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Impacts of the ecological footprint on sustainable development: Evidence from China

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Abstract:

Sustainable development emphasizes the sustainability of natural resources and the environment. Under the background of resource scarcity and environmental constraints, it is of great significance to explore the impacts of the ecological footprint on the resource-rich but unbalanced China's Yangtze River Economic Belt from two perspectives of flow capital occupation and stock capital occupation. This study uses a fixed-effect regression model to investigate the impacts of ecological footprint breadth and depth on sustainable development by the panel data of 108 prefecture-level cities in China's Yangtze River Economic Belt from 2006 to 2018. Further combining the panel threshold regression model results, we identify ecological footprint breadth and depth as having inverted N-shaped and inverted U-shaped relationships with sustainable development. Firstly, there is a double threshold effect between ecological footprint breadth and sustainable development. Then, there is a single threshold effect between ecological footprint depth and sustainable development. When ecological footprint breadth is within the threshold of (0.2802, 0.7997), it is conducive to sustainable development. When ecological footprint depth is less than 2.5404, it is conducive to sustainable development. Secondly, ecological footprint breadth improves sustainable development of the Yangtze River Economic Belt by rationalizing and advancing industrial structure. Ecological footprint depth achieves sustainable development through rationalizing industrial structure. Thirdly, the mechanism of the ecological footprint on sustainable development has regional heterogeneity. Finally, this paper proposes several policy implications for achieving China's sustainable development.

Keywords: Ecological footprint breadth, Ecological footprint depth, Sustainable development, Panel threshold regression, China's Yangtze River Economic Belt

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33 1. Introduction

34 In the industrialization process, excessive exploitation and utilization of natural resources have led
35 to global environmental pollution and ecological destruction, thus posing a significant threat to human
36 survival and development (Mahmood et al., 2020). Environmental issues have become a major social
37 problem in developed and developing countries (Zhu et al., 2015; Korhonen et al., 2018; David et al.,
38 2021). As the largest developing country with the largest population globally, China's sustainable
39 development has become a key force in achieving the global Sustainable Development Goals. For the
40 fundamental purpose of maintaining the healthy growth between ecosystem and human beings, the
41 overall coordinated development of economy, politics, society, and ecological environment is included
42 in sustainable development (Liu et al., 2021). On the one hand, the ecological environment is the
43 material basis of economic development, so protecting the ecological environment continuously
44 improves productivity (Hu et al., 2020). In this way, under the background of rapid economic growth
45 and increasingly prominent contradiction between supply and demand of resources, it is imperative to
46 effectively ease the development pressure and promote sustainable development.

47 On the other hand, natural resource capital is increasingly becoming the critical factor restricting
48 sustainable development. Natural resource capital refers to the natural resources provided by the
49 ecosystem, which is divided into flow capital and stock capital (Dong et al., 2019). Specifically, flow
50 capital refers to the accumulation of natural capital in a certain period, reflecting the changing trend.
51 Stock capital refers to the total amount of natural capital at a certain point. The ecological footprint is
52 regarded as the "footprint" retained by human economic activities in the ecological environment,
53 reflecting the occupation of natural resources by economic development. The breadth of ecological
54 footprint demonstrates the occupation of flow capital, and the depth of ecological footprint
55 demonstrates the occupation of stock capital (Long et al., 2020). As a result, it is realistic to consider
56 the impact of natural resource utilization degree on sustainable development from the two dimensions
57 of ecological footprint breadth and ecological footprint depth.

58 Since sustainable development effectively alleviates the contradiction between an infinite demand
59 for human development and a limited natural resource (Bryan et al., 2018), it will become the new
60 direction of sustainable development of China's economy, especially the critical areas. At present,
61 China's Yangtze River Economic Belt has become an inland river economic belt with global influence.
62 It is the economic belt with the most vital economic strength and tremendous development potential in
63 China. By the end of 2020, the Yangtze River Economic Belt accounted for 43 percent of the country's
64 population and contributed nearly 40 percent of China's GDP and more than 80 percent of the country's
65 mineral reserves. So it is an important starting point to realize reasonable utilization of regional
66 resources and sustainable economic development. With urbanization and industrialization, resource and
67 energy consumption continues to increase, and China's Yangtze River Economic Belt is faced with a
68 serious ecological environment and uncoordinated development. In this context, sustainable
69 development is the central theme of China's economic growth in the new era and the latest direction of
70 the future. Therefore, exploring the path to promote the sustainable development of China's Yangtze
71 River Economic Belt is an urgent problem.

72 More and more scholars have explored sustainable development from a micro perspective (Liu et

73 al., 2020; Shao et al., 2020). They have studied the factors that influence sustainable development from
74 the perspective of enterprises. The advantage is that it reveals a micro-enterprise's inner workings, thus
75 providing more targeted arguments for formulating relevant policies. However, its potential defect may
76 lie in the particularity of sample selection, which cannot reflect the prevailing law of sustainable
77 development. Scholars have also carried out regional and industrial explorations (Carla et al., 2011;
78 Simone et al., 2016; Li et al., 2021). It is worth pointing out that Chen et al. (2020) found in their
79 research that regional scale and resources are conducive to improving innovation ability and
80 competitiveness. Jeffrey (2001) found that the financial market improved capital allocation from the
81 industry perspective. The higher the level of financial development, the higher the investment in
82 growing industries.

83 Furthermore, as sustainable development has gradually become a new way to solve the
84 contradiction between economic development and environmental pollution, the environmental problem
85 has also become a hot research object of scholars. Liu et al. (2020) and Hou et al. (2021) studied the
86 coordination degree among population, economy, space, and environment based on the coupling
87 coordination model. They found that the coupling coordination degree between ecological environment
88 and economic growth quality was low. As a primary condition for economic development and human
89 survival, resources and environment have become the focus of scholars increasingly, and the research
90 results show that resources and environment promote or hinder economic development (Sergei et al.,
91 2019; Ran et al., 2020; Zhang et al., 2020; Filippo et al., 2021). Because these studies are based on
92 different stages of resources and environment to explore their impact on economic development, it also
93 provides some ideas for the research design of this paper. In addition, the research on natural capital in
94 China's Yangtze River Economic Belt mainly focuses on land and water, forest land, grassland, wetland,
95 construction land, and the coordination degree of the carrying capacity of these natural capital and
96 ecological environment (Zhang et al., 2014; Qu et al., 2018; Tian et al., 2021). The results show that the
97 cultivated land area in the Yangtze River basin is decreasing, but the ecological environment in the
98 upper reaches is improving. In terms of ecological footprint, previous studies explored emissions from
99 the atmospheric, biospheric, lithospheric, and hydrospheric aspects of environmental degradations
100 (Usman et al., 2020). Long et al. (2020) evaluated the sustainable development of four major island
101 regions in China based on improved ecological footprint. The above literature shows that the
102 considerable scarcity of natural capital has restricted sustainable human development.

103 Consequently, there has been a focus on the relationship between the ecological environment and
104 sustainable development. However, it is more about the coordination between the two, and the research
105 on its internal logic is mostly reflected in the theoretical level, with less empirical analysis. Then, will
106 the different degrees of natural resources utilization in the Yangtze River Economic Belt affect the local,
107 sustainable development? Will it have other effects in different regions? What are the possible
108 pathways of action? An in-depth discussion on these issues will provide a theoretical basis for local
109 governments to formulate and implement effective environmental policies, which has important
110 theoretical and practical significance for China to achieve sustainable development. However, there is
111 no further empirical research into the internal relationship between resources and economic
112 development.

