

The impact of blue finance development on the green total factor productivity of coastal areas

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Abstract: Against the backdrop of the "dual-carbon" strategy, examining how blue finance affects green total factor productivity (GTFP) is of great significance for promoting green transformation and high-quality development in coastal areas. Based on panel data for 51 coastal cities in China from 2006 to 2024, this paper constructs a blue finance development index and uses the SBM-GML method to measure city-level GTFP. It then empirically investigates the impact and internal mechanisms of blue finance development on GTFP in coastal areas. The results show that blue finance development significantly enhances GTFP in coastal areas. Heterogeneity tests further indicate that this effect is more pronounced in regions north of the Yangtze River and in regions with higher levels of economic development, while the roles of financial scale and financial agglomeration are more significant. Mechanism analysis shows that blue finance promotes GTFP by advancing industrial structure upgrading, improving the allocation of green financial resources, and strengthening environmental regulation. These findings enrich the literature on blue finance and green efficiency and provide empirical evidence and policy implications for improving the marine financial system and promoting regional green transformation.

Keywords: blue finance; green total factor productivity; green finance

1. Introduction

Against the backdrop of the continuous advancement of the "dual-carbon" strategy and the in-depth implementation of the maritime power strategy, coastal areas, as the core regions of China's green transformation and high-quality development, are facing the dual challenges of resource and environmental constraints and growth-driver transformation. How to improve economic efficiency and environmental performance while safeguarding marine ecological security has become a key issue for coastal cities. As an extension of green finance, blue finance directs capital toward marine conservation, clean energy, ecological restoration, and sustainable fisheries (Kılıç, 2024). Existing studies suggest that blue finance and related blue-bond practices have begun to play a positive role in ocean conservation, marine governance, and the sustainable development of the ocean economy (Thompson, 2022; Kittinger et al., 2024; Hunt & Hilborn, 2025).

Meanwhile, green total factor productivity (GTFP), as a comprehensive indicator of the coordination between economic growth and environmental performance, has attracted increasing scholarly attention. Unlike traditional total factor productivity, GTFP incorporates undesirable

outputs such as pollutant emissions and is therefore better able to capture productivity under resource constraints and environmental pressure (Li et al., 2025; Qiu et al., 2025; Zheng et al., 2023). Existing studies show that green innovation, environmental regulation, industrial structure upgrading, and the digital economy can all affect GTFP (Hunjra et al., 2024; Zheng et al., 2023; Tao & Wen, 2022; Wang et al., 2024; Ding & Hu, 2025). For example, Hunjra et al. (2024) find that green innovation not only improves local green efficiency but also generates spatial spillovers, while Ding and Hu (2025) show that artificial intelligence exhibits a threshold effect in improving green efficiency.

However, studies on how blue finance affects GTFP remain limited. Most existing studies focus on the relationship between green finance and environmental performance (Imran et al., 2024; Xie et al., 2023), while empirical evidence on blue finance is still insufficient. Although some studies have discussed the role of blue finance in marine conservation, ocean sustainability, and related financing mechanisms (Thompson, 2022; Kılıç, 2024; Hunt & Hilborn, 2025), systematic evidence on its productivity effects, transmission mechanisms, and regional heterogeneity is still lacking. Meanwhile, although blue bonds and blue credit instruments are developing rapidly in many countries, they are still accompanied by imperfect market standards and the risk of bluewashing, and their environmental performance and credibility remain controversial (Kılıç, 2024; Mallin & Bouma, 2022).

Against this background, this paper takes 51 coastal cities in China from 2006 to 2024 as the research sample, measures green total factor productivity using the SBM-GML index, and systematically analyzes the impact of blue finance development on GTFP. Compared with the existing literature, the main contributions of this paper are as follows: (1) it links blue finance with green total factor productivity, thereby extending the literature on blue finance and efficiency effects; (2) it identifies the mechanisms through which blue finance affects green efficiency by using mediation analysis; and (3) it further explores the heterogeneity of blue finance across north-south regional differences, levels of economic development, and sub-dimensions of blue finance. These analyses help deepen the understanding of the relationship between blue finance and green efficiency and provide policy implications for improving blue finance system design and promoting the green transformation of the marine economy.

2. Theoretical analysis and Research Hypotheses

Blue finance, as an extension of the concept of green finance in the marine economy, aims to promote the efficient allocation of financial resources through green-oriented mechanisms while simultaneously serving the dual goals of marine ecological protection and green industrial upgrading (Chen, 2025). Compared with the traditional financial system, blue finance emphasizes not only the expansion of capital input but also the green shift in allocation efficiency (Kılıç, 2024). Against the backdrop of increasingly stringent resource and environmental constraints and deepening green transformation, the channels through which blue finance affects GTFP in coastal areas have become increasingly important, yet the relevant mechanisms have not reached a unified consensus and both theoretical and empirical evidence remain limited (Mallin & Bouma, 2022; Kittinger et al., 2024). Therefore, this paper proposes the following hypothesis:

Hypothesis 1: Blue finance development can significantly enhance GTFP in coastal areas.

GTFP, as an important indicator of the coordination between economic output and ecological cost, depends not only on improvements in the allocation efficiency of traditional production factors such as capital and labor, but also on the joint effects of industrial structure optimization, more efficient allocation of green resources, and stronger environmental governance (Li et al., 2025; Qiu et al., 2025; Zheng et al., 2023). Existing studies show that green finance can improve GTFP by easing financing constraints, optimizing industrial structure, and improving resource allocation efficiency (Tao & Wen, 2022; Zou et al., 2024; Imran et al., 2024). As an extension of green finance in the marine economy, blue finance focuses more directly on marine ecological protection, marine green industries, and coastal low-carbon transition, and it exhibits a stronger policy orientation in terms of capital allocation, instrument design, and ecological constraints (Gan & Li, 2020; Guo & Li, 2021). Therefore, blue finance is expected to support GTFP by guiding funds toward green marine infrastructure, ecological restoration, clean energy development, green shipping, and pollution control, thereby alleviating structural mismatches in green investment (Zhao et al., 2021).

