 environmental regulations to attract foreign investment as they did in the past, making the GDP
583 championship competition mechanism, which has always emphasized economic growth at the expense of
584 environmental protection, no longer exist due to the loss of environmental institutional foundation.

585 Therefore, we can speculate that the conclusions of Lu and Zhang (2016), Zhang et al. (2017) and Qi et al.
586 (2014) that environmental decentralization aggravates carbon emissions may be related to their earlier
587 study period. Second, the local carbon emission reduction incentive mechanism under the decentralized
588 environmental management system is gradually formed. Along with the intensification of local carbon
589 emissions in recent years, China is under tremendous pressure to meet its 2030 national voluntary
590 emissions reduction commitments. Therefore, the Chinese government attaches great importance to carbon
591 emission control, and has gradually made the effective curbing of carbon emissions an important criterion
592 for evaluating the performance of local officials, combining this with economic incentives such as transfer
593 payments to local governments. To a certain extent, this mobilizes local officials to take the initiative and
594 enthusiasm to implement carbon emission reduction. It means that local governments are given more power
595 over environmental management, which may enable them to formulate more accurate environmental
596 regulations and reasonable investment in environmental management according to the local ecological and
597 environmental conditions and economic development level, thus forming an incentive and compatibility
598 mechanism to effectively curb carbon emissions and solve the problem of inconsistent goals and
599 asymmetric information between the central and local governments in carbon emission management, and
600 ultimately reduce carbon emissions throughout China, and improve the effectiveness of environmental
601 management. Therefore, in the case of carbon emissions, a modest decentralization of authority for
602 environmental management and responsibility for carbon emission governance to local governments will
603 facilitate further governance of carbon emissions, while over-centralization may result in increased carbon
604 emissions.

605 In terms of the effect of fiscal decentralization on carbon emissions, the estimated coefficient of fiscal
606 decentralization is significantly positive at the 1% level in all three models (Model 2, Model 4 and Model
607 6), which is consistent with the results of Zhang's (2011) study, that is, the improvement of fiscal
608 decentralization will significantly increase carbon emissions. The reason for this may be that fiscal
609 decentralization significantly reduces local governments' efforts to regulate the environment and their
610 investment in environmental governance, thus hindering the innovative development of low-carbon
611 environmental technologies. Moreover, although increased fiscal autonomy helps to motivate local
612 governments and to some extent plays an important role in motivating local officials to develop the
613 regional economy, this appraisal model of official promotion, which focuses on GDP growth, usually
614 comes at the expense of the environment (Yan 2012; Wang et al. 2014). For these two reasons, fiscal
615 decentralization ultimately leads to increased environmental pollution and rising carbon emissions. The
616 above-mentioned positive correlation between fiscal decentralization and provincial per capita emissions
617 suggests that fiscal autonomy is not suitable for local governments as much as it is for environmental
618 decentralization. At the same time, as analyzed above, it is difficult to reflect the impact of Chinese
619 environmental decentralization on carbon emissions if fiscal decentralization is used as a simple indicator

620 to measure local environmental decentralization. Therefore, this study analyzes the relationship between
 621 environmental decentralization and carbon emissions directly from the internal logic of environmental
 622 management, and the results may be more suitable for assessing the effect of Chinese environmental
 623 federalism.

624 **Table 4** Basic regression results of environmental decentralization and provincial carbon emissions in China

Variables	Ordinary least squares (OLS)		Static space panel		Dynamic spatial panel	
			regression		regression	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
<i>L.lnPCO₂</i>					0.3651*** (0.0284)	0.3660*** (0.0283)
<i>ED</i>	-0.1267** (0.0659)		-0.0922** (0.0386)		-0.1056*** (0.0523)	
<i>FD</i>		0.1242*** (0.0252)		0.1608*** (0.0150)		0.1124*** (0.0237)
<i>lnPGDP</i>	0.9143*** (0.1413)	0.8487** (0.4267)	0.4169*** (0.1263)	0.3536*** (0.1249)	0.1980*** (0.0511)	0.1531*** (0.0095)
<i>(lnPGDP)²</i>	-0.0543 (0.0354)	-0.0442 (0.0731)	-0.0054 (0.0216)	0.0031 (0.0216)	-0.0126 (0.0188)	-0.0187 (0.0189)
<i>lnPD</i>	-0.1475* (0.0825)	-0.1138* (0.06970)	-0.0192 (0.1209)	-0.0215 (0.1788)	-0.1567 (0.1584)	-0.1295 (0.1562)
<i>RD</i>	-0.0660*** (0.0207)	-0.0663* (0.0413)	-0.1044*** (0.0194)	-0.1052*** (0.0194)	-0.0616*** (0.0173)	-0.0621*** (0.0174)
<i>FDI</i>	-0.0154** (0.0065)	-0.0125 (0.0110)	-0.0099** (0.0042)	-0.0081 (0.0051)	-0.0051 (0.0045)	-0.0038 (0.0045)
<i>lnINDUS</i>	0.2351*** (0.0849)	0.2413*** (0.0741)	0.2986*** (0.0726)	0.3155*** (0.0736)	0.1594*** (0.0541)	0.1716*** (0.0650)
<i>OPEN</i>	0.1154* (0.0771)	0.0810 (0.1312)	0.1126* (0.0697)	0.0793 (0.0665)	0.1182** (0.0604)	0.1364** (0.0576)
<i>W*lnPCO₂</i>			0.5328*** (0.1149)	0.5517*** (0.1143)	0.2739** (0.1140)	0.2864** (0.1135)
<i>Constants</i>	-0.3704* (0.4568)	-0.6521 (0.6601)				
<i>R²</i>	0.7205	0.7153	0.8183	0.8178	0.8620	0.8619
Log-L			315.51	314.88	377.41	377.19
Individual Effects/Time Effects	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y
Sample Size <i>Obs</i>	450	450	450	450	450	450

625 Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels respectively; values in parentheses are standard
 626 errors; *W* indicates a geographic adjacency matrix; and *Y* indicates that the variable has been controlled. Same table below.

627 Further from the regression results of the static and dynamic spatial panel models (Table 4), the

628 estimated coefficients of the spatial lag ($W*\ln PCO_2$) are both significantly positive at least at the 5% level,
629 indicating that there is a significant path dependence (spatial autocorrelation) of carbon emissions among
630 Chinese provinces, that is, the carbon emission level of any province will be influenced by the carbon
631 emissions of the neighboring areas, and the estimated results will be biased if the spatial correlation is
632 ignored. In addition, the first-order lagged term of the explained variable (per capita carbon emissions) is
633 positively correlated with the per capita carbon emissions in the current period at the 1% level, which
634 indicates that the per capita carbon emissions in each province have obvious continuity and stickiness in
635 time, thus highlighting that carbon emissions have a certain inertia-dependent feature (Zhang et al. 2017),
636 that is to say, the carbon emissions remaining in the atmosphere in the previous period may aggravate the
637 carbon emissions of the region in the current period. Therefore, if short-term carbon emissions are not dealt
638 with in a timely and effective manner, it will lead to long-term and more costly negative environmental
639 effects.