113 Therefore, this paper tries to contribute in the following aspects: (1) By studying the relationship
114 between ecological footprint and sustainable development, the importance of rational utilization of
115 resources is revealed. It provides a theoretical basis for local government to seek a win-win situation
116 between environmental protection and sustainable economic development. (2) Taking 108
117 prefecture-level cities in China's Yangtze River Economic Belt as research objects, the spatial panel
118 model is used to examine the impacts of ecological footprint breadth and ecological footprint depth
119 (hereafter referred to as footprint breadth and footprint depth) on sustainable development from the
120 perspective of natural resource utilization. The conclusions are consistent with scholars' analyses using
121 other regions or countries (Zhang et al., 2020; Filippo et al., 2021). It enriches relevant literature at the
122 margin and is conducive to proposing comprehensive and practical policy recommendations. (3) Based
123 on the data of prefecture-level cities, this study analyzes the potential mechanism of ecological
124 footprint affecting sustainable development, which is rarely covered by existing literature. This paper
125 focuses on how the ecological footprint affects sustainable development through the rationalization of
126 industrial structure and the advancement of industrial structure, and considers the different mechanisms
127 of the three regions in the east, the middle, and the west to reveal the profound relationship between the
128 ecological footprint and sustainable development, which provides a valuable supplement and
129 improvement for the existing literature.

130 The empirical results indicate that ecological footprints have different impacts on sustainable
131 development. When footprint breadth is between 0.2802 and 0.7997, and footprint depth is less than
132 2.5404, both are beneficial to sustainable development. Moreover, the effects vary from region to
133 region. Crucially, for the eastern region of China's Yangtze River Economic Belt, industrial structure
134 advancing is the main path of ecological footprint affecting sustainable development, technological
135 innovation level is mainly influenced path in the central region, and urbanization level is especially the
136 path of the western region.

137 The remainder of this paper is structured as follows. Section 2 details the methodology. Section 3
138 provides variables and data. Section 4 contains the results. Section 5 concludes this study and proposes
139 policy implications.

140

141 **2. Methodology**

142 **2.1 Panel threshold regression analysis**

143 Generally speaking, the utilization of natural resources has different effects on sustainable
144 development. At the beginning of the development cycle, the exploitation and utilization of resources
145 positively affect the ecological environment and social economy (Wu et al., 2018). However, with the
146 rapid development of the economy, extensive growth leads to excessive consumption of natural
147 resources. Therefore, natural resources become rigid constraints on sustainable development (Patricia et
148 al., 2005; Ren et al., 2021). In addition, policy guidance and market selection "force" industrial
149 structure transformation (Tao et al., 2010; Lu et al., 2020). As a result, footprint breadth and depth
150 effects on sustainable development show nonlinear characteristics. **Based on the above analysis,**
151 **referring to the spatial panel model in Jiang et al. (2021), the following panel regression model is built**
152 **as follows:**

$$ESD_{it} = \alpha_0 + \alpha_1 EF_{it} + \alpha_2 EF_{it}^2 + \alpha_3 EF_{it}^3 + \gamma X_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

154 where ESD is sustainable development. EF is the ecological footprint, divided into $EF_{breadth}$ and EF_{depth} .
 155 X is control variables affecting sustainable development. i and t are region and time, respectively. μ_i is
 156 regional fixation effect. ε_{it} is the random disturbance term.

157 To further explore the threshold of the ecological footprint on sustainable development, the above
 158 panel regression model is expanded into multiple threshold panel regression models with footprint
 159 breadth ($EF_{breadth}$) and footprint depth (EF_{depth}) as threshold variables, referring to the threshold
 160 regression model proposed by Hansen (1999):

$$ESD_{it} = \beta_1 REC_{it} I(EF_{size} \leq \eta_1) + \beta_2 REC_{it} I(\eta_1 < EF_{size} \leq \eta_2) + \dots + \beta_{n+1} REC_{it} I(EF_{size} > \eta_n) + \gamma_j X_{itj} + \mu_i + \varepsilon_{it} \quad (2)$$

$$ESD_{it} = \beta_1 REC_{it} I(EF_{depth} \leq \eta_1) + \beta_2 REC_{it} I(\eta_1 < EF_{depth} \leq \eta_2) + \dots + \beta_{n+1} REC_{it} I(EF_{depth} > \eta_n) + \gamma_j X_{itj} + \mu_i + \varepsilon_{it} \quad (3)$$

163 where $\eta_1, \eta_2, \dots, \eta_n$ is the first, second and n-th threshold value respectively. $I(\cdot)$ is an indicator
 164 function. $EF_{breadth}$ and EF_{depth} are threshold variables. The existence of the threshold effect depends on
 165 the estimated parameters β_1 and β_2 whether there is a significant difference. If there is a
 166 considerable difference, it indicates that the threshold effect exists; otherwise, it does not.

167

168 2.2 Mechanism test model

169 Referring to the mediating effect test method proposed by Zhao et al. (2010), this study explores
 170 how footprint breadth and footprint depth affect sustainable development. As an essential part of
 171 regulating resource allocation, industrial structure transformation integrates the elements of sustainable
 172 development so that it may play a bridge role between natural resource utilization and sustainable
 173 development. Therefore, this paper selects the rationalization of industrial structure (RIS) and
 174 advancement of industrial structure (AIS) as mediating variables. Based on Formula (1), the following
 175 test model is further structured:

$$ESD_{it} = i_1 + c_1 EF_{it} + c_2 EF_{it}^2 + c_3 EF_{it}^3 + \alpha_4 X_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

$$Z_{it} = i_2 + a_1 EF_{it} + a_2 EF_{it}^2 + a_3 EF_{it}^3 + \zeta X_{it} + \theta_i + \delta_{it} \quad (5)$$

$$ESD_{it} = i_3 + c_1' EF_{it} + c_2' EF_{it}^2 + c_3' EF_{it}^3 + bZ_{it} + \gamma_3 X_{it} + \rho_i + \omega_{it} \quad (6)$$

179 where, EF refers to $EF_{breadth}$ and EF_{depth} , respectively. Z is mediating variable, representing
 180 rationalization of industrial structure (RIS) and advancement of industrial structure (AIS). Other
 181 variables are the same as Formula (1).

182

183 2.3 The proposed integrated model for impacts of the ecological footprint on 184 sustainable development

185 This study proposes a research framework to explore whether and how ecological footprint affects

186 sustainable development and their influencing mechanisms and regional heterogeneity. The proposed
187 integrated model consists of three parts, as shown in Fig. 1.

188 Step 1: Measurement. Sustainable development is measured comprehensively by an index system
189 of six dimensions of economic development, innovation, coordination, green, openness, and sharing.
190 The core explanatory variables include footprint breadth and footprint depth, and the explained variable
191 includes the sustainable development level. The improved three-dimensional ecological footprint model
192 measures the footprint breadth and depth refer to Yang et al. (2018) research.

193 Step 2: Robustness test. The fixed-effect model is used to investigate the impacts of the ecological
194 footprint on sustainable development. To ensure the reliability of regression results, the instrumental
195 variable method and replacement of explained variables are used to conduct a robustness test. In
196 addition, a multiple threshold regression model with footprint breadth and footprint depth as threshold
197 variables is structured to test the threshold effect.

198 Step 3: Mechanism and heterogeneity analysis. To explore the mechanism of the ecological
199 footprint on sustainable development, two mediating variables, rationalization of industrial structure
200 and advancement of industrial structure, are introduced into building the mediating effect models.
201 Furthermore, the heterogeneity is tested in different regions. The regressions of prefecture-level cities
202 in China's Yangtze River Economic Belt are carried out according to the eastern, central, and western
203 regions, respectively.