First, blue finance may enhance GTFP by promoting industrial structure upgrading. Blue finance has clear functions in directing capital flows and optimizing industrial structure. Its development helps shift capital from traditional marine industries that are characterized by high energy consumption, high pollution, and low value added toward marine high-end manufacturing,

modern marine services, and green low-carbon industries, thereby accelerating both the upgrading and rationalization of industrial structure in coastal areas. As industrial development shifts from extensive expansion to intensive and efficient growth, resource-use efficiency will improve further and undesirable outputs will decline accordingly, ultimately raising GTFP (Zou et al., 2024; Yu & Wu, 2023). Therefore, this paper proposes the following hypothesis:

Hypothesis 2: Blue finance indirectly enhances GTFP by promoting industrial structure upgrading.

Second, blue finance may enhance GTFP by optimizing the allocation of green financial resources. Green marine projects are typically characterized by large investment requirements, long payback periods, and high uncertainty, so the traditional financial system often finds it difficult to provide sustained and stable support, leading to a misallocation of green financial resources. In contrast, by relying on diverse instruments such as blue credit, blue bonds, blue funds, and blue insurance, blue finance can improve financing availability for green projects and allocate limited financial resources more effectively to marine ecological restoration, green ports, offshore wind power, and marine energy conservation and environmental protection, thereby alleviating capital misallocation, improving the efficiency of green investment, and promoting GTFP growth (Liu et al., 2015; Yu & Wu, 2023; Hunjra et al., 2024; Zhao et al., 2021). Therefore, this paper proposes the following hypothesis:

Hypothesis 3: Blue finance indirectly enhances GTFP by optimizing the allocation of green financial resources.

Third, blue finance may enhance GTFP by strengthening environmental regulation. Blue finance is not merely a financing instrument. Its operation is usually accompanied by requirements such as environmental access, information disclosure, green certification, and ecological performance constraints, thereby creating external constraints and behavioral guidance for local governments and enterprises at the financing level. On the one hand, this can strengthen local governments' attention to marine ecological protection and pollution control. On the other hand, it can also push firms to improve energy conservation, emission reduction, and cleaner production, thereby reducing highly polluting and highly emissive activities. Although stricter environmental regulation may increase firms' adjustment costs in the short run, it is likely to facilitate green transition and improve GTFP in the long run (Zheng et al., 2023; Imran et al., 2024; Qiu et al., 2025).

Therefore, this paper proposes the following hypothesis:

Hypothesis 4: Blue finance indirectly enhances GTFP by strengthening environmental regulation.

3. Research design

3.1 Sample selection and data sources

To comprehensively assess the impact of blue finance development on green total factor productivity, this paper selects prefecture-level cities and municipalities directly under the central government in 11 coastal provinces of China from 2006 to 2024 as the research sample. Considering data availability and city-level marine characteristics, and in order to ensure data integrity and robust empirical results, cities with missing years or severely incomplete key variables are excluded. The final sample consists of 51 typical coastal cities. These cities not only possess strong marine industrial bases and resource endowments, but also occupy a key position in China's national strategies for building a "blue economic circle" and a maritime power. Relevant city-level data are mainly drawn from the China City Statistical Yearbook, China Marine Statistical Yearbook, China Financial Statistical Yearbook, China Environmental Statistical Yearbook, as well as municipal statistical bulletins and government annual reports.

3.2 Description of Variables

3.2.1 Dependent variable

The dependent variable in this paper is green total factor productivity (GTFP). GTFP not only captures factor-use efficiency in the traditional sense, but also incorporates undesirable outputs into the evaluation system, allowing it to more accurately reflect the evolution of production efficiency under a green development orientation. Compared with traditional total factor productivity, GTFP is more closely aligned with the goals of ecological civilization and sustainable development, and has been widely used in recent studies on energy efficiency and regional green performance (Li et al., 2025; Qiu et al., 2025).

Specifically, this paper adopts the SBM-GML index to calculate the green production efficiency of 51 coastal cities from 2006 to 2024. Building on the time comparability of the Malmquist index, the SBM-GML framework introduces a non-radial SBM model to overcome the inadequate treatment of slack variables in traditional DEA methods, and incorporates undesirable outputs to address the omission of environmental factors. This makes it possible to more accurately measure the dynamic evolution of urban green production efficiency over time. Following existing

studies (Tao & Wen, 2022; Zhang & Zhang, 2024), capital input is measured by capital stock, labor input by the number of employees at year-end, and energy input by total electricity consumption. Expected output is measured by real regional GDP, while undesirable output is measured by three pollutants: industrial wastewater discharge, sulfur dioxide emissions, and smoke and dust emissions, as shown in Table 1. Given the limited year-to-year variation in GTFP, this study further uses a cumulatively chained index to characterize its dynamic evolution.

Table 1 Green Total factor productivity Input and Output Indicators

Primary indicators	Secondary indicators	Tertiary indicators
Green total factor productivity	Input indicators	Number of employees
		Capital stock
		Electricity consumption
	Expected output	Real GDP
	Unexpected output	Industrial smoke emissions
		Industrial wastewater discharge
		Industrial sulfur dioxide emissions

3.2.2 Explanatory variables

The key independent variable in this paper is the level of blue finance development (BFD), which measures the financial support capacity and institutional supply intensity shown by coastal cities in promoting the development of the green marine economy. As an extension of green finance in the marine field, blue finance emphasizes the use of financial instruments to promote the sustainable use of marine resources and pollution prevention and control. Its essence lies in guiding capital toward marine-related industries through financial market mechanisms. Since no unified measurement standard for blue finance has yet been established, this paper constructs an index system for blue finance development from three dimensions—financial scale, financial structure, and financial agglomeration—based on the existing literature, as shown in Table 2¹:

Table 2 Indicators of Marine Financial Support

Primary indicators	Secondary indicators	Indicator description	Attributes
Blue Finance Development	Financial scale	Estimated Marine gross domestic product/regional gross domestic product for coastal areas	+

¹ The estimated marine gross product of coastal areas is extrapolated from the marine gross product of coastal provinces, with data sourced from the *China Marine Statistical Yearbook*. Specifically, the provincial marine gross product is apportioned according to each prefecture-level city's share of provincial GDP, thereby constructing an estimated value of marine gross product for each prefecture-level city.

