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Research article

Evidence from China's shipping sector on the impact of fiscal measures in enabling a low-carbon economic transition

Wei Wu [a,b], Min Zhao [c,*], Zheng Ji [d], Muhammad Haroon [e]

[a] Business School, Jiangsu University of Science and Technology, Zhangjiagang 215600, China
[b] Yangtze River Delta Social Development Research Center, Jiangsu University of Science and Technology, Zhangjiagang 215600, China
[c] Suzhou Institute of Technology, Jiangsu University of Science and Technology, Zhangjiagang 215600, China
[d] National School of Development and Policy, Southeast University, Nanjing 211189, China
[e] Department of Economics, Ghazi University Dera Ghazi Khan, Pakistan

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ABSTRACT

The Green Economy Initiative aims to achieve economic development while minimizing carbon emissions by implementing a low-carbon economy across all sectors. It is noteworthy that ships play a significant role in global commodity transportation, accounting for approximately 80–90 percent. However, this also leads to a surge in fossil fuel consumption and alarming pollution levels. The data utilized in this article spans from 2010 to 2022 and specifically focuses on the shipping industry, drawing from information collected in 20 different provinces of China. Multiple panel regression models were constructed to analyze the influence of fiscal policies on facilitating the transition toward a low-carbon economy. In addition, a vector autoregression model was employed to examine the interconnected dynamics between low-carbon transition and budgetary guidelines. The findings indicate that tax-based policies demonstrate an inverted U-shaped relationship with low-carbon transition, whereas transfer payment policies exhibit an N-shaped pattern. The shipping sector is actively embracing low-carbon practices, largely due to incorporating digital technologies that mitigate the adverse impacts of fiscal regulations.

1. Introduction

China's economy has experienced significant growth since implementing reforms and opening up. This remarkable achievement, often called the "Chinese speed" and "Chinese miracle," has gained global recognition. However, this rapid expansion has also led to certain consequences. One of the major challenges is the increasing discord between the capacity of the Environment to sustain growth and the need for sustainable economic and social development. Consequently, it is imperative to shift towards a development strategy that prioritizes low-carbon and environmentally friendly practices [1]. The transition to a green and low-carbon economy focuses on leveraging technology and effective management to reduce waste. This shift is crucial for conserving energy and reducing emissions [2]. China has officially committed to significant energy consumption and emissions reduction targets during the Eleventh Five-Year Plan and aims to further advance these goals in the Twelfth, Thirteenth, and Fourteenth Five-Year Plans. Sustainable development faces constraints related to resources and the Environment, and energy conservation and emission reduction present new opportunities

* Corresponding author.
E-mail addresses: wwjust2023@163.com (W. Wu), zmjust@163.com (M. Zhao), jz0429@163.com (Z. Ji), haroonbaloch007.hb@gmail.com (M. Haroon).

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for economic growth while addressing these limitations. The Chinese government has introduced various legislative initiatives to promote energy efficiency and pollution reduction, recognizing the importance of energy conservation and emission reduction.

The government is leading in reducing pollution and adapting to climate change. This is due to recognizing the public benefits of the natural Environment, the positive effects of governance, and the negative consequences of pollution. Challenges arise when market mechanisms are used in isolation. According to theories of environmental federalism and centralism, fiscal policies play a crucial role in maintaining the collaboration between federal and state governments in managing pollution and addressing climate change. The federal government has implemented numerous programs between 2010 and 2022 focusing on investing in renewable energy, energy conservation, and emission reduction. To effectively tackle pollution and climate change, public policies must incorporate economic considerations as a fundamental aspect of national governance. Monetary policy motivates, constrains, coordinates, and compensates in achieving sustainable development and establishing an ecological civilization [3]. This raises an important question: Can fiscal policy effectively promote and facilitate the transition to a low-carbon and environmentally friendly society and economy? This inquiry will now commence.

The transition towards a low-carbon and environmentally friendly society emphasizes improving production efficiency over time and pursuing harmonious coexistence with nature. This necessitates greater fiscal commitment and the government's ability to govern in this new phase. Existing research has primarily focused on local government competition, environmental regulation, industrial agglomeration, the digital economy, green technology, financial development, media attention, public participation, and the development of green and low-carbon transformations [3]. Additionally, many academic studies have examined the interplay between fiscal and other public policies and their impact on the environment and carbon emissions. According to Ref. [4], carbon taxes and government subsidies for technology research and development are the most effective policies to implement during the transition towards a green industry. Consequently, researchers have explored the implications of various fiscal policies on green development, including income tax systems, budgetary decentralization, fiscal relations between governments, and the structure of fiscal expenditures. To prevent economic development from being trapped in a "low-carbon trap," they also examine how budgetary policy interacts with other public policies, such as financial, environmental, industrial, and energy policies [5].