640 As far as the control variables are concerned, this paper is mainly based on the interpretation of the
641 regression results from the dynamic spatial panel model 5. Table 4 shows that the estimated coefficients of
642 the economic growth variables are significantly positive, indicating that in China's economic transition
643 period, with rapid economic development, increasing energy consumption will significantly increase
644 carbon emissions in each province. It is noteworthy that the squared term coefficient of economic growth is
645 negative but not significant, which indicates that there is an inverted U-shaped Kuznets curve between
646 economic growth and provincial carbon emissions in China. This means that when the economic
647 development reaches a certain level, people's demand for environmental quality will become higher and
648 higher, and local governments will provide some financial and policy support to effectively control carbon
649 emissions, so as to curb carbon emissions and improve environmental quality, but the current effect is not
650 obvious. The relationship between population density and carbon emissions is insignificant but negative,
651 indicating that an increase in population density decreases provincial carbon emissions. The reason for this
652 is that the carbon emissions in this study were measured on a per capita basis, which is not inconsistent
653 with previous findings that population growth contributes to increased carbon emissions (Zhu et al. 2010).
654 Of course, regions with higher population densities usually have more skilled people and capital, which is
655 likely to lead to economic growth and rapid development of carbon abatement technologies, thus reducing
656 carbon emissions. The estimated coefficient of R&D intensity is significantly negative at the 1% level,
657 indicating that R&D intensity has a significant inhibitory effect on carbon emissions, which is consistent
658 with the findings of Cole (2013) and Han (2018), implying that improving energy efficiency by inducing
659 low-carbon technological progress through science and technology innovation is an important means to
660 curb the growth of carbon emissions and effectively promote the achievement of carbon emission
661 reduction targets in China. The estimated coefficient for FDI is negative, but it does not pass the
662 significance test in most of the models (Table 4), indicating that FDI has some inhibitory effect on carbon

663 emissions, but the effect is not obvious. This may be due to the fact that China is currently undergoing a
664 transition from quantity to quality of foreign investment. On the one hand, due to the influence of the
665 "pollution refuge" effect, most foreign investors usually move enterprises at the lower end of the value
666 chain and with higher carbon emissions to developing countries, thus exacerbating China's carbon
667 emissions to a certain extent; On the other hand, as China has paid more attention to the "quality" of foreign
668 investment in recent years, it has encouraged localities to prioritize the introduction of enterprises with new
669 technologies and strict implementation of environmental protection standards to achieve clean or green
670 production by reducing energy consumption, thereby reducing carbon emissions and exerting a "pollution
671 halo" effects. With these two opposite directions, the positive environmental effects of FDI due to
672 technology transfer (carbon abatement effects) are likely to be partially offset by the negative
673 environmental effects they generate (increased carbon emissions), resulting in insignificant effects of FDI
674 in curbing carbon emissions. The impact of industrial structure on carbon emissions, as measured by the
675 proportion of industry, is significantly positive at the 1% level, indicating that the high proportion of
676 secondary industries is an important factor contributing to the increase in carbon emissions, and also
677 indicating that the impact of industrial structure on carbon emissions cannot be ignored. This means that
678 although China is currently accelerating the transformation, upgrading and greening of its industrial
679 structure, it has not fundamentally reversed the extensive economic growth model of industrial
680 development, and the growth of industrial output is still at the expense of massive primary energy
681 consumption and environmental sacrifice (Zhang et al. 2020), which in turn leads to increased carbon
682 emissions and serious environmental pollution. Therefore, the development of new and strategic industries
683 based on clean production and the reduction of dependence on resource-based industries are still important
684 means to reduce carbon emissions. In addition, the effect of trade openness on carbon emissions is also
685 significantly positive, indicating that trade openness has a significant role in promoting the growth of per
686 capita carbon emissions in the province, which is not conducive to energy conservation and emission
687 reduction. The reason may be related to the negative function of trade openness in transferring
688 environmental pollution. It has been reported that environmental pollution is transferred from areas with
689 stronger environmental regulations to areas with weaker environmental regulations through trade openness,
690 and that less stringent environmental regulations usually promote economic growth, which in turn can lead
691 to more carbon emissions everywhere.

692 **The impact of decomposition indicators of environmental decentralization on China's carbon** 693 **emissions**

694 In order to further explore the impact of environmental decentralization on provincial carbon
695 emissions in China, the three decomposition indicators of environmental decentralization are re-estimated
696 by dynamic spatial measurement in this paper. The results in Table 5 show that the estimated coefficient of
697 environmental administrative decentralization is negative and significant at the 1% level, indicating that

698 higher environmental administrative decentralization is beneficial to local environmental administrations in
699 arranging reasonable investment in environmental governance and adjusting environmental policies in a
700 scientific and timely manner according to the local social, economic and ecological conditions, thus
701 forming a "race to the top" in environmental administrative matters. The mechanism of healthy competition
702 will ultimately reduce carbon emissions everywhere. The estimated coefficient of environmental
703 monitoring decentralization is also significantly negative at the 1% level, indicating that the
704 decentralization of environmental monitoring will also suppress local carbon emissions. This is because
705 local governments have more advantages than the central government in environmental quality monitoring,
706 assessment and early warning, so a moderate increase in environmental monitoring decentralization is more
707 conducive to local environmental protection departments effectively carrying out environmental monitoring
708 activities and environmental quality assessment, thus providing more accurate environmental quality
709 information to environmental administration and environmental supervision departments to some extent,
710 and improving environmental quality and reducing carbon emissions. It is noteworthy that the absolute
711 value of the estimated coefficient of the environmental monitoring decentralization is the smallest among
712 the three decomposers, which may be related to the fact that the role of environmental monitoring on
713 carbon emissions is mainly indirect through the provision of environmental information for environmental
714 administration and inspection. In contrast to the environmental administration and environmental
715 monitoring decentralization, the estimated coefficient for the environmental supervision decentralization is
716 significantly positive at the 1% level, indicating that the decentralization of environmental supervision
717 would increase carbon emissions. This is because environmental supervision departments are the most
718 direct pollution emission control departments, and their environmental supervision services (mainly
719 including environmental enforcement and environmental supervision) are usually influenced by both the
720 local government's primary goal of economic development and excessive regulation by higher-level
721 environmental protection departments, so that local implementation may face greater resistance and affect
722 the supervision effect. In particular, when environmental supervision conflicts with local economic
723 interests, local environmental protection departments will be interfered by local governments in the pursuit
724 of economic growth and environmental supervision and enforcement, thus relaxing environmental
725 regulations in terms of emissions declaration, environmental project acceptance, environmental
726 enforcement and inspection, and thus increasing carbon emissions. Therefore, on the premise of advocating
727 green GDP development and reforming performance assessment standards, the power of environmental
728 supervision should be appropriately shifted upward, and supplemented by the coordination and supervision
729 of the central government, which is the only way to exert the inhibiting effect of environmental supervision
730 on carbon emissions.