	Financial structure	Loans/deposits of financial institutions in coastal areas	+
	Financial aggregation	(Financial industry workers in coastal areas * financial industry workers nationwide) / (Number of workers in coastal areas * national workforce)	+

To enhance the objectivity and scientificity of the weight distribution of indicators, this paper adopts the entropy weight method to standardize and weight the indicator data of each city, and then constructs a comprehensive blue finance development index. The steps are as follows:

The first step is to standardize the indicators.

$$z_{ij} = \frac{X_{ij} - \min\{X_j\}}{\max\{X_j\} - \min\{X_j\}} \text{ (Positive indicators)}$$

Here, z_{ij} and X_{ij} respectively represent the normalized value of the i th indicator for each city, and the raw value represents the minimum value of the raw data of a certain indicator, and represents the maximum value of the raw data of a certain indicator. $\min\{X_j\}$ and $\max\{X_j\}$

The second step j is to calculate the entropy of the second indicator e_j .

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n P_{ij} \ln(P_{ij})$$

Here, P_{ij} is the proportion of the region on the indicator. $0 \leq e_j \leq 1$ $P_{ij} = \frac{z_{ij}}{\sum_{i=1}^n z_{ij}}$ $i = 1, 2, \dots, n$ $j = 1, 2, \dots, m$

Step 3, calculate and determine the weight coefficients of each indicator as W .

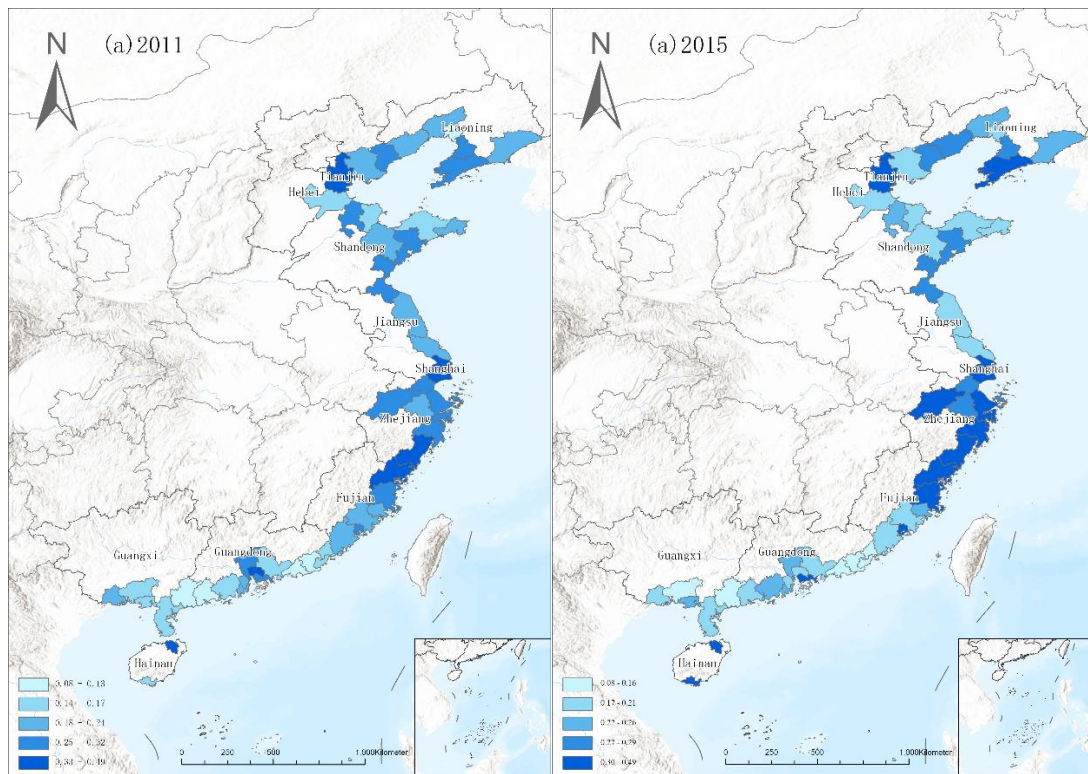
$$W = \frac{1 - e_j}{\sum_{j=1}^m (1 - e_j)}$$

Step 4, calculate the final result.

$$R_{ij} = Z_{ij} W$$

After the standardization and entropy weight calculation of the indicators were completed, a comprehensive index for the development of blue finance in coastal areas was obtained. This paper presents the evolution trajectory of the level of blue finance development starting from 2011, as shown in Figure 1. Overall, the development level of blue finance in coastal cities has shown a continuous upward trend. In 2011, the blue finance development index of most cities was at a relatively low level, with only some core cities in the Yangtze River Delta, Pearl River Delta and

Bohai Rim showing relatively high values. By 2015, the overall level had improved, the financial advantage of the eastern coastal areas was further consolidated, and some cities in the central and northern provinces also saw some growth. After 2019, the development of blue finance showed a more pronounced gradient in space: high-value clusters were formed in the eastern coastal areas and some sub-provincial cities, while the less developed regions remained at a low level. By 2023, the level of blue finance development has generally improved, and the high-value areas in major coastal cities have significantly expanded, showing a trend of evolving from point-like agglomeration to band-like distribution. This process indicates that blue finance is gradually moving towards equilibrium under the impetus of national policies and the synergy of regional economies, but regional disparities still exist.