In 2010, the Chinese government initiated a comprehensive exhibition of fiscal measures to promote energy conservation and reduce emissions to address the issue of "point-to-point" subsidies for ongoing projects during China's Eleventh Five-Year Plan period. Thirty cities were selected in three rounds for implementing this policy trial, known as the "ECER-CD" program. At the local level, the "ECER-CD" policy endeavors to enhance the alignment of budgetary resources with other policies by focusing on six key areas: "low-carbonization of industries," "clean transportation," "green construction," "intensification of modern service industries," "reduction of major pollutants," and "scaling up the utilization of renewable energy." The program spans three years and aims for energy efficiency and pollution prevention. The central government also provides substantial incentives to the demonstration cities. Additionally, the federal government has established a performance evaluation system to ensure the effective implementation of mandated programs.

Few industries are as distinctive and exceptional as the shipping sector, which operates on its own rules and dynamics. However, it is intriguing to note that previous studies have solely focused on exploring the impact of fiscal policies on the transformation of the industrial sector, neglecting to delve into the specific effects on the shipping industry. To shed light on this unexplored area, we aim to provide comprehensive methodologies for measuring labor cost transformation (LCT) within the Chinese shipping sector. By doing so, we can examine and establish a correlation between the budgetary policies implemented and the subsequent migration rates within the shipping industry. This research endeavor will enhance our understanding of the intricate relationship between fiscal policies and the ongoing transformation within the shipping sector.

The rest of the paper consists of a literature review in Section 2, research methodology in Section 3, empirical analysis results in Section 4, and a conclusion and policy recommendations in Section 5.

2. Literature review

In recent times, there has been a growing level of concern expressed by various stakeholders about the global shipping industry, primarily due to its substantial impact on carbon emissions and the consequent environmental deterioration that ensues [6]. As one of the major maritime countries globally, China assumes a pivotal role in addressing and tackling these pressing ecological concerns. Therefore, policymakers and relevant authorities must take decisive and proactive measures to ensure the nation's sustainable development of the shipping sector [7]. Policymakers have recognized this urgency and have enacted and implemented a range of fiscal policies to incentivize and facilitate a shift towards a low-carbon economy within the shipping industry in China. This comprehensive literature review seeks to critically analyze and evaluate the current body of research that explores the effects and outcomes of these fiscal policies on carbon emissions reduction and the promotion of sustainability within China's shipping industry [8]. The development and implementation of these fiscal policies in China's shipping industry indicate an increasing recognition and acknowledgment of the need to achieve a harmonious equilibrium between economic expansion and environmental sustainability. Historically, fiscal policies have predominantly focused on fostering and promoting economic competitiveness and expansion. However, with the growing importance placed on environmental issues and concerns, there has been a significant shift in approach and mindset towards the creation and implementation of regulations and policies that actively encourage and promote the adoption and utilization of more environmentally friendly technologies, practices, and processes within the shipping industry [9].

These policies encompass a wide range of measures, including but not limited to subsidies provided for ships that demonstrate fuel efficiency, tax benefits and incentives for projects that align with and promote environmentally friendly practices and initiatives, and the establishment of systems and mechanisms for pricing carbon emissions, with the ultimate goal of accounting for the additional costs that are associated with carbon emissions. These policies aim to incentivize and encourage the shipping industry to proactively reduce their carbon footprint and embrace sustainable practices and technologies. Several empirical studies have been conducted to assess and evaluate the effectiveness and impact of these fiscal policies in mitigating carbon emissions and fostering sustainability within China's maritime industry. For instance Ref. [10], conducted an extensive and rigorous examination of the subsidies that have been provided specifically for fuel-efficient ships. Through their study, they were able to conclusively demonstrate and illustrate that these policies and measures have resulted in a noteworthy and significant decrease in greenhouse gas emissions within the shipping sector. This finding further supports and reinforces the notion that fiscal policies play a crucial and pivotal role in driving and incentivizing sustainable practices and behaviors within the industry.