731 **Table 5** Dynamic spatial regression results of different environmental decentralization and provincial carbon emissions

Variables	Dynamic Spatial Regression
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	Model 7	Model 8	Model 9
<i>EAD</i>	-0.0814*** (0.0108)		
<i>ESD</i>		0.0725*** (0.0228)	
<i>EMD</i>			-0.0306*** (0.0086)
Control Variables	Y	Y	Y
<i>L.lnPCO₂</i>	0.3540*** (0.0283)	0.3509*** (0.0281)	0.3547*** (0.0284)
<i>W*lnPCO₂</i>	0.3402*** (0.1123)	0.3498*** (0.1121)	0.3415*** (0.1123)
<i>R</i> ²	0.8646	0.8674	0.8645
<i>Log-L</i>	381.74	386.43	381.48
Individual Effects/Time Effects	Y/Y	Y/Y	Y/Y
Sample Size	450	450	450

732 **The impact of interaction between environmental decentralization and fiscal decentralization on**
733 **carbon emissions in China**

734 In order to explore the impact of the interaction of environmental and fiscal decentralization on carbon
735 emissions under the fiscal decentralization system, the interaction terms of environmental decentralization
736 and fiscal decentralization variables were added to the model and the results are listed in Table 6. Table 6
737 shows that the regression coefficients of the interaction terms of environmental decentralization and fiscal
738 decentralization, environmental administrative decentralization and fiscal decentralization, environmental
739 monitoring decentralization and fiscal decentralization, environmental supervision decentralization and
740 fiscal decentralization are all significantly positive at the 5% level, indicating that the combination of
741 different types of environmental decentralization and fiscal decentralization will promote carbon emissions
742 in each province, and the increase of fiscal autonomy is not conducive to the suppression of carbon
743 emissions by environmental decentralization, which also means that the impact of environmental
744 decentralization on carbon emissions will be constrained to some extent by fiscal decentralization after the
745 integration of environmental decentralization and fiscal decentralization. The reason for this is that fiscal
746 decentralization gives local governments more financial autonomy and economic incentives, while
747 environmental decentralization gives local governments the power to protect and manage the environment.
748 When local governments have the financial autonomy delegated by the central government and the ability
749 to intervene in local environmental matters, they usually sacrifice the environment for rapid economic
750 growth, and even the phenomenon of government-to-government "free-riding" and "government-business
751 collusion" occurs. When the environmental degradation effect of fiscal decentralization is greater than the
752 inhibitory effect of environmental decentralization on carbon emissions, carbon emissions will be

753 intensified. The empirical results in this paper support the findings of Tian and Wang (Tian et al. 2018).
 754 Although the relationship between fiscal decentralization and carbon emissions has been discussed in many
 755 studies (Zhang et al. 2011; Ran et al. 2020; Yan 2012; Wang et al. 2014), this study is more relevant
 756 because it fits into the theory of environmental federalism.

757 In addition, comparing the regression coefficients of the interaction terms in Table 6, it is found that
 758 the decentralization of the environmental system is the largest, the decentralization of environmental
 759 administration is the second largest, and the decentralization of environmental supervision and monitoring
 760 is the smallest, and the reason for this difference may be related to the distribution of environmental powers
 761 set up by the environmental authorities. The environmental system department, which is the prime
 762 minister's agency for environmental governance, has the highest estimated interaction coefficients because
 763 its environmental powers are most affected by the increase in financial autonomy; the environmental
 764 administration department, which is responsible for formulating environmental policies and coordinating
 765 resource allocation, has the second-highest estimated interaction coefficients because these powers are
 766 weakened to a large extent by financial decentralization, which in turn affects the inhibitory effect of
 767 environmental decentralization on the growth of carbon emissions; and the environmental monitoring
 768 department and the environmental supervision department, which are the concrete implementers of
 769 environmental protection, are less affected by fiscal decentralization because their functions are
 770 non-substitutional, so their interaction coefficients are smaller.

771 **Table 6** Dynamic spatial regression results of the interaction between environmental decentralization and fiscal
 772 decentralization on China's provincial carbon emissions

Variables	$X=ED$	$X=EAD$	$X=ESD$	$X=EMD$
$L.lnPCO_2$	0.3512*** (0.0285)	0.3543*** (0.02836)	0.3485*** (0.0279)	0.3558*** (0.0284)
X	-0.1007** (0.0507)	-0.1635** (0.0680)	0.0731** (0.0267)	-0.1491** (0.0542)
FD	0.1301*** (0.0171)	0.0933*** (0.0211)	0.1163*** (0.0241)	0.1162*** (0.0323)
$X*FD$	0.0784** (0.0146)	0.0643** (0.0184)	0.0587** (0.0180)	0.0574** (0.0201)
Control Variables	Y	Y	Y	Y
$W*lnPCO_2$	0.3283*** (0.1127)	0.3379*** (0.1124)	0.3440*** (0.1121)	0.3467*** (0.1125)
R^2	0.8652	0.8650	0.8683	0.8560
Log-L	382.63	382.33	387.98	382.34
Individual Effects/Time Effects	Y/Y	Y/Y	Y/Y	Y/Y
Sample Size	450	450	450	450

773 Note: ED, EAD, ESD and EMD stand for Environmental Systems Decentralization, Environmental Administration

774 Decentralization, Environmental Supervision Decentralization and Environmental Monitoring Decentralization, respectively.
775 The same table below.

776 **Estimates of the impact of environmental decentralization on carbon emissions at different regions in**
777 **China**