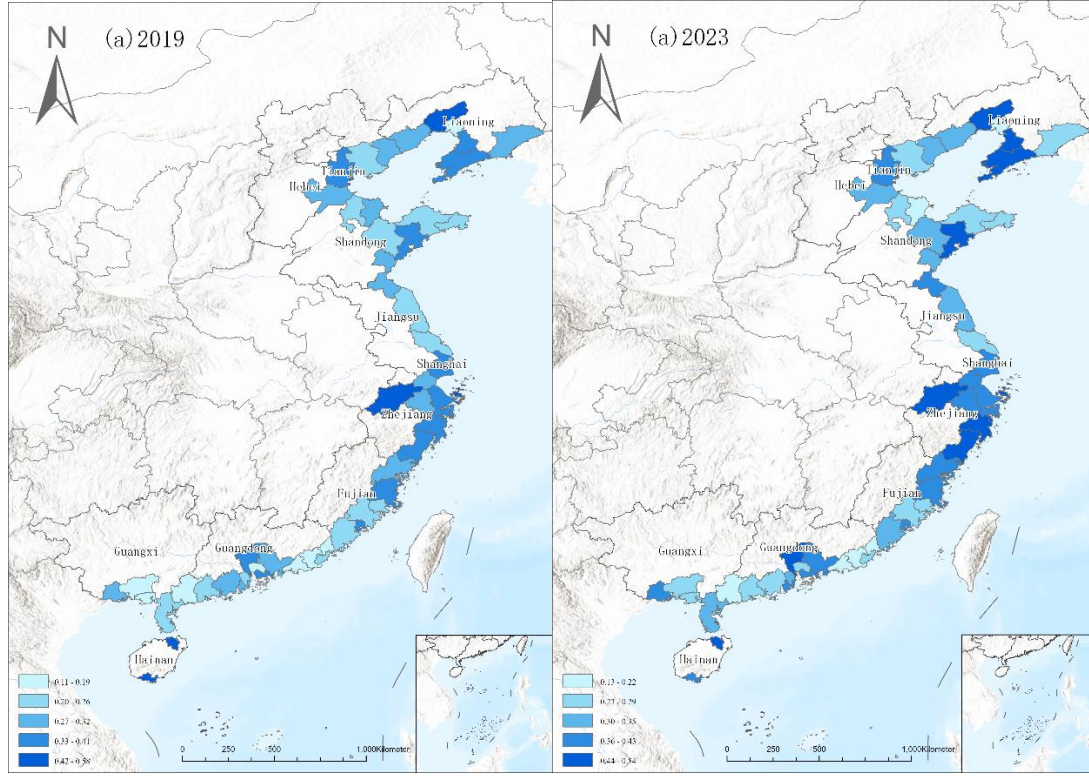


Figure 1 Visualization of the results of blue finance development levels

3.2.3 Control variables

Following existing studies (Li et al., 2025; Yu & Wu, 2023), this paper introduces the following control variables to improve the explanatory power of the model: (1) economic development level (RGDP), measured as the logarithm of per capita regional GDP; (2) fiscal pressure (FIS), measured as (local general public budget expenditure – local general public budget revenue) / regional GDP; (3) government intervention (GOV), measured as local general public budget expenditure / regional GDP, reflecting government governance input; (4) openness (OPEN), measured by the share of foreign direct investment in GDP; and (5) human capital (LAB), measured by the proportion of students enrolled in higher education institutions to the total population, reflecting the quality of the regional labor force.

3.2.4 Mediating variables

To further identify the mechanisms through which blue finance development affects green total factor productivity, this paper adopts industrial structure upgrading (IND), green financial resource allocation (GRE), and environmental regulation intensity (ENVO) as mediating variables. Among them, IND is calculated as the share of value added by the primary industry in GDP $\times$ 1 + the share of value added by the secondary industry in GDP $\times$ 2 + the share of value added by the tertiary industry in GDP $\times$ 3. GRE is measured by the entropy-weighted composite index of green credit,

green securities, green insurance, and green investment. ENVO is measured by using Python to scrape the frequency of keywords such as environmental protection, ecology, green, energy consumption, and emission reduction from local government work reports.

3.3 Benchmark model construction

The benchmark regression model for this article is as follows:

$$GTFP_{it} = \beta_0 + \beta_1 BFD_{it} + \beta_2 Control_{it} + u_i + \theta_t + \varepsilon_{it}$$

In the model, $GTFP_{it}$ denotes the green total factor productivity of city i in year t ; BFD_{it} denotes the level of blue finance development of city i in year t ; X_{it} denotes the vector of control variables; μ_i and λ_t denote city fixed effects and year fixed effects, respectively; and ε_{it} is the random disturbance term.

To further examine the mechanisms through which blue finance affects GTFP, this paper follows Jiang (2022) and uses the following mediation model for testing:

$$MID_{it} = \beta_0 + \beta_1 BFD_{it} + \beta_2 Control_{it} + u_i + \theta_t + \varepsilon_{it}$$

In the mediation model, M_{it} denotes the mediating variable for city i in year t , while the remaining variables are defined in the same way as in the baseline regression.

3.4 Descriptive Statistics

Table 3 reports the descriptive statistics of the main variables. Specifically, the mean value of green total factor productivity (GTFP) is 1.375, with a standard deviation of 0.542, a minimum of 0.341, and a maximum of 3.965, indicating substantial differences in GTFP across cities. The mean value of the core explanatory variable, blue finance development (BFD), is 0.145, with a standard deviation of 0.0956 and values ranging from 0.0478 to 0.620, indicating considerable regional disparity and an uneven distribution of blue finance development across the sample cities. As for the control variables, the mean value of economic development level (RGDP) is 10.90, with minimum and maximum values of 9.351 and 12.10, respectively, reflecting marked differences in the economic base of the sample cities. Variables such as fiscal pressure (FIS), openness (OPEN), industrial structure (IND), green financial resource allocation (GRE), and environmental regulation (ENVO) also show relatively large ranges, further indicating strong heterogeneity across coastal cities in terms of institutional environment, openness, industrial transformation, and green development conditions.

Table 3 Descriptive Statistical Results

VARIABLES	(1)	(2)	(3)	(4)	(5)
	N	mean	sd	min	max
GTFP	969	1.375	0.542	0.341	3.965
BFD	969	0.145	0.0956	0.0478	0.620
RGDP	969	10.90	0.619	9.351	12.10
FIS	969	0.0562	0.0416	0.00136	0.203
GOV	969	0.138	0.0504	0.0604	0.297
OPEN	969	0.507	0.470	0.0351	2.420
LAB	969	0.0193	0.0170	0.00151	0.0709
IND	969	1.143	0.699	0.242	6.243
GRE	969	0.309	0.105	0.124	1.127
ENVO	969	3.573	0.462	0.791	4.771

4. Empirical results

4.1 Benchmark regression

Table 4 reports the baseline regression results for the impact of blue finance on green total factor productivity. The estimated coefficient of the core explanatory variable, BFD, is positive under different model specifications and is significant at least at the 5% level, indicating that blue finance development exerts a stable positive effect on green total factor productivity. In the two-way fixed-effects model, the estimated coefficient of BFD is 0.589 and is significant at the 1% level, indicating that blue finance can still significantly improve green total factor productivity after controlling for unobservable city-specific effects and common year shocks.