204

205

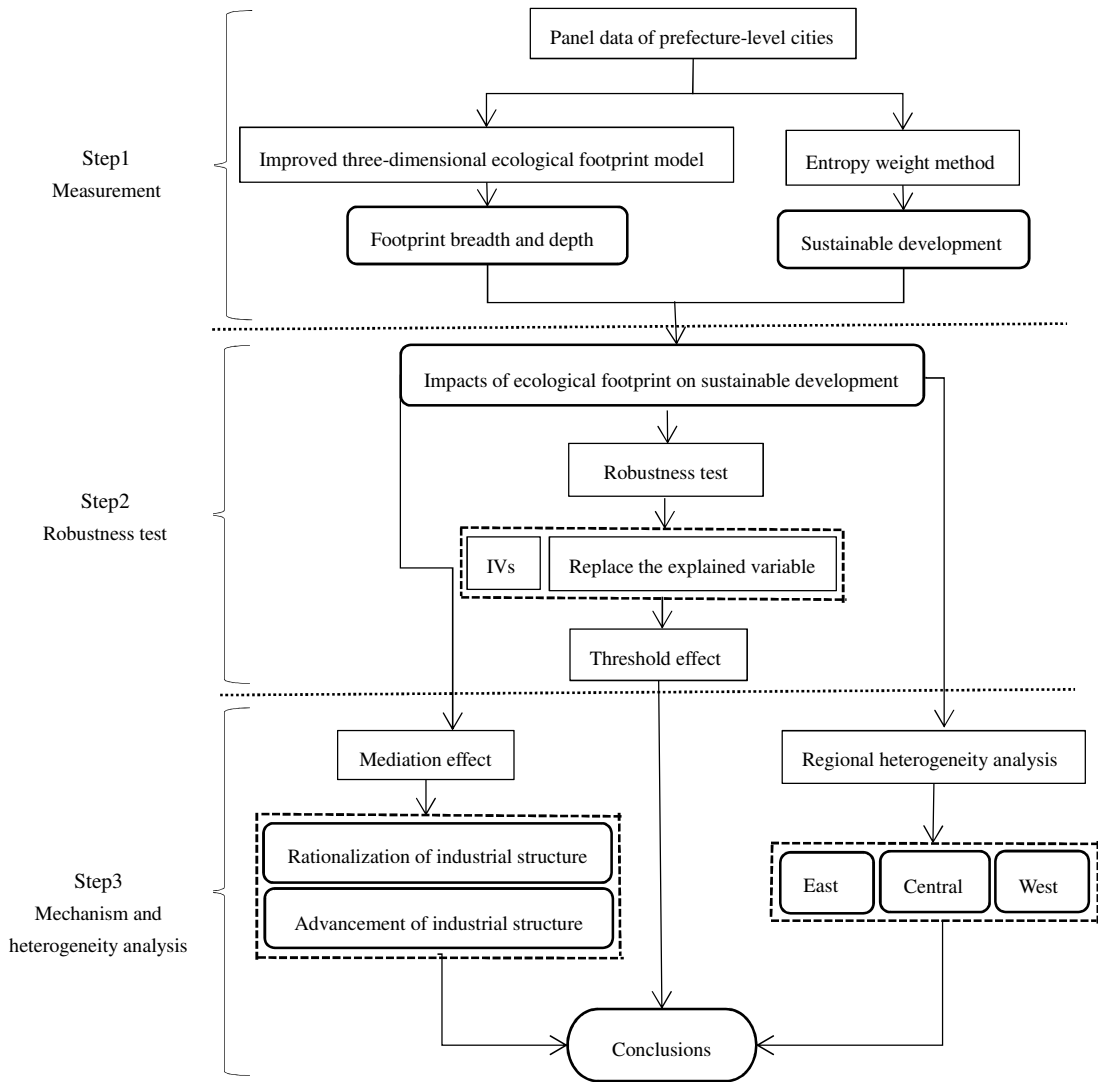


Fig. 1. The proposed integrated model for impacts of the ecological footprint on sustainable development.

3. Data

3.1 Explained (dependent) variable

Sustainable development is efficient, fair, and green development to meet people's ever-growing needs for a better life. The new development concept of “innovation, coordination, green, openness, and sharing” becomes an essence of sustainable development. Economic development is the material basis of regional sustainable development (Chen et al., 2021). So in this study, we define sustainable development as a certain speed of economic development coupled with efficient and high-quality development results. Specifically, economic development needs to consider both the development

245 achievements and the economic risks that may affect development (Falihat et al., 2020). Innovation is
 246 the primary driving force of sustainable urban development, and the improvement of innovation mainly
 247 depends on the progress of talents and technology (Chen et al., 2020). Therefore, this paper selects
 248 indicators from the input and output of innovation. Coordination is the inherent requirement of
 249 sustainable urban development, including urban and rural coordination and regional coordination.
 250 Green is the essential requirement of sustainable urban development. Therefore, we should hold the
 251 concept of sustainable development and solve the problems of environmental damage and resource
 252 waste caused by human activities. Openness is the key to the sustainable development of cities. With
 253 the continuous development of globalization and digitalization, cities need to integrate into the global
 254 governance system through external economic and cultural exchanges. Sharing is the cornerstone of
 255 sustainable urban development and a necessary condition for improving people's quality of life and
 256 happiness (Destek et al., 2020). In addition, concerning the selection of relevant indicators in existing
 257 studies (Fang et al., 2014; Xu et al., 2020), we measure sustainable development levels of 108
 258 prefecture-level cities in China's Yangtze River Economic Belt from six dimensions of economic
 259 development, innovation, coordination, green, openness, and sharing, as shown in Table 1.

260

261

262

263

Table 1. Sustainable development evaluation index system

Variable	Indicator	Definition
Sustainable development level	Economic growth rate (%)	(Current real GDP-Real GDP of the previous period)/Real GDP of the last period
	Per capita welfare level(Ten thousand yuan)	Real GDP/The population of permanent residents
	Economic volatility (%)	(Real GDP growth rate that year-Real GDP growth over the previous year)/Real GDP growth from a year earlier
	Unemployment rate (%)	Urban unemployment rate
	R&D (Ten thousand yuan)	R&D capital stock
	The growth rate of mobile Internet users (%)	Number of Internet subscribers/The total number of households
	Number of patents granted by ten thousand people	Number of patents granted/The total population
	Number of students in institutions of higher learning by 10,000 people(Ten thousand people)	Total number of students in institutions of higher learning/The total population
	Urban-rural income ratio (%)	Rural residents disposable income/Disposable income of urban residents
	Rationalization level of consumption structure (%)	Total retail sales of consumer goods/GDP

Green coverage of built-up areas (%)	Green coverage area of built-up area/built-up area
Per capita park green area(m ²)	Park green area/urban resident population
Level of environmental governance (%)	Household garbage harmless disposal rate Sewage treatment rate
Percentage of actually utilized foreign capital in GDP (%)	Actual utilization of foreign capital/GDP
The proportion of total imports and exports in GDP (%)	Total import and export/GDP
Number of inbound foreign tourists(Ten thousand people)	The number of foreign tourists received that year
The number of buses owned by 10,000 people	Number of buses/Number of permanent residents in towns
Medical beds for 10,000 people	Total number of medical beds/Urban resident population
Per capita funding for cultural programs(Ten thousand yuan)	Expenditure for cultural undertakings/Urban resident population
Per capita investment in fixed assets(Ten thousand yuan)	Total investment in fixed assets/Urban resident population