The global shipping industry, including China's maritime sector, has been the subject of increasing concern and scrutiny due to its significant impact on carbon emissions and environmental degradation [11]. China, one of the major maritime nations, has a critical role in addressing these environmental concerns. In response to these challenges, policymakers in China have implemented a range of fiscal policies to promote sustainability and reduce carbon emissions in the shipping industry. These policies demonstrate a shift towards creating regulations that encourage using environmentally friendly technology and practices. Empirical studies have shown that these policies have had a positive impact, decreasing greenhouse gas emissions [12]. These fiscal policies are an important tool in balancing the shipping industry's economic growth and environmental sustainability [13,14]. researched the financial implications of carbon pricing mechanisms. Their findings indicate that while these policies increased operational costs for shipping companies, they also motivated investments in clean technology and improved environmental performance. The studies employed various methodologies, such as econometric modeling approaches, to examine the relationship between fiscal measures and ecological outcomes, case studies, and qualitative analysis to assess the effectiveness of specific policy actions.

Additionally, life cycle analysis was utilized to evaluate the overall environmental impact of shipping operations, considering factors such as fuel consumption, emissions, and waste generation. Generally, the research suggests that fiscal policies have significantly contributed to reducing carbon emissions and promoting sustainable development in China's maritime industry. Subsidies provided for fuel-efficient vessels, shore power facilities, and other clean technologies have stimulated the adoption of ecologically sound practices, decreasing greenhouse gas emissions and other pollutants. Furthermore, introducing carbon pricing systems has effectively accounted for previously unacknowledged costs associated with carbon emissions [15]. This has incentivized shipping companies to embrace more environmentally friendly technologies and operational strategies to maintain their competitiveness in the market. However, despite the favorable outcomes associated with fiscal policies, policymakers must address several challenges and constraints. These concerns include the effectiveness of subsidy programs, the need for enhanced coordination and integration of fiscal measures with other policy instruments like regulatory standards and market-based mechanisms, and the importance of addressing equity and distributional issues to ensure that the benefits of transitioning to a low-carbon economy are equitably shared across society. To progress, officials must implement a comprehensive and well-coordinated strategy to facilitate the transition to a low-carbon economy in China's maritime industry. This requires combining fiscal measures with other policy tools, engaging relevant stakeholders, investing in capacity-building initiatives, establishing robust monitoring and evaluation systems, and collaborating with international partners and organizations to address global challenges such as climate change and environmental degradation.

In summary, this literature analysis provides distinct perspectives on the influence of fiscal policies on the transition towards a low-carbon economy in China's maritime industry. While evidence supports the notion that fiscal policies have significantly reduced carbon emissions and promoted sustainable development, there are still challenges regarding policy effectiveness, economic implications, and implementation. Addressing these issues and capitalizing on the opportunities at hand is crucial in ensuring that fiscal policies effectively achieve a low-carbon economy and a sustainable future for the maritime sector. Consequently, we propose.

Hypothesis 1. A correlation of a negative nature can be observed between the impact of shipping company LCT and tax policies. As stated by Ref. [16], the governmental TPPs have the potential to influence market behavior by providing specific market signals and offering subsidies for technical innovation and other measures. By reducing inefficient resource use and enhancing productivity, companies can increase their eligibility for subsidies from various government entities. The Chinese government has demonstrated its strong commitment to regulating emissions in the maritime sector by subsidizing the renovation of highly polluting vessels since 2013 to reduce their emissions. This approach impacts LCT through TPPs and its influence on the maritime industry. Some marine companies may swiftly reduce emissions by prioritizing investment in pollution control equipment to benefit from government incentives. Financial transfers are likely to encourage companies to invest in pollution control technologies.

Consequently, it can be inferred that TPPs promote protecting the marine Environment by encouraging businesses to allocate more resources to these technologies. While subsidies may facilitate advancements in environmental management [17], argue that they do not necessarily drive innovation in environmental technologies. Large-scale firms actively adhere to subsidy policies as they can easily obtain government subsidies by reducing emissions [18,19]. However, smaller shipping companies may hesitate to invest in environmental tech innovation due to the high cost associated with emission reduction initiatives, which could impact their budget for other research and development projects. Therefore, businesses use government subsidies to support technical innovation up to a certain point on their correlation curve. Even if subsidies are increased, LCT will have minimal to no impact. In addition to meeting other technological requirements, businesses would allocate more capital to pollution control technology if subsidies were to expand [20] steadily. Once companies overcome the technological challenges in pollution management, they can benefit from substantial LCTs subsidized by the government. Hence, this forms the working hypothesis.