778 Considering the spatial heterogeneity of environmental decentralization levels in different regions and
779 the differences in resource endowment, economic development and technological innovation, this paper
780 divided mainland China into eastern, central and western regions according to their economic development
781 levels, and explored the heterogeneity of environmental decentralization's impact on carbon emissions from
782 a regional perspective. The empirical results of the impact of environmental decentralization on carbon
783 emissions in different regions are shown in Table 7. From the regression results, the regression coefficients
784 of environmental decentralization and its disaggregated variables in the eastern region are negative (except
785 for environmental supervision decentralization) but not significant, indicating that the decentralization of
786 environmental management in this region is conducive to reducing carbon emissions, further indicating that
787 environmental decentralization is an important means of energy conservation and emission reduction in the
788 eastern region, but the positive effect has not yet fully emerged. This may be due to the fact that the eastern
789 part of the country is economically more developed, and local governments have already attached a certain
790 degree of importance to environmental protection, and technological innovation and human capital have a
791 stronger driving effect on the upgrading of the regional industrial structure; in addition, the distribution of
792 environmental protection personnel at the grass-roots level in the eastern part of the country is already at a
793 high level, thus weakening the inhibitory effect of environmental decentralization on carbon emissions. The
794 estimated coefficients on the environmental decentralization, environmental administrative decentralization
795 and environmental supervision decentralization variables are significantly positive at the 10% level in the
796 central region compared to the eastern region, suggesting that environmental decentralization in the central
797 region contributes to the increase in carbon emissions, although environmental monitoring decentralization
798 helps to curb carbon emissions in the central region (the coefficient on environmental monitoring
799 decentralization is significantly negative), overall decentralization of environmental management matters
800 are not conducive to carbon reduction in the region. This may be due to the relatively lagging economic
801 development in the central region, where local governments are heavily influenced by incentives for
802 economic growth, and environmental decentralization facilitates local governments to focus more on
803 economic development and at the expense of the environment. Therefore, the existing performance
804 appraisal system in the central region should be reformed and environmental management powers (such as
805 environmental administration and environmental supervision) in the area of carbon emissions should be
806 appropriately transferred upwards to avoid the negative impact of excessive environmental decentralization
807 on carbon emission reduction. The coefficients of environmental decentralization, environmental
808 administrative decentralization and environmental monitoring decentralization in western China are all

809 significantly negative at the 5% level, while environmental supervision decentralization has a significant
810 positive correlation with the growth of carbon emissions (Table 7), indicating that environmental
811 decentralization has a greater impact on carbon emissions in western China than in eastern and central
812 China. The reason for this is that the western region is currently in the stage of shifting from the stage of
813 laying the foundation for western development (2000-2010) to the stage of accelerated development
814 (2010-2030), and the conflict between economic development and resources and environment in this region
815 is the most intense, and the ecological environment is very fragile. In addition to adjusting the industrial
816 structure, improving the investment environment and developing infrastructure such as science, technology
817 and education, the construction of the ecological environment is also its main task. Especially in recent
818 years, the central government has increased its intervention in the ecological and environmental protection
819 of western regions, and has made the environmental protection of key ecological function areas in western
820 regions an important indicator in local performance appraisals, while giving local governments in western
821 regions sufficient incentives and necessary policy support for environmental protection. In this context,
822 once the environmental management is decentralized, it will make up for the shortcomings of the
823 environmental management system in the past, which will lead to the gradual formation of a more
824 comprehensive environmental regulatory mechanism in the western grassroots regions, and enable local
825 governments to formulate environmental policies and control carbon emissions on time by virtue of the
826 emerging information and resource allocation advantages. As a result, the increase in environmental
827 decentralization in the west has a greater dampening effect on carbon emissions than in the east and central
828 regions. It is worth mentioning that the regression coefficients of environmental supervision
829 decentralization in the eastern, central and western regions are positive, but only in the western region
830 passed the 5% significance test, indicating that the promotion effect of environmental supervision
831 decentralization on the growth of carbon emissions in China is more pronounced in the western region.
832 This is mainly because the western region has a lower level of economic development than the eastern and
833 central regions, and local governments are more influenced by the incentives of economic growth, and the
834 contradiction between environmental supervision and local economic development is greater than that in
835 the eastern and central regions, which leads to greater resistance to the implementation of environmental
836 supervision in the western region and ultimately affects the inspection effect. Therefore, it is necessary to
837 appropriately transfer the power of environmental supervision upwards and to manage environmental
838 inspection matters vertically.

839 Table 7 shows that the estimated coefficients of the impact of fiscal decentralization on carbon
840 emissions are positive in the eastern, central and western regions, indicating that an increase in the degree
841 of fiscal decentralization contributes to the growth of carbon emissions, but the extent to which fiscal
842 decentralization affects the growth of carbon emissions varies across regions. In the eastern region, there is
843 no significant positive correlation between fiscal decentralization and carbon emissions, and the regression

844 coefficients are the smallest, while in the central and western regions, the two show significant positive
845 correlation at the level of at least 5% and 10%, respectively. The reasons for this difference may be related
846 to the different incentives created by the economic development and financial resources of each region, as
847 well as the differences in resource endowments due to the ecological situation. In the eastern region,
848 economic development and financial resources are higher, local governments prefer the environment over
849 economic growth incentives, thus in the context of fiscal decentralization, local environmental protection
850 departments are determined to implement environmental protection policies, making fiscal decentralization
851 have less influence on environmental management matters, thus resulting in fiscal decentralization has the
852 weakest effect on the growth of carbon emissions; in the central region, because of the relative lag in
853 economic development, fiscal decentralization gives local governments much greater incentives to develop
854 the economy than local governments' preferences for the environment. Thus, as fiscal autonomy increases,
855 local governments make way for economic development by reducing environmental regulations or
856 distorting environmental policies, resulting in the strongest contribution of fiscal decentralization to
857 increasing carbon emissions. As for the western region, although the level of economic development is the
858 lowest and local governments are more influenced by the incentives for economic development given by
859 fiscal decentralization, the central and local governments have paid more attention to environmental issues
860 in the western region and have given sufficient incentives for environmental protection due to the fragile
861 ecological environment of the region. Thus, even though local governments still have strong incentives for
862 economic development, economic development at the expense of the environment has been largely curbed.
863 As a result, the regression coefficient of the impact of fiscal decentralization on carbon emissions in the
864 western region is small and only significantly positive at the 10% level.

865 The impact of the interaction term between environmental decentralization and its decomposition
866 variables and fiscal decentralization on regional carbon emissions shows some heterogeneity (Table 7). In
867 the eastern region, the coefficients of the interaction terms are all negative, indicating that the combination
868 of environmental decentralization and its disaggregated variables with fiscal decentralization will have a
869 restraining effect on carbon emissions in the eastern region; while in the central and western regions, the
870 coefficients of the interaction terms are all positive and significant in the western region, except for the
871 central region, where the coefficients of the interaction terms of environmental decentralization and
872 environmental administrative decentralization with fiscal decentralization are negative, indicating that most
873 of the interaction term between the decentralization variable and fiscal decentralization in the central and
874 western regions promote carbon emissions. This is mainly because the central and western regions are
875 relatively underdeveloped, and local governments have stronger incentives to pursue economic growth than
876 the eastern regions, even squeezing out environmental protection spending for high-return productive
877 investments, thus leading to an increase in the hindering effect of fiscal decentralization on the
878 management of local environmental affairs; while in the economically developed eastern regions, local

879 governments have a stronger preference for the environment and have relatively sufficient funds to control
880 environmental pollution, so fiscal decentralization interferes less with environmental management matters,
881 resulting in the inhibitory effect of the interaction terms on carbon emissions.