Table 4 Results of the benchmark regression

VARIABLES	(1)	(2)	(3)	(4)
	FEM	FEM	TFEM	OLS
BFD	1.110 * * *	0.270 * *	0.589 * * *	0.350 * * *
	(5.25)	(2.47)	(2.78)	(3.19)
RGDP	2.998 * * *	1.645 * * *	1.944 * * *	2.939 * * *
	(10.62)	(4.12)	(-3.30)	(14.35)
FIS	1.173 * *	4.849 * * *	1.451 * *	3.302 * * *
	(-1.98)	(-8.76)	(-2.29)	(-7.22)
GOV	1.321 * * *	1.344 * * *	1.966 * * *	0.650 *
	(-2.91)	(3.81)	(-3.64)	(1.94)
OPEN	0.148 * * *	0.065 * * *	0.116 * * *	0.074 * * *
	(-6.72)	(-4.89)	(-5.53)	(-5.70)
LAB	6.304 * * *	-0.493	12.162 * * *	-0.150
	(-3.50)	(-0.75)	(-6.88)	(-0.23)
Year FE	NO	YES	YES	NO
City FE	YES	NO	YES	NO
Constant	6.340 * * *	3.843 * * *	5.432 * * *	6.797 * * *

	(-10.26)	(-4.16)	(3.93)	(-14.13)
Observations	969	969	969	969
R ²	0.685	0.357	0.734	0.321

Note: *, **, *** indicate significance at statistical significance levels of 10%, 5%, and 1% respectively.

4.2 Robustness analysis

4.2.1 Endogeneity analysis

To further alleviate endogeneity problems that may arise from omitted variables, reverse causality, and measurement error, this paper adopts two-stage least squares (2SLS) for instrumental-variable estimation to strengthen causal identification. Following the existing literature and taking into account the geospatial characteristics of blue finance, this paper constructs the interaction term between river density and contemporaneous regional fixed-asset investment as the instrumental variable (IV). In terms of relevance, river density, as a geographical environmental variable, is closely related to cities' marine industrial endowments, port development conditions, and shipping accessibility, and thus indirectly affects the tendency of financial resources to flow into marine-related fields; it therefore has a certain correlation with blue finance development. In terms of exogeneity, river density itself is a natural geographical characteristic and does not directly affect green total factor productivity (GTFP), thereby satisfying the exclusion restriction of the instrumental variable. Specifically, based on national river-system vector data, this paper first clips river polylines and provincial and municipal administrative boundaries in a GIS platform and projects them into an equal-area coordinate system to ensure comparability of length and area. It then calculates river-length density (total river length per unit area) by measuring total river length and land area for each province and sample city, and also computes river-count density using the number of major rivers flowing into the sea as an auxiliary measure. To avoid boundary effects, river sections crossing city boundaries are allocated by area ratio, while for coastal cities only estuary and coastal river sections are retained. The resulting river-density indicators are then standardized and used in the subsequent empirical analysis, with length density serving as the baseline indicator and count density as an alternative indicator for robustness tests. The procedure is illustrated in Figure 2.

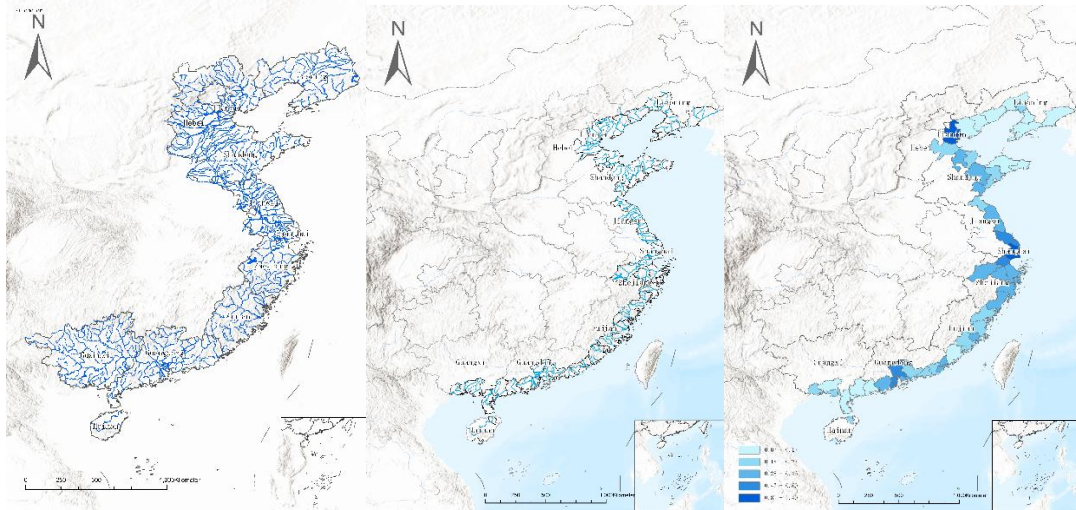


Figure 2 River density measurement

Table 5 reports the instrumental-variable estimation results. In the first-stage regression, the coefficient on IV is 0.012 and is significant at the 1% level, indicating that the constructed instrumental variable is significantly correlated with the core explanatory variable BFD. The Kleibergen-Paap LM statistic is 10.277, rejecting the null hypothesis of underidentification, while the Kleibergen-Paap Wald F statistic is 18.276, well above the commonly used Stock-Yogo critical value. The second-stage results show that the coefficient on BFD is 2.746 and is significant at the 1% level, indicating that blue finance development still significantly promotes green total factor productivity in coastal areas after controlling for potential endogeneity.

Table 5 Regression results of Instrumental variables

VARIABLES	The First Stage	The Second Stage
BFD		2.746 *** (3.67)
IV	0.012 *** (3.58)	
Control	Yes	Yes
Kleibergen-Paap LM		10.277 ***
Kleibergen-Paap Wald F		18.276
Cragg-Donald Wald F		12.790
Observations		969
R ²	0.131	0.304

Note: *, **, *** indicate significance at statistical significance levels of 10%, 5%, and 1% respectively.

4.2.2 Replacing the dependent and independent variables

This paper uses the non-cumulated SBM-GML index to replace the dependent variable and re-estimates the core explanatory variable by principal component analysis to test the robustness of the baseline conclusions. The results are shown in columns (1) and (2) of Table 6. It can be seen

that the estimated coefficient of blue finance development remains significantly positive whether the measurement of the dependent variable is changed or the construction of the core explanatory variable is altered. Specifically, the regression coefficient of BFD in column (1) is 0.278 and is significant at the 5% level, while the coefficient in column (2) is 0.045 and is significant at the 1% level. These results suggest that the baseline findings of this paper do not depend on a specific indicator construction method, and that the promoting effect of blue finance on green total factor productivity is robust.