Hypothesis 2. The impact of the TPP and LCT on the shipping industry can be described as a connection that follows an N-shaped pattern. Initially positive, it turns negative, returns to a positive state, and stabilizes. The maritime sector is benefiting from the advancements in digital technology, leading to increased autonomy and improved automation. By utilizing digital technology, the shipping industry has the potential to enhance energy efficiency and reduce carbon emissions during LCT by creating precise ship schedules. Furthermore, digital technology can improve pollution control technologies and reduce carbon emissions. While technical advancements generally result in a significant decrease in carbon emissions, the impact of economic growth on these emissions in 66 countries is nonlinear and varies. According to a study by Ref. [21], technology was crucial in improving environmental quality in 12 Asian economies between 2010 and 2022. An empirical analysis of the most visited countries revealed that technology moderated in reducing transportation-related carbon emissions [22]. Digital technology is extensively utilized in the industrial, electromechanical, and healthcare sectors. The adoption of digital technology by shipping companies can accelerate LCT by fostering the development of innovative solutions. With strong governmental support, businesses can overcome technological barriers and amplify the positive impact of fiscal measures. According to Xu et al. (2020), new technology is a critical factor in reducing carbon emissions from international shipping. Thus, this hypothesis serves as the working premise:

Hypothesis 3. In the shipping business, fiscal policies and LCT are moderated by the deployment of digital technology.

3. Research methodology

Initially, we employ principal component analysis to quantify the DTA level and assess the shipping industry's carbon emissions. Subsequently, we present an economic framework that examines the influence of fiscal policies, LCT, and DTA on China's shipping sector.

3.1. Research aims and data sources

The objectives of this research are clearly outlined in Table 1. One key aim is to quantify the emissions within China's shipping sector. The information about the transportation of goods across these 20 provinces was gathered from various sources spanning the years 2010–2022. Notably, China does not serve as a necessary conduit for all river and maritime routes. Most shipping traffic, amounting to 86 % in 2022, is concentrated in ten coastal provinces where the country's main ports are. Additionally, eleven provinces situated along rivers accounted for 13.8 % of all traded commodities in 2022, while the remaining nine provinces only transported a minimal 0.3 % of goods along rougher interior riverways.

3.2. Analyzing the shipping industry's carbon emissions

Several factors influence carbon emissions in the shipping industry, including the amount of freight and the distance traveled. Unfortunately, there is currently no universally accepted method for measuring these emissions. However, we can evaluate shipping-related carbon emissions using a methodology commonly used in urban transport, as outlined in Eq (1):

$$Carbon_{it} = \sum_j \left(FC_j \times C_{fj} \times \eta_j\right) \tag{1}$$

The equation presented demonstrates the correlation among various energy sources. In this equation, the variables j, FCj, jth, and ηj represent the type of energy source, its consumption, carbon emission factor, and conversion coefficient to standard coal, respectively, in Table 2.

3.3. Factors influencing the maritime sector

3.3.1. Explained variables

Lowering business pollution levels and modifying industrial structures, as Xu et al. (2017) discussed, is an important aspect of LCT. To assess the effectiveness of LCTs in businesses, various metrics have been developed by researchers, focusing on energy efficiency, total factor productivity, and carbon productivity. Carbon emissions are used as an indicator to evaluate the performance of LCTs in the shipping industry, considering the indirect nature of these goods. According to Ref. [23], greenhouse gas emissions primarily stem from energy combustion, which accounts for approximately 90 % of these emissions in economically developed regions. The significant power and fuel required to operate a ship contributes to these emissions. Promoting LNG and other fuels as alternatives to conventional fossil fuels aims to reduce greenhouse gas emissions from ships. However, it is important to note that this approach is not a cure-all solution, as highlighted by Ref. [24].

3.3.2. Explanatory variables

In this case, the explanatory variables refer to the financial policies that provinces have implemented. While numerous studies have been conducted on the impact of environmental regulations on businesses' ability to upgrade their industrial structures, it is important

Table 1
Objectives of the study.

Chinese provinces	No.	Cargo volume	Registered vessels	Research objectives
Coastal provinces	11	28,840/Kton	88,846	Yes
Riverine provinces	11	4668/Kton	24,484	Yes
Riverless provinces	8	8/Kton	428	No

Table 2
Coefficient of Carbon emission.