264

265 The evaluation index system in Table 1 measures the comprehensive index of sustainable
266 economic development of 108 prefecture-level cities in China's Yangtze River Economic Belt. The
267 weight assignment method commonly used in academia mainly includes subjective and objective
268 evaluations. The entropy method is one of the most common objective evaluation methods. Its basic
269 idea is to judge the importance of an index according to the degree of dispersion. If the dispersion
270 degree is larger, it indicates that the index has a more significant impact on the evaluation system, and
271 the index is given greater weight. Otherwise, the smaller the dispersion degree, the smaller the weight
272 (Zhao et al., 2020). The entropy method avoids the interference of human factors in the subjective
273 evaluation method and objectively reflects the importance of each index in the whole evaluation system.
274 The specific calculation steps are as follows: ① The data is processed dimensionless, and obtained
275 value is Z_j . Then, the index horizontal matrix is constructed and normalized to obtain the matrix R ,
276 $R = (r_{ij})_{m \times n}$. ② We quantify each index in the same degree and calculate the proportion of index j index
277 each prefecture-level city every year, namely P_{ij} , $P_{ij} = r_{ij} / \sum r_{ij}$. ③ We calculate the entropy of
278 index j , namely e_j , $e_j = -k \sum p_{ij} \ln p_{ij}$, $k = 1 / \ln m$. ④ The difference coefficient a_j of j is
279 calculated, $a_j = 1 - e_j$. ⑤ We calculate the weight of j . ⑥ We calculate the sustainable development
280 index according to formula $g_j = \frac{a_j}{\sum a_j}$, by referring to the measurement method of the United Nations
281 Human Development Index (HDI).

282 The green total factor productivity reflects sustainable development in the robustness test.
 283 Therefore, this paper uses the Data Envelopment Analysis (DEA) and Malmquist method to measure
 284 urban green total factor productivity, replacing the original explained variable. Moreover, the labor
 285 force (L), capital stock (K), and energy consumption (E) are the inputs. At the same time, the real gross
 286 domestic product serves as the desired output, and CO₂ emissions from fossil-fuel energy consumption
 287 as the unwanted output. L is the sum of the number of units employed, private and self-employed at the
 288 end of the year in each prefecture-level city. K draws on the method of Dmitry and Alexander (2021)
 289 and uses the perpetual inventory method to estimate capital stock over the years. Energy consumption
 290 is given by fossil-fuel consumption, measured in tons of coal equivalent. Because no special
 291 department exists to account for the urban energy consumption, the relevant data of urban fossil-fuel
 292 consumption are not extensive.

293 In contrast, the urban household gas consumption and family consumption of liquefied petroleum
 294 gas are more complete data. The CO₂ emissions are measured by multiplying the quantity of the urban
 295 household gas consumption and family consumption of liquefied petroleum gas; detailed measuring
 296 methods and steps are presented in Li (2016). Data are obtained from China City Statistical Yearbook
 297 2006-2019 and China Energy Statistical Yearbook 2006-2019. All data are converted into in constant
 298 price of 2000.

299

300 **3.2 Explanatory (independent) variables**

301 Ecological footprint, as a critical indicator of sustainable utilization of resources and the
 302 environment, refers to the geographical space with biological production capacity that maintains the
 303 necessary resources for human activities and consumes waste (Zahoor et al., 2020). The utilization of
 304 resources can be studied from two aspects: the occupation of flow capital (denoted by footprint breadth)
 305 and the consumption of stock capital (represented by footprint depth) (Yang et al., 2018; Xun et al.,
 306 2019; Long et al., 2020). The improved three-dimensional model considers footprint breadth and
 307 footprint depth as two components of spatial cross-section and time axis to study the utilization of
 308 natural capital (Bi et al., 2021). Based on the existing classical model, the improved three-dimensional
 309 model realizes the classification and measurement of flow capital and stock capital by adding
 310 dimension and further extends the regional scale of the existing three-dimensional model to the specific
 311 biological productive land below the region. Therefore, the improved three-dimensional ecological
 312 footprint model is adopted to measure footprint breadth and footprint depth.

$$313 \quad EF_{breadth,region} = \sum_{i=1}^n \min\{EF_i, BC_i\} \quad (7)$$

$$314 \quad EF_{depth,region} = 1 + \frac{\sum_{i=1}^n \max\{EF_i - BC_i, 0\}}{\sum_{i=1}^n BC_i} \quad (8)$$

$$315 \quad EF_{3D,region} = EF_{breadth,region} \times EF_{depth,region} \quad (9)$$

316 where, $EF_{breadth,region}$ is footprint breadth. $EF_{depth,region}$ is footprint depth. $EF_{3D,region}$ is

317 three-dimensional ecological footprint. i is land type. EF_i 、 BC_i are the ecological footprint and the
318 biological capacity of different land types, respectively.

319 The improved three-dimensional ecological footprint model involves six land types: cultivated
320 land, woodland, grassland, and water land belonging to biological resource consumption, fossil fuel
321 land, and building land belonging to energy consumption. Considering the actual situation of
322 prefecture-level cities in China's Yangtze River Economic Belt and data availability, this paper selects
323 37 indicators corresponding to different land types to represent the six productive land types. The land
324 area data are mainly obtained from the Comprehensive Statistical Annual Report of Land and
325 Resources and the application service platform of land survey results sharing. Refer to the urban
326 environmental quality bulletin and water resources bulletin. We use relevant websites to obtain land
327 and water data. The output data of different land types are mainly derived from China Urban Statistical
328 Yearbook 2006-2019. In addition, the productivity of different land types varies greatly. **To compare the
329 ecological footprint and carrying capacity of the six land types, the equilibrium factor and yield factor
330 corresponding to each land type are multiplied in the calculation. The yield factor is derived from Wang
331 et al.'s (2020) research, and the equilibrium factor is derived from the National Ecological Footprint
332 Account in 2018 (Maria et al., 2018).** Then, combined with the principle of threshold variable selection,
333 footprint breadth and footprint depth are respectively taken as threshold variables to test whether they
334 have threshold effects on sustainable development and the possible threshold values.

335

336 **3.3 Control variables**

337 We consider control variables in addition to the core variables such as footprint breadth, footprint
338 depth, and sustainable development. Referred to the existing literature (Roger et al., 2021; Yu et al.,
339 2021), this paper further introduces human capital level (hcl), market degree (market), and
340 infrastructure (infra) to control the impacts of the ecological footprint on sustainable development. The
341 reasons are as follows: The improvement of human capital enhances the acquisition and application of
342 knowledge, technology, and all kinds of information by innovation subjects, and this improves the
343 efficiency of innovation (Yu et al., 2021). Therefore, the level of human capital has an essential impact
344 on the quality of economic development. This paper uses the per capita education years to measure the
345 human capital level (hcl). The degree of marketization reflects the ability of the market to regulate the
346 allocation of resources. A higher degree of marketization is beneficial to weaken the distorting effect of
347 resource allocation and improve the economy's overall natural resource utilization efficiency. This
348 boosts green total factor productivity (Lu et al., 2020). In this paper, the proportion of the number of
349 private and self-employed persons in the total population represents the degree of marketization
350 (market). Infrastructure (Infra) plays an essential role in the sustainable development of China's
351 economy (Lin, 2016). It is generally measured by the per capita kilometers of each prefecture-level city.
352 The data are mainly obtained from the Statistical Yearbook of Chinese Cities 2006-2019.

353

354 **3.4 Mediator variables**

355 To reveal the internal mechanism of the ecological footprint on sustainable development, this
356 paper explores its potential mediating effect from the perspective of urban industrial structure

357 transformation. For mediator variables, the rationalization and advancement of the industrial structure
 358 are selected by referring to the research of Li et al. (2017). Industrial structure rationalization

359
$$RIS_{it} = 1 - \frac{1}{3} \sum_{i=1}^3 \left| \frac{Y_{it}}{Y_t} - \frac{L_{it}}{L_t} \right|$$
, where Y is output. L is the number of people employed. $\frac{Y_{it}}{Y}$ is the

360 proportion of the added value of the three industries in the total output value. $\frac{L_{it}}{L}$ is the proportion of

361 employment in the three industries in the total employment. Advancement of industrial structure

362
$$AIS_{it} = \sum_{i=1}^3 i \frac{Y_{it}}{Y_t}$$
, where $\frac{Y_{it}}{Y_t}$ is the proportion of the added value of industry i in the year t in the total

363 output value. The data are obtained from China City Statistical Yearbook 2006-2019.