882 In addition, the period lag coefficients, spatial autocorrelation coefficients, and the effects of other
883 control variables for carbon emissions (not listed due to space limitations) are all generally consistent with
884 the results in Table 4 and will not be repeated here. It is worth pointing out that the coefficient of the spatial
885 lag term of carbon emissions in the eastern region is positive but not significant, while the coefficient of the
886 spatial lag term in the central and western regions is significantly positive at least at the 5% level (Table 7),
887 which reflects that there is still an obvious path dependence of carbon emissions in the central and western
888 regions, while the positive spatial correlation of carbon emissions in the eastern region is weakening. The
889 reason for this may be that the eastern region has high-technology and high-efficiency resources that are
890 constantly flowing to Beijing, Tianjin, Shanghai and other regions, coupled with the gradual transfer of
891 high-energy consumption and high-emission industries in these regions to provinces and regions with lower
892 environmental regulations in close proximity, leading to a significant decline in carbon emissions in the
893 above-mentioned regions, while carbon emissions in relatively backward eastern provinces such as
894 Liaoning, Hebei and Fujian have declined less (Liu et al. 2018), thus weakening the positive spatial
895 correlation of carbon emissions within the region; the economic development of the central and western
896 regions mainly relies on the region's resource endowments and the transfer of industries from the eastern
897 region, with obvious synergistic development effects, resulting in a strong spatial dependence of carbon
898 emissions within the region.

899 **Table 7** dynamic spatial regression results of environmental decentralization and its interaction with administrative decentralization on carbon emissions in different regions of China

Variables	Eastern Region				Central Region				Western Region			
	<i>X=ED</i>	<i>X=EAD</i>	<i>X=ESD</i>	<i>X=EMD</i>	<i>X=ED</i>	<i>X=EAD</i>	<i>X=ESD</i>	<i>X=EMD</i>	<i>X=ED</i>	<i>X=EAD</i>	<i>X=ESD</i>	<i>X=EMD</i>
<i>L.lnPCO₂</i>	0.0816** (0.0468)	0.1402*** (0.0460)	0.0993** (0.0465)	0.0928** (0.0434)	0.2048*** (0.0785)	0.2142*** (0.0781)	0.1929*** (0.0781)	0.2181*** (0.0785)	0.2537*** (0.0477)	0.2593*** (0.0490)	0.2581*** (0.0491)	0.2570*** (0.0483)
<i>X</i>	-0.1399 (0.1483)	-0.1024 (0.0980)	0.1016 (0.1077)	-0.0714 (0.1442)	0.2545* (0.1094)	0.4120* (0.2103)	0.2584* (0.1612)	-0.0762* (0.0384)	-0.3023** (0.1020)	-0.1355** (0.0461)	0.1346** (0.0385)	-0.0933** (0.0273)
<i>FD</i>	0.0424 (0.0864)	0.02315 (0.0384)	0.0142 (0.0412)	0.0356 (0.0885)	0.1581** (0.0419)	0.2105*** (0.0228)	0.1490** (0.0208)	0.1329** (0.0126)	0.0527* (0.0369)	0.0312* (0.0215)	0.0221* (0.0146)	0.0394* (0.0285)
<i>X*FD</i>	-0.0698 (0.1010)	-0.1025 (0.0501)	-0.0470 (0.0651)	-0.0481 (0.0890)	-0.0572 (0.1122)	-0.1618 (0.1104)	0.0684 (0.0763)	0.0446 (0.0522)	0.0387** (0.0113)	0.0289** (0.0078)	0.0741** (0.0391)	0.0257** (0.0171)
Control Variables	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
<i>W*lnPCO₂</i>	0.1327 (0.1398)	0.1686 (0.1411)	0.1205 (0.1413)	0.1887 (0.1393)	0.2240** (0.1038)	0.2765** (0.1064)	0.2042** (0.1027)	0.2485** (0.0516)	0.5071*** (0.1778)	0.5280*** (0.1796)	0.5352*** (0.1785)	0.5279*** (0.1783)
<i>R</i> ²	0.9017	0.8959	0.8983	0.9057	0.8556	0.8578	0.8575	0.8556	0.9082	0.9025	0.9041	0.9016
Log-L	202.78	198.03	199.99	206.17	102.58	103.52	103.38	102.61	143.60	136.54	136.51	137.91
Individual Effects/Time Effects	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y
Sample Size	165	165	165	165	120	120	120	120	165	165	165	165

900 Note: According to the National Development and Reform Commission, the eastern region includes 11 provinces (cities) of Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang,
 901 Fujian, Shandong, Guangdong and Hainan; the central region includes 8 provinces (Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan); and the western region includes
 902 11 provinces (autonomous regions) of Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang.

903 **Robustness test of the impact of environmental decentralization on carbon emissions**

904 In order to test the robustness and validity of the above empirical results, this paper referred to the
 905 method of Lu (2016) for calculating the environmental decentralization, and remeasures the environmental
 906 decentralization and its three decomposition indexes without considering the economic scale reduction
 907 factor, and regressed them with the per capita carbon emissions of Chinese provinces, and the results of the
 908 robustness test are listed in Table 8. Comparing with the results in Tables 4-6, it is found that the
 909 relationship between environmental decentralization, environmental administrative decentralization,
 910 environmental monitoring decentralization and environmental supervision decentralization, which do not
 911 take into account the economic scale reduction factor, and carbon emissions all remain stable. In addition,
 912 although the regression coefficients of other variables change to different degrees, the direction and
 913 significance of the changes are basically the same as the previous results, which indicates that the
 914 estimation results in this paper are more robust.

915 **Table 8** Estimation results of the robustness test

Variables	$X=ED$	$X=EAD$	$X=ESD$	$X=EMD$
$L.lnPCO_2$	0.3523*** (0.0284)	0.3538*** (0.0284)	0.3469*** (0.0283)	0.3540*** (0.0284)
X	-0.1169*** (0.0128)	-0.0110*** (0.0036)	0.0723*** (0.0268)	-0.0531*** (0.0126)
FD	0.1016*** (0.0128)	0.0812*** (0.0129)	0.0918*** (0.0103)	0.1134*** (0.0129)
Control Variables	Y	Y	Y	Y
$W*lnPCO_2$	0.3278*** (0.1134)	0.3386*** (0.1129)	0.3519*** (0.1127)	0.3398*** (0.1129)
R^2	0.8647	0.8644	0.8666	0.8644
Log-L	381.90	381.43	384.98	381.38
Individual Effects/Time Effects	Y/Y	Y/Y	Y/Y	Y/Y
Sample Size	450	450	450	450

916 **Conclusions and policy recommendations**

917 To achieve the set 2030 carbon emission reduction target in China, it is necessary to construct a
 918 reasonable environmental management system for carbon emissions among government levels. This article
 919 empirically examined environmental decentralization and its impact on carbon emissions in the context of
 920 fiscal decentralization by constructing a dynamic spatial panel model using inter-provincial panel data
 921 from 2003 to 2017 in China. The results show that: (1) The period lag and spatial lag coefficients of carbon