Energy types	CO_2 concentration	Emission factors ($CO2/10^{3\ kg}$)
Marine diesel oil/gasoline	0.864	2.2020
Marine light fuel oil	0.86	2.1410
Marine heavy fuel oil	0.84	2.1144
Liquefied petroleum gas	0.818	2.0000
Liquefied natural gas	0.64	2.6400

to note that various stakeholders, such as the public, businesses, and the government, influence these regulations. In particular, the government plays a crucial role in guiding these regulations in Table 3. The entropy weight approach is employed to assess the effectiveness of two different fiscal plans. This evaluation process consists of several stages.

Step 1. Source data standardization in Eq (2).

$$X_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}} \tag{2}$$

Step 2. Constructing a Scale Matrix Calculate $Y_{ij} = \{ Y_{ij} \}_{m*n}$ in Eq 3

$$Y_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \tag{3}$$

Which is the ratio of the jth index for that year to the sum of all indices.

Step 3. Finding the information entropy, ej in Eq (4).

$$e_j = -K\sum_{i=1}^{m}\left(Y_{ij} \times ln\ Y_{ij}\right) \tag{4}$$

Step 4. Calculation the weight of each indicator w_j in Eq (5).

$$w_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \tag{5}$$

Step 5. Deciding on budgetary allocations.

A weighted total is used to get the levels of TBPi and TPPi in the ith year in Eq (6).

$$TBP_i orTPP_i = \sum_{i=1}^{m}\left(w_j \times Y_{ij}\right) \tag{6}$$

3.3.3. Mediating variables

The DTA consists of three components: the provincial statistics that assess the digital technology infrastructure, the progress in digital technology, and the outcomes achieved through digital technology. These components are represented by the average values of digital technology indicators for provincial vessels, as presented in Table 4.

These indicators are integrated into many vital components to gauge the extent to which China's maritime sector has undergone digital change.

Step 1. Initial data standardization in Eq (7).

Table 3
Weight fiscal policy results.

Fiscal policy	Measuring indicator	Indicator's weight
TBP	Vessel tax	0.307707
	Tax of pollution and emissions	0.480080
TPP	Subsidy I	0.550530
	Subsidy II	0.035161
	Subsidy III	0.182076

Table 4
Indicators for DTA evaluation in the provincial shipping business.

1st level	2nd level
Underpinnings of information technology	Digital backbone
	Data foundation
Advancements in digitalization	Autonomous guidance
	Intelligent hull monitoring
	Intelligent engine room
	Management of energy efficiency on ships
	Intelligent cargo management
	Intelligent integration platform
Results from using digital tools	Safety and reliability
	Power and ecological concerns
	Economy and efficiency

$$x_{ij}^{'} = \frac{X_{ij} - \mu_j}{\delta_j} \tag{7}$$

Step 2. Develop a correlation matrix $R_{k \times k}$ in Eq 8

$$downright\,R = \begin{bmatrix} r_{11} & \cdots & r_{1k} \\ \vdots & \ddots & \vdots \\ r_{k1} & \cdots & r_{kk} \end{bmatrix} \tag{8}$$

Step 3. Following the eigenvalue solution, they are ranked from largest to smallest, and w is the number of primary components chosen from those with eigenvalues more significant than 1.0. Indicators' variance-adjusted functions (VAF) are then derived in Eq (9).

$$\alpha_i = \frac{\lambda_i}{\sum_{i=1}^{n} \lambda_i} \tag{9}$$

Step 4. The mean score calculates DTAi in Province I in Eq (10).

$$DTA_i = \sum_{i=1}^{\omega} (\alpha_i \times x_i) \tag{10}$$

The provincial shipping sector's data transfer functions (DTAs) are derived through principal component analysis. Over the period from 2010 to 2022, the average level of 20 provinces experienced a steady increase, reaching 1.70, before declining again during the COVID-19 pandemic. The shipping sector was significantly affected by the coronavirus outbreak in 2010 and 2022, with a substantial decrease in the transportation of goods due to quarantine and lockdown measures. The distribution of DTAs varies considerably among different regions, as indicated by a study examining 11 coastal provinces in China from 2010 to 2022.

3.3.4. Control variables

The growth of the shipping industry heavily relies on the availability of skilled human resources. The population of each province is determined by the annual number of individuals employed in the shipping sector. The economic development of a region plays a significant role in influencing the operations of businesses in the shipping industry. This brings us to our second point: measuring the province's financial status through the annual growth rate of regional GDP. The allocation of funds towards research and development (R&D) can greatly benefit businesses in a particular area if it encourages them to adopt new technologies, thereby enhancing their performance in the shipping industry. China's shipping market is closely tied to the international trade of goods, as evidenced by the export dependency ratio (EDR).