364 Table 2 reports the descriptive statistics for all the variables. It is found that the mean value of
 365 sustainable development is 0.3633, the standard deviation is 0.0819, the minimum value is 0.0042, and
 366 the maximum value is 0.5398, which indicates the sustainable development level of China's Yangtze
 367 River Economic Belt is still at a relatively low level. There are significant differences in the sustainable
 368 development of different prefecture-level cities. The maximum footprint breadth is 0.5523. The
 369 minimum footprint breadth is 0.0508. The maximum footprint depth is 36.7420, and the minimum
 370 footprint depth is 2.3189. The above analysis means significant differences in the utilization of natural
 371 resources among the prefecture-level cities. The above study provides an objective basis and entry
 372 point for the follow-up research on the impacts of the ecological footprint on sustainable development.

373

374

Table 2. Descriptive statistics

Variables	Variable declaration	Mean	SD	Min	Max
<i>ESD</i>	Sustainable development	0.3633	0.0819	0.0042	0.5398
<i>EF_{depth}</i>	Footprint depth	6.1912	3.9214	2.3189	36.7240
<i>EF_{breadth}</i>	Footprint breadth	0.3752	0.1081	0.0508	0.5532
<i>hcl</i>	Human capital level	9.7420	0.9741	5.9232	13.5614
<i>market</i>	Marketization degree	0.3245	0.1251	0.0677	0.8274
<i>infra</i>	Infrastructure	23.5443	14.6910	8.8534	58.2353
<i>RIS</i>	Rationalization of industrial structure	0.7449	0.0571	0.7010	0.9172
<i>AIS</i>	Advancement of Industrial structure	1.2983	0.6471	0.5880	4.0136

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377 4. Results and discussion

378 4.1 Baseline regression results

379 To avoid the multicollinearity problem, all variables' correlation analyses were first carried out. It
 380 is found that the correlation coefficients are all within (-0.5, 0.5), indicating that there is no
 381 multicollinearity problem among the variables. The F-test results show that the fixed-effect is better
 382 than mixed OLS, and the Hausman test results show that the fixed-effect model is more effective than

383 the random-effect model in estimating parameters. So the fixed effect is used for regression. From
384 Model 1 to Model 4, control variables are gradually added, respectively, and the results are shown in
385 Table 3. It can be found that after the introduction of control variables, the regression coefficient of the
386 first-order item of footprint breadth is significantly negative at the level of 10%. The regression
387 coefficient of the square item is significantly positive at the level of 5%, and the regression coefficient
388 of the cubic item is significantly negative at the level of 5%. It shows that there is an inverted N-shaped
389 relationship between footprint breadth and sustainable development, which is “first decreased, then
390 increased and then decreased”. In addition, regardless of whether the control variables are introduced,
391 the regression coefficient of the first term of footprint depth is significantly positive at the level of 1%.
392 The regression coefficient of the square term is significantly negative at the level of 1%, but the
393 regression coefficient of the cubic term does not pass the significance test. It shows an inverted
394 U-shaped relationship between footprint depth and sustainable development, which increases first and
395 then decreases.

396 Further from Model 4, it is found that sustainable development level will decrease by 0.2498% on
397 average when footprint breadth increases by 1%. However, with the continuous increase of footprint
398 breadth, when it is in the “Pareto optima” of natural resource utilization and sustainable development,
399 sustainable development level will increase by 0.4457% on average when footprint breadth increases
400 by 1%. However, when footprint breadth exceeds the second inflection point, sustainable development
401 level will decrease by 0.2635% on average when footprint breadth rises by 1%. On the other hand,
402 sustainable development level increases by 0.0101% when footprint depth increases by 1%. However,
403 when footprint depth exceeds the critical value, the sustainable development level will decrease by
404 0.0020% when it increases by 1%. **The reason may be that, in the early stage of economic development,**
405 **the industrial supporting system is not perfect, the public service is not excellent. Faced with the dual**
406 **constraints of emission reduction pressure and economic development demands, local governments**
407 **choose industries with high pollution and high energy consumption to drive economic growth. The**
408 **transfer of polluting industries inhibits the technological innovation of enterprises. It aggravates the**
409 **deterioration of the environment in the undertaking areas and the massive consumption of resources,**
410 **which is not conducive to improving the environment and the quality of economic life growth. With the**
411 **continuous increase of footprint breadth, the input of factors is increasingly close to the optimal**
412 **combination ratio, thus stepping into the win-win stage of ecological environment and sustainable**
413 **development. When the flow capital is constantly used, the rigid constraints of resources will lead to**
414 **unreasonable industrial spatial layout, especially when the stock capital is excessively consumed and**
415 **close to or even exceeds the ecological carrying capacity, which is not conducive to sustainable**
416 **development.**

417 In addition, in terms of control variables, the impacts of human capital, marketization degree, and
418 infrastructure on sustainable development should not be ignored. Among them, the regression
419 coefficient of human capital level is significantly positive at the level of 5%. This is because the
420 increase in the proportion of high-quality talents is conducive to the efficient and sustainable
421 development of all walks of life. The coefficients of marketization degree and infrastructure are both
422 significantly positive at the level of 1%, indicating that marketization degree and infrastructure are also

423 very important for sustainable development. This is because marketization is the internal driving force
424 of economic development. The higher the degree of marketization is, the better it is to solve the
425 problem of inefficient or ineffective resource allocation in economic development. In this way, it
426 effectively improves the efficiency of resource integration and market expansion and realizes
427 sustainable development (Lu et al., 2020). Infrastructure is the cornerstone of sustainable development.
428 Therefore, improving infrastructure construction is critical to promoting sustainable development (Lin,
429 2016).

430

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Table 3. Baseline regression results

Variables	Model 1	Model 2	Model 3	Model 4
$EF_{breadth}$	-0.2437 (0.1879)	-0.24380* (0.1880)	-0.2437* (0.1884)	-0.2498* (0.1890)
$EF_{breadth}^2$	0.4332* (0.2562)	0.4331* (0.2557)	0.4333* (0.2568)	0.4457** (0.2568)
$EF_{breadth}^3$	-0.2116** (0.2073)	-0.2117* (0.2052)	-0.2119* (0.2097)	-0.2635** (0.2139)
EF_{depth}	0.0125*** (0.0019)	0.0122*** (0.0016)	0.0121*** (0.0015)	0.0101*** (0.0011)
EF_{depth}^2	-0.0017** (0.0006)	-0.0017*** (0.0007)	-0.0017*** (0.0007)	-0.0020*** (0.0008)
EF_{depth}^3	-0.0066 (0.0047)	-0.0072 (0.0055)	0.0216 (0.083)	-0.0547 (0.077)
<i>hcl</i>		0.0055** (0.0013)	0.0053* (0.0012)	0.0054** (0.0013)
<i>market</i>			0.0138** (0.0061)	0.0138*** (0.0062)
<i>infra</i>				0.0172*** (0.0074)
Constant	0.0226*** (0.0102)	0.1045*** (0.0824)	0.1131*** (0.0889)	0.0762*** (0.0371)
City effect	Yes	Yes	Yes	Yes
Year effect	Yes	Yes	Yes	Yes
<i>N</i>	1404	1404	1404	1404
R^2	0.1346	0.1346	0.1349	0.1377

432 Note: *, ** and *** indicate significant at the level of 10%, 5% and 1%, respectively. Standard
433 errors are in parentheses, the same as below.