4.2.3 Excluding the impact of major events

To further eliminate the possible interference of major shocks in extreme years on the regression results, this paper, based on the principal regression model, excluded the sample of 2020, a year significantly affected by unexpected events such as the COVID-19 pandemic, to verify the robustness of the impact of blue finance development on GTFP. The results are shown in column (3) of Table 6. The results show that the positive impact of blue finance development on green total factor productivity in coastal areas remains significant after excluding years with greater potential disturbances, further confirming the robustness of the basic conclusions of this paper.

4.2.4 Excluding some sample areas

To test whether the conclusion is influenced by a few municipalities directly under the Central Government with highly developed finance, this paper further excluded Tianjin and Shanghai from the sample and re-conducted regression estimation. The results are shown in Table 6 (4). It can be seen that the regression coefficient of BFD remains positive under different model Settings and is significant at the 1% statistical level, indicating that the exclusion of cities such as Tianjin and Shanghai does not change the empirical conclusion that the promoting effect of blue finance development on green total factor productivity remains robust.

Table 6 Results of the robustness test

VARIABLES	(1) Replace the interpreted variable	(2) Replace the explanatory variable	(3) Eliminating major events	(4) Eliminate samples
BFD	0.278 * * (2.13)	0.045 * * * (3.30)	0.698 * * * (3.03)	0.734 * * * (3.49)
RGDP	-0.022 (-0.06)	2.090 * * * (-3.53)	1.908 * * * (-3.11)	1.679 * * * (-2.87)

FIS	0.754 *	1.427 **	1.553 **	1.431 **
	(1.93)	(-2.26)	(-2.34)	(-2.17)
GOV	1.064 ***	2.036 ***	2.083 ***	1.783 ***
	(-3.19)	(-3.78)	(-3.74)	(-3.10)
OPEN	-0.007	0.115 ***	0.111 ***	0.103 ***
	(-0.56)	(-5.48)	(-4.97)	(-4.94)
LAB	2.245 **	12.419 ***	11.726 ***	11.314 ***
	(-2.06)	(-7.02)	(-6.41)	(-6.43)
Constant	1.299	5.859 ***	5.325 ***	4.760 ***
	(1.52)	(4.21)	(3.71)	(3.46)
Observations	969	969	867	931
R ²	0.233	0.735	0.729	0.728

Note: *, **, and *** indicate significance at the statistical significance levels of 10%, 5%, and 1% respectively.

5. Further analysis

5.1 Heterogeneity Analysis

5.1.1 Geographical location heterogeneity

To further examine regional differences in the impact of blue finance development on GTFP, this paper divides the coastal sample cities into two subsamples—north and south of the Yangtze River—and estimates the model separately. The results are reported in columns (1) and (2) of Table 7. In the regions north of the Yangtze River, the estimated coefficient of BFD is 0.789 and is significant at the 5% level. In the regions south of the Yangtze River, the estimated coefficient of BFD is 0.456 and is significant at the 10% level. In comparison, the promoting effect of blue finance on GTFP is stronger in the regions north of the Yangtze River, indicating clear regional heterogeneity.

The results suggest that in the coastal areas north of the Yangtze River, where the proportion of traditional industries is relatively high and the pressure for green transformation is greater, the marginal improvement effect of blue finance on resource reallocation, industrial upgrading and environmental governance is more prominent. As blue finance continues to tilt towards areas such as Marine green industries, ecological restoration and pollution control, the original high energy consumption and high emission development model of northern coastal cities is more likely to be corrected, thereby releasing a stronger green efficiency improvement effect. In contrast, the region south of the Yangtze River has a relatively more developed foundation for Marine economy, a higher degree of financial marketization and a green industry system. Although blue finance can still significantly boost GTFP, due to its better green transformation foundation and higher initial

efficiency level, the marginal promoting effect of blue finance is relatively weak. Overall, blue finance does not have a single, homogeneous pattern of effect on the increase of GTFP in coastal areas, but rather shows a more obvious geographical location heterogeneity.

Table 7 Results of heterogeneity tests

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	Geographical location		Level of economic development		Subdimensions		
	North of the Yangtze	South of the Yangtze	Low level	High level	Financial scale	Financial structure	Financial aggregation
BFD	0.789 ** (2.00)	0.456 * (1.73)	0.825 ** (-2.18)	0.824 ** * (2.81)	0.053 * (1.91)	0.263 *** (-3.71)	0.173 *** (9.18)
RGDP	-0.359 (-0.24)	0.398 (0.50)	-1.336 (-1.53)	-1.750 (-1.27)	1.829 *** (-3.11)	1.265 ** (-2.10)	1.561 *** (-2.77)
FIS	0.609 (0.76)	3.291 *** (-3.19)	0.303 (0.35)	-1.497 (-1.43)	1.445 ** (-2.27)	1.468 ** (-2.33)	1.548 ** (-2.54)
GOV	4.022 ** * (-6.75)	-0.118 (-0.13)	1.782 ** (-2.48)	0.266 ** (-2.23)	1.961 *** (-3.61)	1.919 *** (-3.56)	1.966 *** (-3.79)
OPEN	0.051 * (-1.87)	0.158 *** (-5.11)	0.055 * (-1.71)	0.095 ** * (-2.64)	0.116 *** (-5.48)	0.123 *** (-5.82)	0.139 *** (-6.83)
LAB	6.524 ** * (-2.67)	17.479 ** (-7.26)	13.225 ** (-5.15)	0.313 ** (-5.50)	11.942 ** (-6.73)	12.067 ** (-6.85)	14.613 ** (-8.49)
Constant	1.635 (0.47)	-0.822 (-0.45)	3.963 * (1.92)	2.536 (0.78)	5.209 *** (3.77)	4.088 *** (2.92)	4.412 *** (3.33)
Observations	323	646	460	509	969	969	969
R ²	0.783	0.736	0.766	0.794	0.733	0.736	0.755

Note: *, **, *** indicate significance at statistical significance levels of 10%, 5%, and 1% respectively.

5.1.2 Heterogeneity in economic development levels

To further examine the heterogeneity associated with different levels of regional economic development in the impact of blue finance on GTFP, this paper divides the sample into regions with high and low levels of economic development according to the mean level of regional per capita GDP and estimates the model separately. The results are reported in columns (3) and (4) of Table 7. In regions with a lower level of economic development, the regression coefficient of the core explanatory variable BFD is -0.825 and is significant at the 5% level, indicating that blue finance development has not yet been effectively transformed into higher green production

efficiency in underdeveloped regions and instead suppresses GTFP growth to some extent. In contrast, in regions with a higher level of economic development, the coefficient of BFD is 0.824 and is significantly positive at the 1% level, indicating that blue finance can significantly promote green total factor productivity in regions with a stronger economic foundation. This shows that the effect of blue finance on GTFP exhibits clear heterogeneity across levels of economic development, and that its positive effect depends heavily on regional development conditions.