Given that China is the largest global manufacturer and exporter, the EDR is a crucial factor influencing the shipping sector in China. However, China's reliance on exports has gradually decreased since 2006. Its international trade volume determines the EDR of a province as a percentage of GDP. Port cargo throughput (PCT) serves as a valuable statistical measure that reflects the overall health of a province's shipping industry. It is calculated by aggregating the weight of all items that enter and exit the ports within the province.

3.4. Least squares regression models for the maritime sector

After reviewing the research, fiscal policies and other things affect LCT in the shipping sector. The following models show how two government initiatives affected LCT in the maritime industry using panel regression analysis in Eqs (11) and (12):

$$Carbon_{it} = \beta_0 + \beta_2 \times TBP^2_{it-1} + \beta_3 \times TBP_{it-1} + \beta_4 \times Controls_{it} + \varepsilon_{it} \quad (11)$$

$$Carbon_{it} = \beta_0 + \beta_1 \times TPP^3_{it-1} + \beta_2 \times TPP^2_{it-1} + \beta_3 \times TPP_{it-1} + \beta_4 \times Controls_{it} + \varepsilon_{it} \quad (12)$$

Here are two updated regression models considering DTA's moderating impact in Eqs (13) and (14).

$$Carbon_{it} = \beta_0 + \beta_2 \times TBP^2_{it-1} + \beta_3 \times TBP_{it-1} + \beta_5 \times DTA_{it} \times TBP^2_{it-1} + \beta_6 \times DTA_{it} \times TBP_{it-1} + \beta_7 \times DTA_{it} + \beta_8 \times Controls_{it} + \varepsilon_{it} \quad (13)$$

$$Carbon_{it} = \beta_0 + \beta_1 \times TPP^3_{it-1} + \beta_2 \times TPP^2_{it-1} + \beta_3 \times TPP_{it-1} + \beta_4 \times DTA_{it} \times TPP^3_{it-1} + \beta_5 \times DTA_{it} \times TPP^2_{it-1} + \beta_6 \times DTA_{it} \times TPP_{it-1} + \beta_7 \times DTA_{it} + \beta_8 \times Controls_{it} + \varepsilon_{it} \quad (14)$$

DTA_{it} is the shipping industry's DTA level, and the interaction factors of DTA x TBP and DTA x TPP reflect the effects of both fiscal measures on DTA.

4. Empirical analysis findings

4.1. Statistics for description and correlation

In this particular experiment, 352 genuine samples were collected and evaluated. The findings from Table 5 illustrate the outcomes of the descriptive statistics analysis, indicating a significant variation in TBP, TPP, GDP, and EDR across different provincial boundaries.

Table 6 showcases the correlations between the two variables. The findings confirm that each of the selected variables holds statistical significance.

4.2. Regression analysis

The econometric models represented by Equations (11) and (12) have undergone the application of Hausmann and F tests in Tables 7 and 8, wherein a p-value of 0.000 was obtained [6,25].

There is a positive square term coefficient of 1.131 and a negative primary term coefficient of −1.1644. When the moderating impact of DTA is not considered, the saturation point is 2.66. When government spending is kept below a certain threshold, carbon emissions from ships decline in tandem with the policy. But if the fiscal policy hits saturation, it will no longer be able to lower carbon emissions. This finding demonstrates that LCT benefits from adequate taxes in the shipping business. So, H1 is proven. The shipping industry's carbon emissions are inversely proportional to the amount of TPPs. There is a negative coefficient (−1.1216) for the principal term, a positive coefficient (1.1122) for the square term, and a negative coefficient (−1.1111) for the cubic term. The TPP emission curve has two inflection points, at 4.1 and 16.46 TPP levels, where the moderating impact of DTA is not considered. Carbon emissions fall as government subsidies rise, from 16.46 to below 4.1. However, the subsidy would increase carbon emissions (4.1–16.46). So, H2 is proven.

Incorporating DTA's moderating effect into a panel regression model of TBP results in an upbeat interactive square term coefficient (1.1264) and a negative leading coefficient in the interaction term (−1.1262). At TBP = 2.46, the optimal tax amount is below the threshold at which the moderating influence is ignored. Based on these findings, digital technology may play a moderating role in assisting TBPs in promoting LCT within the shipping sector. This indicates that digital technology increases the positive effects of government subsidies on carbon reduction while decreasing their adverse effects. According to H3, Digital technology moderates the shipping industry's connection between fiscal measures and LCT [26–28].