434

435 4.2 Robustness test

436 Firstly, we use the instrumental variable method (IV_s) to solve the endogeneity problem.

437 According to the correlation and exogenous conditions that the effective instrumental variable needs to
438 meet, this study selects the footprint breadth lagging one period as the instrumental variable IV_1 .
439 Meanwhile, the activities of prefecture-level cities are easily influenced by the same activities in their
440 surrounding areas (Liu et al., 2017). The mean footprint depths of other cities in the eastern, central,
441 and western regions are calculated. They are used as the instrumental variable IV_2 for the local
442 footprint depth to solve the resulting bias caused by endogeneity.

443 The results of the under-recognition test (P-value of LM statistic is 0.04) and the weak
444 instrumental variable test (F statistic of Wald test is 37.14) both indicate that the above IV_s are effective.
445 Further, 2SLS is used for regression, and results are shown in Table 4. Model 5 and Model 6 are the
446 first and second stages, respectively. For IV_1 , the inverted N-shaped relationship between footprint
447 breadth and sustainable development is still credible. For IV_2 , the regression coefficient of model 5 is
448 positive at the level of 1%, indicating a significant correlation between IV_2 and footprint depth. In
449 model 6, the first-order regression coefficient of ecological footprint depth is significantly positive at
450 the level of 1%. Still, the regression coefficient of its square term is significantly negative, indicating
451 that the inverted U-shaped relationship between the footprint depth and sustainable development is still
452 credible. Therefore, the results of the endogeneity test are consistent with the baseline regression results.
453 This shows that the results of baseline regression are robust.

454 Secondly, to further ensure the robustness of the research results, green total factor productivity of
455 cities is used to replace the explained variables for testing. In addition, urban economic activities are
456 usually constrained by the technological frontier. To reveal the dynamic changes of green total factor
457 productivity, DEA-Malmquist is adopted to measure it by referring to Tang et al.'s (2017) research
458 ideas. The regression results are shown in Table 4. Model 7 controls the year, and model 8 controls the
459 year and city. The fixed effect regression results show that the relationship between footprint breadth
460 and sustainable development is “suppression-promotion-suppression”. The relationship between
461 footprint depth and sustainable development is “promotion-suppression”. Again, this proves that the
462 conclusions of this paper are robust.

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Table 4. Robustness test results

Variables	Model 5	Model 6	Model 7	Model 8
$EF_{breadth}$		-0.2413* (0.1152)	-0.2124** (0.1672)	-0.2230** (0.1871)
$EF_{breadth}^2$		0.4104** (0.1347)	0.3531* (0.2106)	0.4047** (0.2138)
$EF_{breadth}^3$		-0.2119** (0.0972)	-0.1821* (0.1952)	-0.2209* (0.2133)
IV_1	0.3710* (0.1904)			
EF_{depth}		0.0108*** (0.0044)	0.0072** (0.0011)	0.0108** (0.0024)
EF_{depth}^2		-0.0007*** (0.0008)	-0.0021*** (0.0005)	-0.0035*** (0.0008)
IV_2	0.1301*** (0.0172)			
Control variables	Yes	Yes	Yes	Yes
City effect	Yes	Yes	Yes	Yes
Year effect	Yes	Yes	Yes	Yes
N	1404	1404	1404	1404
R^2	0.1374	0.1379	0.1102	0.1105

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4.3 Threshold effect analysis

469 The previous fixed effect results show that footprint breadth and sustainable development present
 470 an inverted N-shaped relationship, and footprint depth and sustainable development present an inverted
 471 U-shaped relationship. However, the inflection points of their effects on sustainable development are
 472 still not clear. Therefore, this study uses the panel threshold effect model to explore further the
 473 threshold values of footprint breadth and footprint depth on sustainable development.

474 Firstly, we determined the threshold number and threshold value. Table 5 reports the test results of
 475 the panel threshold model. From Table 5, the F-statistic of footprint breadth rejects the original
 476 hypothesis at the significance level of 10% successively. This indicates that there is a double threshold
 477 effect on sustainable development. The F statistic of footprint depth significantly rejects the original
 478 hypothesis at the significance level of 10%, indicating a single threshold effect on sustainable
 479 development.

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Table 5. Panel threshold model test results

Threshold variables	Hypothesis testing	F statistic	Critical values for different levels of significance		
			90%	95%	99%
$EF_{breadth}$	H ₀ : There's no threshold	14.13*	9.153	15.722	21.426
	H ₁ : There's a threshold				
	H ₀ : There's a threshold	17.42*	15.429	18.026	22.714
	H ₁ : There are two thresholds				
	H ₀ : There are two thresholds	19.60	17.336	19.051	23.522
	H ₁ : There are three thresholds				
EF_{depth}	H ₀ : There's no threshold	21.44*	20.417	21.782	24.339
	H ₁ : There's a threshold				
	H ₀ : There's a threshold	20.07	19.482	21.446	26.725
	H ₁ : There are two thresholds				
	H ₀ : There are two thresholds	22.32	22.421	25.711	29.641
	H ₁ : There are three thresholds				

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According to the above test results, the double threshold effect model of footprint breadth on sustainable development and the single threshold model of footprint depth on sustainable development are respectively structured to analyze, as shown in Table 6. The estimated values of double threshold variables for footprint breadth are 0.2802 and 0.7997, respectively. The single threshold value for footprint depth is 2.5404.

Table 6. Threshold estimation results and confidence interval

Threshold variables	The value of the threshold estimate	95% confidence interval
$EF_{breadth}$ the first threshold	0.2802*	[0.2761, 0.2842]
$EF_{breadth}$ the second threshold	0.7997*	[0.7883, 0.7998]
EF_{depth} the threshold value	2.5404**	[1.9722, 2.7641]

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Secondly, after determining the threshold value, the threshold effect regression is carried out, the results are shown in Table 7. The impact of footprint breadth on sustainable development is a nonlinear relationship. With the increase of footprint breadth, sustainable development presents an inverted N-shaped trend of "down-up-down". The thresholds are 0.2802 and 0.7997, respectively. The estimation coefficient is significantly negative when footprint breadth is less than 0.2802 (-0.2531). When footprint breadth is between 0.2802 and 0.7997, the estimated coefficient is significantly positive

502 at the significance level of 10% (0.3042). Furthermore, when footprint breadth greater than 0.7997, the
503 estimated coefficient is significantly negative (-0.2191). In addition, footprint depth and sustainable
504 development show an inverted U-shaped relationship of “promotion-suppression”. The threshold value
505 is 2.5404. When footprint depth is less than 2.5404, the regression coefficient is significantly positive at
506 the significance level of 5% (0.0214). The regression coefficient is significantly negative when the
507 footprint depth is greater than 2.5404 (-0.0038). This is because China's Yangtze River Economic Belt
508 has prominent regional characteristics, and natural resources are unevenly distributed. Under the
509 constraints of resources and environment, the continuous increase of footprint breadth and footprint
510 depth will ultimately be not conducive to sustainable development. At present, some cities in China’s
511 Yangtze River Economic Belt (some cities in Yunnan, Guizhou, and Sichuan) realize the rational use of
512 natural capital, which promotes their sustainable development. This further indicates that it is necessary
513 to explore the impact of an ecological footprint on sustainable development.