These results suggest that regions with higher levels of economic development typically have more developed financial markets, more mature green industrial systems, and more abundant reserves of green projects. Blue finance is therefore more likely to translate into higher green productivity through channels such as capital allocation optimization, industrial structure upgrading, and stronger environmental governance. By contrast, regions with lower levels of economic development often still depend on traditional high-energy-consuming and high-emission industries, have a weaker green industrial base, and possess relatively insufficient financial intermediation systems and green investment instruments. As a result, blue financial resources are less likely to be allocated precisely and may even weaken green development performance because of resource misallocation. Therefore, the positive effect of blue finance on GTFP is not automatic; it requires support from a certain level of economic development and industrial conditions, and its marginal promoting effect is more likely to be released in regions with higher levels of economic development.

5.1.3 Heterogeneity of the sub-dimensions of blue finance

Further, this paper examines the differences in the impact of different sub-dimensions of blue finance on green total factor productivity, as shown in columns (5)–(7) of Table 7. The regression results show clear differences in both the direction and magnitude of the effects of different sub-dimensions of blue finance on GTFP. Among them, the coefficient on the financial-scale dimension is 0.053 and significantly positive at the 10% level, indicating that the expansion of blue finance scale generally helps improve green total factor productivity, although its promoting effect is relatively limited. The coefficient on the financial-structure dimension is -0.263 and significantly negative at the 1% level, indicating that the current internal structure of blue finance has not yet fully adapted to the demands of green transition and may even suppress GTFP because of an imbalance in the allocation structure of funds. By contrast, the coefficient on the financial-

agglomeration dimension is 0.173 and significantly positive at the 1% level, indicating that the agglomeration of financial resources can significantly improve green total factor productivity, and that its promoting effect is the most prominent among the sub-dimensions.

This result indicates that the impact of blue finance on GTFP is not solely dependent on the expansion of the total amount of funds, but rather on the degree of optimization of its internal structure and the efficiency of the aggregation and allocation of financial resources. Specifically, the expansion of financial scale can, to some extent, alleviate the financing constraints of green projects and provide financial support for Marine ecological protection, green ports and shipping, and clean energy development, thus having a positive effect on GTFP; However, if the financial structure is still unreasonable, there is a long-term shortage of funds, or more funds still flow to inefficient, non-green sectors, it may weaken the green conversion efficiency of blue finance and thus have a negative impact on GTFP. In contrast, financial aggregation not only helps to enhance capital supply capacity, but also improves the efficiency of green financial resource allocation through information spillover, resource matching and specialized division of labor, and therefore is more conducive to promoting the continuous improvement of green total factor productivity. It can be seen that the key to promoting GTFP through blue finance in the future lies not only in expanding the scale of blue finance, but also in optimizing its internal structure and enhancing the agglomeration effect of financial resources.

5.2 Mechanism Analysis

5.2.1 Upgrading of industrial structure

Table 8, column (1), reports the regression results of BFD on industrial structure upgrading (IND). The results show that the estimated coefficient of BFD is 0.001 and is significant at the 5% level, indicating that the development of blue finance can significantly promote industrial structure upgrading in coastal areas. This suggests that blue finance is not merely about expanding the supply of funds, but also performs a strong policy-guidance and structural-optimization function in the process of capital allocation and project screening. As blue finance continues to tilt toward marine high-end manufacturing, green shipping, marine energy conservation and environmental protection, ecological restoration, and modern marine services, capital will gradually shift from traditional sectors characterized by high energy consumption, high pollution, and low value added toward green, low-carbon, high-value-added, and technology-intensive

sectors, thereby driving the transformation of coastal industrial structure from an extensive pattern to an intensive one and from resource dependence to innovation-driven development.

Further, industrial structure upgrading can improve GTFP. First, industrial structure optimization helps improve resource allocation efficiency by allowing factors such as capital, labor, and technology to flow toward industrial sectors with higher production efficiency and lower environmental costs, thereby enhancing the green output capacity of the overall economic system. Second, industrial upgrading is often accompanied by the diffusion of green technologies, the spread of cleaner production methods, and the exit of backward, highly polluting capacity, which not only helps reduce undesirable outputs but also improves input-output matching and increases the level of green output generated by each unit of resource input. Finally, in the context of coastal areas, the upgrading of marine industries driven by blue finance can also strengthen internal coordination within the green marine industrial chain and promote the transformation of marine economic growth from scale expansion to quality improvement.

5.2.2 Allocation of green financial resources

Table 8, column (2), reports the regression results of BFD on green financial resource allocation (GRE). The results show that the regression coefficient of BFD is 0.135 and is significant at the 10% level, indicating that the development of blue finance can improve the allocation of green financial resources to a certain extent. Although the significance of this effect is weaker than that of industrial structure upgrading, the coefficient is stably positive, indicating that blue finance does help increase the likelihood that green projects obtain financial support. The reason is that green marine projects typically involve large investments, long construction periods, delayed returns, and difficulties in risk identification. The traditional financial system often prefers short-term, low-risk, and clearly profitable projects, resulting in mismatches of green capital across sectors, regions, and firms. Through instruments such as blue credit, blue bonds, blue funds, and blue insurance, blue finance can improve the availability of financing for green projects and enhance the targeting and continuity of capital allocation.

The improvement in the efficiency of green financial resource allocation can further promote GTFP. First, when financial resources are directed more precisely toward high-efficiency and low-emission sectors such as marine ecological restoration, green ports, offshore wind power, marine pollution control, and marine cleaner production, the marginal output of green investment will rise

and the degree of capital misallocation will fall. Second, a more effective allocation of financial resources means that green projects can not only obtain funding, but can also obtain suitable funding, which helps reduce capital constraints, maturity mismatches, and structural financing gaps during project implementation, thereby improving the actual conversion efficiency of green investment. Third, improvements in financial resource allocation can strengthen stable expectations for the development of green industries, attract more factors to cluster in green sectors, and improve the green efficiency of the overall production system through better matching among capital, technology, and projects.