922 emissions are both significantly positive, indicating that there is an obvious inertia dependence (continuity)
923 and spatial path dependence of carbon emissions in China, with high-high and low-low aggregation
924 characteristics. (2) At the national level, considering the spatial spillover effect of carbon emissions, the
925 overall environmental decentralization, environmental administrative decentralization and environmental
926 monitoring decentralization have a significant and stable negative impact on carbon emissions, indicating
927 that environmental administrative decentralization, environmental monitoring decentralization and overall
928 environmental decentralization are conducive to reducing carbon emissions in China, while
929 environmental supervision decentralization plays a significant and stable role in promoting carbon
930 emissions, implying that, compared with environmental centralization, the current environmental
931 decentralization system is generally conducive to carbon emission control, but environmental supervision
932 decentralization has certain negative effects on carbon emission reduction. Fiscal decentralization
933 significantly exacerbates carbon emissions, because fiscal decentralization is prone to distort incentives and
934 significantly reduces local governments' efforts to regulate the environment, thus failing to impose effective
935 constraints on carbon emissions; the interaction term coefficients of environmental decentralization and its
936 disaggregated indicators and fiscal decentralization are both significantly positive at the 5% level, showing
937 that the combination of environmental management rights and fiscal autonomy will have a facilitating
938 effect on carbon emissions, implying that fiscal decentralization weakens the incentives of environmental
939 decentralization for environmental protection and thus exacerbates carbon emissions. (3) At the regional
940 level, there is great spatial heterogeneity in the effects of environmental decentralization on carbon
941 emissions in different regions. The suppression effect of environmental decentralization, environmental
942 administrative decentralization and environmental monitoring decentralization on carbon emissions in the
943 western region is significantly larger than that in the eastern region; similarly, the promotion effect of
944 environmental supervision decentralization on carbon emissions is also more significant than that in the
945 eastern region. In the central region, in addition to the environmental monitoring decentralization inhibits
946 carbon emissions, environmental decentralization, environmental administration decentralization and
947 environmental supervision decentralization promote carbon emissions, indicating that the decentralization
948 of environmental management in the central region does not form an effective incentive for carbon
949 emission management in general, and is not conducive to the implementation of carbon emission reduction.
950 The promotion effect of fiscal decentralization in the eastern part of the country is significantly weaker than
951 that in the central and western part of the country, but the combination of environmental decentralization
952 and its decomposition index with fiscal decentralization is significantly better than that in the central and
953 western part of the country in terms of its inhibiting effect on carbon emissions.

954 The above results have important implications for the construction of an environmental management
955 system for carbon emissions in China. Based on the empirical results, this paper makes the following policy
956 recommendations: (1) At the national level, the degree of environmental decentralization can be increased,

957 and the setting of environmental management agencies and the allocation of environmental protection
958 personnel among different levels of government can be further optimized, so as to improve the efficiency of
959 local government's control over carbon emissions. At the same time, accountability, a veto system and a
960 green GDP assessment system should be implemented to prevent the exacerbation of carbon emissions
961 caused by the excessive combination of fiscal and environmental decentralization, thus reducing the
962 negative impact of fiscal decentralization on carbon emission reduction management. (2) For different
963 types of environmental decentralization, different degrees of decentralization should be adopted.
964 Environmental administrative powers and environmental monitoring powers can be appropriately
965 decentralized in order to make full use of the cost and information advantages of local governments to
966 achieve effective resource allocation in carbon emission control and environmental management, thereby
967 reducing the level of carbon emissions. The power of environmental supervision should be centralized to
968 ensure the authority of environmental inspection, supplemented by the coordination and supervision of the
969 central government, so as to avoid the "bottom-up competition" of carbon emissions by local governments
970 for the sake of economic development. (3) Considering regional heterogeneity, differentiated
971 environmental decentralization strategies should be scientifically formulated in the three major regions of
972 East, Central and West. Specifically, as the eastern regions have obvious advantages in economy,
973 technology, talent and information, and have formed a comprehensive management system for carbon
974 emission management, the central government should further decentralize environmental administration
975 and environmental monitoring, and establish a comprehensive local environmental information disclosure
976 mechanism to ensure the openness and transparency of environmental monitoring data. In the central region,
977 the central government should increase its efforts to intervene and inspect local environments, transfer
978 upward environmental administrative and supervision powers, appropriately reduce the discretionary space
979 of local governments in the formulation of environmental policies, and form an appropriate vertical
980 management system, while a moderate downward transfer of environmental monitoring powers can be
981 considered. In the western region, given the fragility and importance of the region's ecological environment,
982 the central government should grant special treatment to the western region in terms of environmental
983 decentralization. First, in environmental administration and environmental monitoring, it should increase
984 the administrative and monitoring powers of local governments as well as the number of local
985 environmental protection personnel, upgrade environmental infrastructure and environmental monitoring
986 capacity, and gradually improve the grassroots environmental management network in the western region
987 so as to guide local governments to "compete upward" in carbon emission control. Secondly, in
988 environmental supervision, while transferring the power of environmental supervision, the central
989 government should give greater policy preference to environmental inspection matters, and in
990 environmental supervision matters to strengthen local government incentives and constraints on carbon
991 emission reduction, and ultimately form a situation where the incentives for central and regional

992 environmental management are compatible. (4) Considering the negative spatial externalities and spillover
993 effects of carbon emissions, the establishment of a cross-regional and cross-sectoral "joint prevention and
994 control" carbon emissions governance mechanism is an important option to avoid local governments "going
995 it alone" and to curb carbon emissions "free-riding" behavior. "

996 It is worth pointing out that, due to the limitations of data and environmental decentralization
997 measurement methods, this paper discussed the carbon emission effects of environmental decentralization
998 in China from the inter-provincial panel, while the extent of environmental decentralization and its impact
999 on carbon emissions at the inter-municipal level is still unknown. In addition, this article mainly analyzed
1000 the effects of environmental decentralization based on the government's actions, but does not consider the
1001 effects of other social actors. Therefore, it will be the focus of future research to improve the environmental
1002 decentralization indexes from the inter-provincial perspective, and to investigate the environmental
1003 decentralization effects of other entities and the effects of different environmental decentralization degrees.

1004

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1010 **Declarations**

1011 **Ethical Approval** All procedures performed in studies involving human participants were in accordance
1012 with the ethical standards of the institutional and/or national research committee.

1013 **Consent to Participate** Informed consent was obtained from all individual participants included in the
1014 study.

1015 **Consent to Publish** The manuscript is approved by all authors for publication.

1016 **Competing Interests** The authors declare no competing interests.