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Table 7. Panel threshold parameter estimation results

Variables	Model 9	Model 10
Constant	0.0527**(2.0172)	0.0612**(2.1337)
<i>labor</i>	0.0062**(2.0196)	0.0074**(1.944)
<i>market</i>	0.0023**(1.7815)	0.0024**(1.783)
<i>infra</i>	0.0184**(1.922)	0.0201**(2.0542)
$REC(EF_{breadth} < \gamma_1)$	-0.2531*(-3.074)	
$REC(\gamma_1 \leq EF_{breadth} < \gamma_2)$	0.3042*(3.098)	
$REC(EF_{breadth} > \gamma_2)$	-0.2191**(-1.9643)	
$REC(EF_{depth} \leq \gamma)$		0.0214**(2.1208)
$REC(EF_{depth} > \gamma)$		-0.0038**(-1.825)
R^2	0.1391	0.1387

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Note: ***, ** and * denote passing significance test at the level of 1%, 5% and 10%, respectively;

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The corresponding values in parentheses are T values.

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4.4 Heterogeneity analysis

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The Yangtze River Economic Belt consists of three eastern, central, and western China regions.

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There are significant differences among the three regions in population concentration, industrial

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structure, science, technology, education, and natural resources. Therefore, the impact of the ecological

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footprint on sustainable development may be heterogeneous. Table 8 reports the regression results for

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different regions. Model 11, model 12, and model 13 are the regression results of the eastern, central,

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and western regions, respectively. It can be found that the impact of footprint breadth on sustainable

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development in Eastern China is an inverted N-shaped of “restraint-promotion-restraint”. The effect of

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footprint depth on sustainable development presents an inverted U-shaped curve of

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“promotion-suppression”. For the central region, the impact of footprint breadth on sustainable

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development is also an inverted N-shaped.

530 On the contrary, the impact of footprint depth shows an N-shaped relationship of
 531 “promotion-inhibition-promotion”. For the western region, the impact of footprint breadth on
 532 sustainable development shows an inverted U-shaped relationship of “promoting - inhibiting”, and
 533 footprint depth only has a significant promoting effect on sustainable development. The reason may be
 534 that the central and western regions of China’s Yangtze River Economic Belt are rich in natural
 535 resources and occupy a large area of arable land. Therefore, the rational utilization of resources is
 536 conducive to the sustainable development of some cities in western China.

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Table 8 Regression results by regions

Variables	Model 11	Model 12	Model 13
$EF_{breadth}$	-0.2993** (0.2041)	-0.2488* (0.2018)	-0.2416 (0.2015)
$EF_{breadth}^2$	0.3723* (0.3180)	0.4409** (0.3905)	0.4432** (0.3912)
$EF_{breadth}^3$	-0.1537* (0.1481)	-0.2599* (0.2339)	-0.2704** (0.2290)
EF_{depth}	0.0104* (0.0104)	0.0119** (0.0125)	0.0127** (0.0140)
EF_{depth}^2	-0.0023** (0.0011)	-0.0019* (0.0009)	-0.0012 (0.0009)
EF_{depth}^3	0.0052 (0.0070)	0.0001* (0.0027)	-0.0020 (0.0034)
<i>labor</i>	0.0072*** (0.0053)	0.0068** (0.0049)	0.0049** (0.0045)
<i>market</i>	0.0143** (0.0097)	0.0135** (0.0089)	0.0133* (0.0086)
<i>infra</i>	0.0344** (0.0214)	0.0306** (0.0178)	0.0166* (0.0104)
Constant	0.0422** (0.0470)	0.0325** (0.0400)	0.0179** (0.0283)
R^2	0.1197	0.1203	0.1202

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540 **4.5 Mechanism test results**

541 The baseline regression results show that when the footprint breadth is between 0.2802 and 0.7997,
 542 and footprint depth is less than 2.5404, ecological footprint significantly promotes sustainable
 543 development. The rationalization of industrial structure (*RIS*) and the advancement of the industrial
 544 structure (*AIS*) are selected as mediating variables to investigate their mechanisms further.

545 According to the mediating effect analysis method proposed by Zhao et al. (2010), the Bootstrap
 546 proposed by Preacher and Hayes (2004) is used to test the mediating effect. The sample size is 5000.
 547 The mediating effect test results are shown in Table 9. Model 14 and Model 15 are the influences of
 548 independent variables and mediating variables on the dependent variable. Model 16 offers the effects of
 549 independent variables on the dependent variable after controlling the mediating variables. From Table 9,
 550 the interaction terms between footprint breadth and rationalization of industrial structure and the
 551 interaction items between footprint depth and rationalization of industrial structure promote sustainable
 552 development significantly. The interaction terms between footprint breadth and advancement of
 553 industrial structure promote sustainable development.

554 Furthermore, both footprint breadth and footprint depth significantly promote sustainable
 555 development after controlling industrial structure rationalization and industrial structure advancement.

556 According to the principle of mediating effect, this indicates that the rationalization and advancement
557 of industrial structure play a mediating role between footprint breadth and sustainable development.
558 Rationalization of the industrial structure plays a mediating role between footprint depth and
559 sustainable development. The results are consistent with the theoretical expectation. With the increase
560 of flow capital occupation, factors input and output tend to rationalize, the degree of mutual
561 coordination among industries increases, and the unreasonable industrial structure is adjusted. However,
562 when the flow of capital consumption further increases and cannot meet local economic development
563 needs, it needs to consume the stock capital. This will accelerate the evolution of the industrial
564 structure from the primary industry to the second and third industries. The industrial structure is
565 constantly optimized (that is, the advancement of the industrial structure). The advancement of the
566 industrial structure and the rationalization of industrial structure respectively examine the industrial
567 added value and the coordination degree among industries. Therefore, it will promote regional
568 sustainable development. Thus, the industrial structure transformation is an important carrier and key
569 link for rational utilization of resources to boost the sustainable development of China's Yangtze River
570 Economic Belt.

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Table 9. Mediating effect test results

Variables	Model 14	Model 15	Model 16
$EF_{breadth}$ $\times RIS$	0.0200*		
$EF_{breadth}^2$ $\times RIS$	0.0178**		
$EF_{breadth}^3$ $\times RIS$	0.0136*		
$EF_{depth} \times RIS$	0.0120**		
$EF_{depth}^2 \times RIS$	0.0011*		
$EF_{breadth}$ $\times AIS$		0.0224*	
$EF_{breadth}^2$ $\times AIS$		0.0222**	
$EF_{breadth}^3$ $\times AIS$		0.0183*	
$EF_{depth} \times AIS$		0.0211	
$EF_{depth}^2 \times AIS$		0.0014	
$EF_{breadth}$			-0.2177*
$EF_{breadth}^2$			0.4701**
$EF_{breadth}^3$			-0.2643**
EF_{depth}			0.1066***
EF_{depth}^2			-0.0016***

Control variables	Yes	Yes	Yes
<i>N</i>	1404	1404	1404
<i>R</i> ²	0.1355	0.1374	0.1374

573 Note: *, ** and *** are significant at the level of 10%, 5% and 1%, respectively. Standard errors
574 are in parentheses.

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576 Furthermore, the influence paths of the eastern, central, and western regions are considered. The
577 environmental effect of industrial structure adjustment in Eastern China is better than that in central and
578 Western China (Milligan and Michelle, 2018). Therefore, the advancement of industrial structure (*AIS*)
579 is selected as a mediating variable in the eastern region. In the overall economic development of China,
580 the central region has the geographical advantage of connecting the east and the west. It has developed
581 rapidly in recent years and has become a new highlight of regional innovation and development
582 (Shunsuke and Shinji, 2009; Wang et al., 2019). Therefore, technological innovation level (*TIL*) is
583 selected as a mediating variable in the central region. *TIL* is the number of patent applications. In
584 recent years, the level of urbanization in western China has been dramatically improved, but there is
585 still much room for development (Zheng and Patrick, 2019). Therefore, we take urbanization level
586 (*URB*) as a mediating variable in western China. *URB* is the urban resident population / total
587 population. Model 17 and Model 18 are the eastern mediating effect regression results. Model 19 and
588 Model 20 are the regression results of the central region mediating effect. Models 21 and Model 22 are
589 the regression results of the western mediating effect. From Table 10, footprint breadth and depth in the
590 eastern region improve sustainable development by advancing the industrial structure. For the central
591 region, footprint breadth and depth affect technological innovation and improve sustainable
592 development. For the western region, footprint breadth and depth improve the region's sustainable
593 development by influencing urbanization. It can be found that the influence paths of the ecological
594 footprint on sustainable development are different in different regions.