4.3. Robustness test

To assess the energy usage of a shipping company, it is recommended to calculate the product of the regional EC with the

Table 5
Summary statistics.

Variable	Observations	Mean	Maxi	Mini	Stand Dev.
Carbon/$\times 10^4$ Ton	242	0.614	1.816	0.102	0.246
TBP	242	1.428	24.642	0	4.201
TPP	242	1.824	21.88	0	2.218
GDP/$\times 10^{12}$ Yuan	242	2.424	2.840	0.021	0.661
POP/$\times 10^7$ Person	242	0.422	1.142	0.242	0.212
RDI/$\times 10^{12}$ Yuan	242	0.144	1.168	0.026	0.212
EDR	242	6.11	42.2	0	11.18
PCT/$\times 10^9$ Ton	242	2.828	11.261	1.648	2.148
DTA	242	1.226	1.884	0.612	0.204

Table 6
Correlation.

Variable	Carbon	TBP	TPP	POP	GDP	RDI	EDR	PCT	DTA
Carbon	1								
TBP	−1.1861 (0.000)	1							
TPP	−1.2226 (0.000)	0.1862 (0.000)	1						
POP	0.4824 (0.041)	1.2068 (0.114)	0.1244 (0.042)	1					
GDP	1.6128 (0.000)	1.2242 (0.000)	1.228 (0.024)	0.8084 (0.001)	1				
RDI	1.2014 (0.001)	1.1248 (0.028)	1.2224 (0.021)	1.6112 (0.001)	1.8180 (0.000)	1			
EDR	0.4462 (0.000)	0.1288 (0.000)	0.1410 (0.000)	0.2226 (0.122)	0.6416 (0.184)	0.4624 0.684)	1		
PCT	1.602 (0.426)	1.2228 (0.244)	0.2422 (0.064)	0.6424 (0.412)	0.6624 (0.286)	0.4661 (0.446)	0.8121 (0.662)	1	
DTA	0.282 (0.011)	0.044 (0.018)	0.012 (0.026)	0.486 (0.041)	0.642 (0.000)	0.644 (0.000)	0.680 (0.022)	0.2226 (0.008)	1

Table 7
Fiscal policy's impact on ships' emissions of carbon.

Variables	TBP	TPP
TPP^3	/	−1.1111*** (1.681)
TBP^2 or TPP^2	1.1216*** (1.682)	1.1122*** (1.626)
TBP or TPP	−1.1644*** (1.624)	−1.1216** (1.882)
POP	1.111** (1.18)	1.112** (1.62)
GDP	1.112*** (2.14)	1.112*** (2.71)
RDI	1.118*** (6.62)	1.111*** (7.11)
EDR	1.266 (2.33)	1.255 (2.48)
PCT	1.124 (2.14)	1.122 (2.81)
Cons.	2.848***	2.214***
R^2	0.624	0.624
N	242	242

Table 8
DTA Moderating effects.

Variable	TBP)	TPP
TPP^3	/	−1.1111*** (1.681)
TBP^2 or TPP^2	1.1116*** (4.41)	1.1126*** (2.62)
TBP or TPP	−1.2224*** (1.22)	−1.1248** (1.48)
DTA × TBP^3 or DTA × TPP^3	/	−1.1111** (4.41)
DTA × TBP^2 or DTA × TPP^2	1.1264*** (1.12)	1.1122*** (1.44)
DTA × TBP or DTA × TPP	−1.1262*** (1.44)	−1.1261*** (1.81)
DTA	1.1822*** (2.66)	1.1424*** (2.61)
POP	1.112** (2.21)	1.112** (2.86)
GDP	1.112*** (1.48)	1.112*** (1.66)
RDI	1.112*** (6.41)	1.111*** (4.88)
EDR	1.416 (2.61)	1.226 (1.82)
PCT	1.121 (1.64)	1.122 (1.42)
Cons.	1.682***	1.446***
R^2	0.624	0.624
N	242	242

The following three findings are derived from the multiple regression results.

percentage reflecting the region's overall business revenue from Table 9, which specifically focuses on energy consumption [24,29]. The data in question has been sourced from the China Industries' 2010–2022 Yearbook.

4.4. Deterioration experienced by several sectors of the shipping sector

To conduct a more comprehensive analysis of the impact of fiscal policies on the shipping sector, it is beneficial to divide it into various components. Regarding shipping routes, there are two primary classifications: DSS and ISS. Regarding shipping objects, there

Table 9
The robustness test's outcome.