1017 **References**

1018 Anselin L (2001) Spatial effects in econometric practice in environmental and resource economics. *American Journal of*
1019 *Agricultural Economics* 83(3):705–710. <https://doi.org/10.1111/0002-9092.00194>

1020 Bai JH, Nie L (2017) Is environmental decentralization really exacerbating haze pollution. *China Population Resources and*
1021 *Environment* 27(12):59–69. (In Chinese) <https://doi.org/10.12062/cpre.20170911>

1022 Banzhaf HS, Chupp BA (2012) Fiscal federalism and interjurisdictional externalities: new results and an application to US air
1023 pollution. *Journal of Public Economics* 96(5/6):449–464. <https://doi.org/10.1016/j.jpubeco.2012.01.001>

1024 Ben YH, Li XD (2017) Fiscal decentralization and environmental pollution: An empirical analysis based on spatial
1025 measurement. *China Science and Technology Forum* 6:109–114. (In Chinese)
1026 <https://doi.org/10.13580/j.cnki.fstc.2017.06.015>

1027 Besley T, Coate S (2003) Centralized versus decentralized provision of local public goods: A political economy approach.

1028 Journal of Public Economics 87(12):2611–2637. [https://doi.org/10.1016/S0047-2727\(02\)00141-X](https://doi.org/10.1016/S0047-2727(02)00141-X)

1029 Burgess R, Hansen M, Olken BA, et al (2012) The political economy of deforestation in the tropics. *Quarterly Journal of*

1030 *Economics* 127(4):1707–1754. <https://doi.org/10.1093/qje/qjs034>

1031 Cole MA, Elliott RJR, Okubo T, et al (2013) The carbon dioxide emissions of firms: A spatial analysis. *Journal of*

1032 *Environmental Economics and Management* 65(2):290–309. <https://doi.org/10.1016/j.jeem.2012.07.002>

1033 Deng HH, Zheng XY, Huang N, et al (2012) Strategic interaction in spending on environmental protection: spatial evidence

1034 from Chinese cities. *China & World Economy* 20(5):103–120. <https://doi.org/10.1111/j.1749-124X.2012.01304.x>

1035 Dijkstra BR, Fredriksson PG (2010) Regulatory environmental federalism. *Annual Review of Resource Economics*

1036 2(1):319–339. <https://doi.org/10.1146/ANNUREV-RESOURCE-040709-135112>

1037 Feng C, Wang M, Liu GC, et al (2017) Green development performance and its influencing factors: a global perspective.

1038 *Journal of Cleaner Production* 144:323–333. <https://doi.org/10.1016/j.jclepro.2017.01.005>

1039 Ferrara I, Missios P, Yildiz HM (2014) Inter-regional competition, comparative advantage and environmental federalism. *The*

1040 *Canadian Journal of Economics* 47(3):905–952. <https://doi.org/10.1111/caje.12098>

1041 Fredriksson PG, Wollscheid JR (2014) Environmental decentralization and political centralization. *Ecological Economics*

1042 107:402–410. <https://doi.org/10.1016/j.ecolecon.2014.09.019>

1043 Fslleth EI, Hovik S (2009) Local government and nature conservation in Norway: Decentralization as a strategy in

1044 environmental policy. *Local Environment* 14(3):221–231. <https://doi.org/10.1080/13549830802692849>

1045 Goel RK, Mazhar U, Nelson MA, et al (2017) Different forms of decentralization and their impact on government

1046 performance: micro-level evidence from 113 countries. *Economic Modelling*

1047 62:171–183. <https://doi.org/10.1016/j.econmod.2016.12.010>

1048 Gray W, Shadbegian R (2004) Optimal pollution abatement: whose benefits matter and How Much. *Journal of Environmental*

1049 *Economics and Management* 47:510–534. <https://doi.org/10.1016/j.jeem.2003.01.001>

1050 Halkos GE, Tzeremes NG (2013) Carbon dioxide emissions and governance: A nonparametric analysis for the G20. *Energy*

1051 *Economics* 40(2):110–118. <https://doi.org/10.1016/j.eneco.2013.06.010>

1052 Han C (2018) Analysis of the influence of technological progress on industrial carbon emissions in China. *Journal of*

1053 *University of Technology* 39(2):65–73. (In Chinese) <https://doi.org/10.19525/j.issn1008-407x.2018.02.010>

1054 He QC (2015) Fiscal decentralization and environmental pollution: evidence from Chinese panel data. *China Economic*

1055 *Review* 36:86–100. <https://doi.org/10.1016/j.chieco.2015.08.010>

1056 Hossein H, Kaneko S (2013) Can environmental quality spread through institutions. *Energy Policy* 56 (2):312–321.

1057 <https://doi.org/10.1016/j.enpol.2012.12.067>

1058 Huang SF (2017) A study of impacts of fiscal decentralization on smog pollution. *World Economy* 40(2):127–152. (In

1059 Chinese)_CNKI: SUN: SJJJ.0.2017-02-007

1060 Jacobsen GD, Kotchen MJ, Vandenbergh MP (2012) The behavioral response to voluntary provision for an environmental

1061 public good: Evidence from residential electricity demand. *European Economic Review* 56(5):946–960.

1062 <https://doi.org/10.1016/j.euroecorev.2012.02.008>

1063 Kunce M, Shogren J (2007) Destructive interjurisdictional competition firm, capital and labor mobility in a model of direct

1064 emission control. *Ecological Economics* 60(3):543–549. <https://doi.org/10.1016/j.ecolecon.2005.04.024>

1065 Li GS, Han MC (2015) Fiscal decentralization, spatial spillover and China’s urban haze pollution: Mechanism and evidences.

1066 *Contemporary Finance & Economics* 6:26–34. (In Chinese) <https://doi.org/10.13676/j.cnki.cn36-1030/f.2015.06.004>

1067 Li Q (2018) Emission reduction effect of environmental decentralization: from the perspective of the river chief system.

1068 *Industrial Economy Research* 3:53–63. (In Chinese) <https://doi.org/10.13269/j.cnki.ier.2018.03.005>

1069 Li XJ, Liu H (2016) Fiscal decentralization and the plight of regional environmental pollution based on the perspective of

1070 regional differences—the analysis on the pollutant properties of spillover. *Finance and Trade Economy* 2:41–54. (In