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Table 10. Mediating effect test results by regions

Variables	Model 17	Model 18	Variables	Model 19	Model 20	Variables	Model 21	Model 22
$EF_{breadth}$	0.0413**		$EF_{breadth}$	0.0277*		$EF_{breadth}$	0.0104*	
$\times AIS$			$\times TIL$			$\times URB$		
$EF_{breadth}^2$	0.0392*		$EF_{breadth}^2$	0.0049*		$EF_{breadth}^2$	0.0047*	
$\times AIS$			$\times TIL$			$\times URB$		
$EF_{breadth}^3$	0.0377*		$EF_{breadth}^3$	0.0063		$EF_{breadth}^3$	0.0125	
$\times AIS$			$\times TIL$			$\times URB$		
EF_{depth}	0.0510**		EF_{depth}	0.0188**		EF_{depth}	0.0322**	
$\times AIS$			$\times TIL$			$\times URB$		
EF_{depth}^2	0.0334*		EF_{depth}^2	0.0070*		EF_{depth}^2	0.0190	
$\times AIS$			$\times TIL$			$\times URB$		
$EF_{breadth}$		-0.2172**			-0.3246*			-0.2620
$EF_{breadth}^2$		0.2744**			0.3025**			0.0437**
$EF_{breadth}^3$		-0.1160*			-0.4466*			-0.1742**
EF_{depth}		0.0154*			0.0219**			0.0332**
EF_{depth}^2		-0.0202*			-0.0343			-0.0042
Control variables	Yes	Yes	Control variables	Yes	Yes	Control variables	Yes	Yes
N	325	325	N	676	676	N	403	403
R^2	0.1310	0.1313	R^2	0.1322	0.1323	R^2	0.1316	0.1316

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599 5. Conclusions and policy implications

600 This paper links natural resource utilization to sustainable development, selects 108
601 prefecture-level cities in China's Yangtze River Economic Belt as the research objects and uses spatial
602 econometric models to examine the impacts of footprint breadth and depth on sustainable development.
603 Based on baseline regression, the threshold values and the possible effect paths are further discussed
604 using the threshold regression model and mediating effect model, and regional heterogeneity is also
605 considered. The main conclusions are as follows: firstly, the impacts of footprint breadth and footprint
606 depth on sustainable development are shown as inverted N-shaped and inverted U-shaped, respectively.
607 The IV_s and substitution of explained variables show that the conclusions are still robust. Footprint
608 breadth has a double threshold effect on sustainable development, and footprint depth has a single
609 threshold effect. Secondly, the impacts of footprint breadth and depth on sustainable development show
610 regional heterogeneity. Specifically, the eastern region is consistent with the Yangtze River Economic
611 Belt as a whole, and the impacts of footprint breadth and footprint depth on sustainable development
612 show an inverted N-shaped and an inverted U-shaped, respectively. The central region's relationship
613 between footprint breadth and sustainable development shows an inverted N-shaped, while footprint
614 depth shows an N-shaped relationship. In the western region, footprint breadth has an inverted

615 U-shaped effect on sustainable development, while footprint depth only significantly impacts
616 sustainable development. Thirdly, the mechanism test results show that footprint breadth improves
617 sustainable development by promoting the rationalization and advancement of industrial structure.
618 Footprint depth improves the sustainable development level by promoting the rationalization of
619 industrial structure.

620 Moreover, the mechanisms also have regional heterogeneity. Specifically, the advancement of
621 industrial structure, technological innovation, and urbanization are the main mechanisms of the eastern,
622 central, and western regions, respectively. Based on this paper's main conclusions, some relevant policy
623 implications are suggested as follows:

624 Firstly, scientifically and rationally coordinate the relationship between the utilization of natural
625 resources and sustainable development. **The results show that the ecological footprint and sustainable**
626 **development level of China's Yangtze River Economic Belt show regional differences. Rich resources**
627 **and low population density have higher footprint breadth, while footprint depth is the opposite.**
628 **Therefore, On the one hand, we should take a correct view of this imbalance in development because it**
629 **is closely related to the development conditions such as regional resource factor endowment. Local**
630 **governments should adapt their environmental policies to local conditions.**

631 Moreover, the social division of labor and the industrial gradient formed by the reasonable
632 regional differences stimulate economic and social development to a certain extent. On the other hand,
633 more importantly, it is necessary to establish and improve the legal system of environmental protection
634 through macro-control, include resource consumption, ecological benefit, and other indicators into the
635 local government performance evaluation system, and accelerate the improvement of the ecological
636 compensation mechanism of the Yangtze Economic Belt. They improve environmental standards and
637 strengthen law enforcement force industrial transformation and upgrading. Enterprises should increase
638 their investment in green technology research and development through taxation and subsidies. By
639 speeding up innovation in energy conservation and environmental protection technologies, enhancing
640 the supply of clean energy, and speeding up the cultivation of talents for green scientific and
641 technological innovation, a favorable environment for scientific and technological innovation will be
642 created to facilitate sustainable development of the Yangtze Economic Belt.

643 Secondly, the spatial layout should be optimized, and the industrial structure should be adjusted.
644 **The empirical results show that footprint breadth and depth promote sustainable development in a**
645 **specific range, and industrial structure transformation is critical.** Footprint breadth depends on resource
646 endowment and land use mode. Since resource endowment is not easy to change, it is necessary to
647 adjust land use mode to improve the utilization efficiency of flow capital. **In addition, the footprint**
648 **breadth of China's Yangtze River Economic Belt is still at a low level and shows a decreasing trend**
649 **year by year.** Therefore, it is necessary to improve the degree of intensive land use and realize the
650 coordination between natural resource utilization and resource renewal by optimizing the spatial layout
651 of the industry. The increasing scale of construction land should be controlled and efficiently used.

652 Further, the stock capital consumption of all prefecture-level cities is serious, especially in the
653 eastern delta region. Therefore, cities in the Eastern region must strengthen the protection of cultivated
654 land, improve resource utilization efficiency, implement the transformation of old and new driving

655 forces, promote green energy development, and reduce fossil energy consumption. For the central cities,
656 it is necessary to enable the sustainable development of urbanization and promote the rational flow of
657 various production factors. Control fossil energy consumption and vigorously develop new energy
658 sources such as hydropower. The industrial structure should be adjusted reasonably to reduce the
659 proportion of secondary industry. For western cities, it is necessary to improve resource utilization
660 efficiency, protect the arable land area to improve the supply capacity, adjust the industrial structure
661 reasonably, reduce the proportion of the secondary industry, and reduce the pressure on resources and
662 the environment.

663 Our work has limitations. Especially, this paper mainly investigates the mediating effect of
664 industrial structure when examining the mechanism of footprint breadth and footprint depth on
665 sustainable development. In fact, in addition to rationalization and advancement of industrial structure ,
666 there are other possible paths. In addition, since this study chooses cities as the research object,
667 sustainable development includes urban sustainability and inter-enterprise, inter-regional, and
668 inter-national sustainability. There still exists some room for further research. For example, following
669 recent literature, the dynamic effect and spatial spillover effect can also be taken into consideration to
670 discuss this topic from a new perspective.

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