5.2.3 Environmental regulation intensity

Table 8, column (3), reports the regression results of BFD on environmental regulation intensity (ENVO). The estimated coefficient of BFD is 0.666 and is significant at the 10% level, indicating that the development of blue finance can significantly strengthen environmental regulation. This result suggests that blue finance is not merely a financing-support mechanism; it also embeds institutional requirements such as environmental access, green certification, ecological performance assessment, information disclosure, and environmental responsibility constraints in its operation, thereby forming external constraints and behavioral guidance for governments and enterprises at the financing level. On the one hand, the development of blue finance can strengthen local governments' emphasis on marine ecological protection, pollution control, and green governance-system construction, thereby promoting the improvement of environmental supervision systems and the increase in governance investment. On the other hand, the linkage between financial supply and ecological constraints can also prompt firms to pay greater attention to environmental performance and to incorporate environmental requirements into project investment, production organization, and technological upgrading, thereby strengthening the actual enforcement intensity of regional environmental regulation.

Although stricter environmental regulation may increase firms' compliance and adjustment costs in the short run, its promoting effect on green total factor productivity is more significant in the long run. Specifically, environmental regulation can raise the cost of pollution emissions and tighten green entry thresholds, thereby pushing firms to improve production processes, strengthen energy conservation and emission reduction, adopt cleaner technologies, and phase out backward production capacity. At the same time, environmental regulation can also direct resources toward

firms and industries with better environmental performance, higher technological levels, and stronger governance capacity, thereby improving overall input-output efficiency and reducing undesirable outputs. For coastal areas, the environmental regulation strengthened by blue finance can not only improve the quality of the marine ecological environment, but also facilitate the transformation of the marine economic development model toward greener, lower-carbon, and more efficient growth, ultimately raising green total factor productivity.

Table 8 Regression Results of Mechanism Analysis

VARIABLES	(1) IND	(2) GRE	(3) ENVO
BFD	0.001 ** (2.34)	0.135 * (1.91)	0.666 * (1.74)
RGDP	-0.001 (-1.24)	0.675 *** (-3.44)	3.165 *** (2.97)
FIS	0.002 * (1.86)	-0.008 (-0.04)	5.938 *** (5.19)
GOV	0.001 (1.54)	0.013 (0.07)	3.067 *** (-3.14)
OPEN	0.000 (1.37)	0.014 * (1.96)	0.042 (1.10)
LAB	0.007 *** (2.62)	2.853 *** (-4.83)	6.283 ** (1.97)
Constant	0.025 *** (11.76)	1.867 *** (4.05)	4.417 * (-1.77)
Observations	969	969	969
R ²	0.952	0.634	0.444

Note: *, **, *** indicate significance at statistical significance levels of 10%, 5%, and 1% respectively.

6. Conclusion

Based on panel data for 51 coastal cities in China from 2006 to 2024, this paper systematically examines the impact of blue finance development on green total factor productivity (GTFP) and its transmission mechanisms, and further analyzes heterogeneity under different regional development characteristics. The main conclusions are as follows. First, blue finance development has a significant promoting effect on GTFP in coastal areas. This result remains robust after the inclusion of control variables, instrumental-variable estimation, replacement of core variables, and other robustness checks. Second, mechanism analysis shows that blue finance mainly promotes GTFP by advancing industrial structure upgrading, improving the allocation of green financial resources, and strengthening environmental regulation. Third, heterogeneity tests

show that the positive effect of blue finance on GTFP is mainly concentrated in regions north of the Yangtze River and in regions with higher levels of economic development, while the positive effects of financial scale and financial agglomeration are stronger.

Based on these findings, this paper proposes the following policy implications. First, the blue finance system should be improved as quickly as possible. At present, blue finance is still at a stage where development and regulation are advancing simultaneously. In the future, unified standards for identifying blue projects, catalogues for fund allocation, information-disclosure rules, and performance-evaluation mechanisms should be established around key fields such as marine ecological restoration, green ports and shipping, offshore wind power, marine energy conservation and environmental protection, and marine pollution control, so as to enhance the standardization and identifiability of blue finance. At the same time, policy coordination and data sharing among departments such as ocean, finance, and ecological environment should be strengthened to form an institutional closed loop covering project screening, financing support, process supervision, and performance evaluation. Second, efforts should be made to enhance the efficiency of blue financial resource allocation. In view of the long investment cycle, difficulty of risk identification, and slow return recovery of marine green projects, the government can guide more medium- and long-term capital into the marine green sector by establishing blue development funds and providing interest subsidies, financing guarantees, and risk compensation, thereby reducing the concerns of financial institutions and market entities about participating in blue finance. At the same time, financial institutions should develop more targeted blue credit, blue bonds, blue funds, and insurance products according to the characteristics of different projects such as marine ecological restoration, green infrastructure, and clean energy development, so as to effectively improve the efficiency of fund utilization. Third, full play should be given to the guiding role of blue finance in industrial structure upgrading. On the one hand, financial support should be increased for marine high-end manufacturing, modern marine services, green shipping, and marine strategic emerging industries, so as to guide capital toward sectors with high technological content, high value added, and good environmental benefits. On the other hand, the green transformation of traditional marine-related industries should be promoted through equipment renewal, technological upgrading, and investments in energy conservation and emission reduction, so as to facilitate their transition from high-energy-consumption and high-

emission development models toward low-carbon, green, and intensive development. Fourth, the differentiated development of blue finance should be promoted in light of local conditions. For coastal regions with a stronger economic foundation, a better industrial structure, and more mature financial markets, innovation in blue financial products should be further deepened, market-oriented operating mechanisms should be improved, and the advantages of financial agglomeration should be brought into play so as to enhance the depth and efficiency of blue finance in supporting green transformation. For regions with a relatively weak economic foundation and insufficient reserves of green industries, it is not advisable simply to pursue the expansion of blue finance in scale; instead, priority should be given to cultivating green projects, improving financial infrastructure, and strengthening the institutional environment, so as to gradually enhance their capacity to absorb blue financial resources, avoid resource misallocation, and promote more effective and balanced policy outcomes of blue finance across regions.

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Conflict of interest statement

The authors declare that they have no conflict of interest that could have influenced the results reported in this study.

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Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this manuscript, the author(s) used generative artificial intelligence (AI) to assist with language translation and English language polishing. The author(s) subsequently reviewed and revised the manuscript as necessary and accept(s) full responsibility for the final content of the published article.

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