1071 Chinese) <https://doi.org/10.19795/j.cnki.cn11-1166/f.2016.02.004>

- 1072 Liu JJ, Shi D, Wang C (2015) A study on spatial spillover and correlation effect of carbon emissions across 30 provinces in
1073 China. *Journal of Natural Resources* 30(8):1289–1303. (In Chinese) <https://doi.org/10.11849/zrzyxb.2015.08.005>
- 1074 Liu XZ, Gao CC, Zhang Y (2018) Spatial dependence pattern of carbon emission intensity in China's provinces and spatial
1075 heterogeneity of its influencing factors. *Scientia Geographica Sinica* 38(5):681–690. (In Chinese)
1076 <https://doi.org/10.13249/j.cnki.sgs.2018.05.005>
- 1077 Long S, Hu J (2014) Environmental pollution from the perspective of government-enterprise collusion: Theoretical and
1078 empirical analysis. *Journal of Finance and Economic* 40(10):131–144. (In Chinese)
1079 <https://doi.org/10.16538/j.cnki.jfe.2014.10.001>
- 1080 Lopez R, Mitra S (2000) Corruption, pollution and the Kuznets Environment Curve. *Journal of Environmental Economics*
1081 and Management 40:137–150. <https://doi.org/10.1006/jeem.1999.1107>
- 1082 Lu FZ, Yang HC (2019) Environmental decentralization, local government competition and China's ecological environment
1083 pollution. *Industrial Economics Research* 4:113–126. (In Chinese) <https://doi.org/10.13269/j.cnki.ier.2019.04.010>
- 1084 Lu YQ, Zhang DG (2016) Environmental decentralization, market segmentation and carbon emissions. *China Population*
1085 *Resources and Environment* 26(6):107–115. (In Chinese) <https://doi.org/10.3969/j.issn.1002-2104.2016.06.014>
- 1086 Luo B, Ling HC (2020) The internal mechanism of environmental decentralization and regional economic growth: based on
1087 the adjustment of central-local relationship. *Journal of Yunnan University of Finance and Economics*. (In Chinese)
1088 <https://doi.org/10.16537/j.cnki.jynufe.000544>
- 1089 Maddison D (2006) Environmental Kuznets curves: A spatial econometric approach. *Journal of Environmental Economics*
1090 and Management 51:218–230. <https://doi.org/10.1016/j.jeem.2005.07.002>
- 1091 Oates WE, Schwab RM (1988) Economic competition among jurisdictions: Efficiency enhancing or distortion inducing.
1092 *Journal of Public Economics* 35(3):333–354. [https://doi.org/10.1016/0047-2727\(88\)90036-9](https://doi.org/10.1016/0047-2727(88)90036-9)
- 1093 Oyono PR (2005) Profiling local-level outcomes of environmental decentralizations: the case of Cameroon's forests in the
1094 Congo Basin. *Journal of Environment and Development* 14(2):1–21. <https://doi.org/10.1177/1070496505276552>
- 1095 Peng X (2016) Is environmental decentralization conducive to industrial green transformation in China? - Dynamic spatial
1096 effect test under the perspective of upgrading of industrial structure. *Industrial Economy Research* 2:21–31. (In Chinese)
1097 <https://doi.org/10.13269/j.cnki.ier.2016.02.003>
- 1098 Poon J, Casas I and He C (2006) The impact of energy, transport and trade on air pollution in China. *Eurasian Geography and*
1099 *Economics* 47(5):568–584. <https://doi.org/10.2747/1538-7216.47.5.568>
- 1100 Qi Y, Lu HY, Xu YK (2014) Research on reformation of China's environmental decentralization system: institutional change,
1101 numerical estimates and effects assessment. *China Industrial Economics* 1:31–43. (In Chinese)
1102 <https://doi.org/10.19581/j.cnki.ciejournal.2014.01.003>
- 1103 Ran QY, Zhang JN, Hao Y (2020) Does environmental decentralization exacerbate China's carbon emissions? Evidence based
1104 on dynamic threshold effect analysis. *Science of the Total Environment* 721:1–12.
1105 <https://doi.org/10.1016/j.scitotenv.2020.137656>
- 1106 Tan ZX, Zhang YY (2015) An empirical research on the relation between fiscal decentralization and environmental pollution.
1107 *China Population Resources and Environment* 25(4):110–117. (In Chinese)
1108 <https://doi.org/10.3969/j.issn.1002-2104.2015.04.014>
- 1109 Tian JG, Wang YH (2018) Spatial spillover effects between fiscal decentralization, local government's competition and
1110 carbon emissions. *China Population Resources and Environment* 28(10):36–44. (In Chinese)
1111 <https://doi.org/10.12062/cpre.20180511>
- 1112 Wang J, Zhang KZ (2014) Fiscal decentralization, officials and carbon emission: Evidence from the secretary of the CPC
1113 provincial committee and provincial governor. *Modern Finance and Economics* 34(9):3–14. (In Chinese)
1114 <https://doi.org/10.19559/j.cnki.12-1387.2014.09.001>
- 1115 Xiao R, Li YY (2014) Fiscal decentralization, financial expenditure and carbon emissions. *Soft Science* 28(4):21–24. (In

- 1116 Chinese) <https://doi.org/10.13956/j.ss.2014.04.005>
- 1117 Xue G, Pang XZ (2012) An empirical analysis on the impact of fiscal decentralization on environmental pollution in China.
- 1118 China Population Resources and Environment 22(1):1–7. (In Chinese)
- 1119 <https://doi.org/10.3969/j.issn.1002-2104.2012.01.013>
- 1120 Zhang H, Feng C, Liu GC (2017) Chinese-style environmental federalism: a study on the effect of environmental
- 1121 decentralization on carbon emissions. Journal of Financial and Economics 43(9):33–49. (In Chinese)
- 1122 <https://doi.org/10.16538/j.cnki.jfe.2017.09.003>
- 1123 Zhang HY, Wang W (2020) Threshold effect of China's industrial structure on carbon emissions: Based on provincial panel
- 1124 data. Southern Journal 4:41–43. (In Chinese) <https://doi.org/10.3969/j.issn.1004-1133.2020.04.013>
- 1125 Zhang K, Zhang Z, Liang Q (2017) An empirical analysis of the green pradox in China: from the perspective of fiscal
- 1126 decentralization. Energy Policy 103:203–211. <https://doi.org/10.1016/j.enpol.2017.01.023>
- 1127 Zhang KZ, Wang J, Cui XY (2011) Fiscal decentralization and environmental pollution: from the perspective of carbon
- 1128 emission. China Industrial Economics 10:65–75. (In Chinese) <https://doi.org/10.19581/j.cnki.ciejournal.2011.10.007>
- 1129 Zhang WJ, Ye AZ (2017) Research on the carbon emission perspective of environmental benefits of fiscal
- 1130 decentralization—based on semi-parametric panel of spatial lag model. Soft Science 31(1):72–75. (In Chinese)
- 1131 <https://doi.org/10.13956/j.ss.1001-8409.2017.01.16>
- 1132 Zhu Q, Peng XZ, Lu ZM (2010) Analysis model and empirical study of impacts from population and consumption on carbon
- 1133 emissions. China Population Resources and Environment 20(2):98–102. (In Chinese)
- 1134 <https://doi.org/10.3969/j.issn.1002-2104.2010.02.017>
- 1135 Zou X, Lei C, Hu C (2019) Environmental decentralization and regional green development. China Population Resources and
- 1136 Environment 29(6):97–106. (In Chinese) <https://doi.org/10.12062/cpre.20190116>