Variable	TBP	TPP
TPP^3	/	−1.1111***
TBP^2 or TPP^2	1.2282***	1.1186***
TBP or TPP	−1.1488***	−1.1416**
DTA × TBP^3 or DTA × TPP^3	/	−1.1111**
DTA × TBP^2 or DTA × TPP^2	1.1464***	1.1141***
DTA × TBP or DTA × TPP	−1.1446***	−1.1141***
DTA	1.116***	1.168***
POP	1.112**	1.112**
GDP	1.112***	1.112***
RDI	1.118***	1.111***
EDR	1.442	1.416
PCT	1.116	1.114
EC	1.148***	1.182***
Cons.	2.244***	2.162***
R^2	0.814	0.866
N	242	242

are four primary classifications: PSS, DBS, LSS, and CSS.

4.4.1. Using shipping route segments for regression

Vessels can partake in domestic or international shipping, contingent upon the routes approved by the appropriate authorities. To evaluate fiscal policies and LCT, we employ DSS and ISS, respectively, and Eq. (11) (12) is utilized to examine the connections between them. The outcomes for both DSS and ISS can be observed in Table 10.

4.4.2. Determining regression using shipment object parts

Tables 11 and 12 provide a comprehensive analysis of the impact of TBP on the LCT across four distinct shipping phases. Through a meticulous examination, this study delves deep into the various shipping stages and assesses the effects of TBP on the LCT throughout each phase. By meticulously analyzing the data, this research aims to shed light on the intricate relationship between TBP and LCT, thereby contributing to a better understanding of the dynamics during shipping operations. Table 13 presents panel-data unit-root tests.

4.5. Dynamic test

4.5.2. VAR models

Determining the proper lag duration is critical since fiscal actions have a delayed impact on LCT in Eq (15).

$$y_t = a + \sum_{i=1}^{k} \beta_i y_{t-k} + \mu_t \tag{15}$$

A k-dimensional matrix βi, a k-order lagged of yt represented as yt - k, and a random term are included for every time series variable y.

4.5.3. Dynamic test results

We have analyzed the responses of LCT to various fiscal policy impulses in VAR models with different time delays. The LCT of the Chinese shipping industry shows a corresponding reaction to impulses, with a standard deviation of TBPs. In the third stage, there is an increase in LCT levels, indicating a positive impact of TBPs on LCT. Subsequently, LCT stabilizes after a gradual decline from the fourth

Table 10
Discrepancies between fiscal policy and LCT in DSS and ISS.

Variable	(1) DSS (TBP)	(2) DSS(TPP)	(3) ISS(TBP)	(4) ISS(TPP)
TPP^2		−1.1111*** (1.82)		−1.1111*** (1.86)
TBP^2 or TPP^2	1.1284*** (1.64)	1.1144*** (1.26)	1.1224*** (4.66)	1.1124*** (2.42)
TBP or TPP	−1.1266*** (1.64)	−1.1188** (−1.864)	−1.2242*** (1.46)	−1.1268** (1.42)
POP	1.111** (1.12)	1.111** (2.26)	1.112** (2.24)	1.112** (2.16)
GDP	1.111*** (1.88)	1.111*** (2.24)	1.112*** (1.66)	1.112*** (1.64)
RDI	1.116*** (6.24)	1.118*** (6.46)	1.116*** (6.26)	1.112*** (4.86)
EDR	1.262 (2.26)	1.224 (2.28)	1.422 (2.84)	1.244 (2.42)
PCT	1.144 (2.22)	1.122 (1.12)	1.146 (2.68)	1.126 (2.84)
Cons.	2.266***	2.262***	1.648***	1.422***
R^2	0.644	0.646	0.622	0.628
N	242	242	221	221

Table 11
An examination of the effects of TBP on LCT throughout four distinct shipping phases.

Variable	(1) PSS	(2) DBS	(3) LSS	(4) CSS
TBP^2	1.1284*** (1.88)	1.1268*** (2.24)	1.1226*** (2.24)	1.1224*** (4.66)
TBP	−1.1446*** (1.84)	−1.1264*** (1.22)	−1.1846*** (1.64)	−1.2216*** (1.42)
POP	1.111** (1.16)	1.111** (1.21)	1.111** (1.12)	1.112** (2.22)
GDP	1.111*** (1.42)	1.111*** (2.26)	1.112*** (2.18)	1.112*** (1.84)
RDI	1.112*** (6.16)	1.118*** (6.86)	1.111*** (6.26)	1.1141*** (6.22)
EDR	1.262 (2.44)	1.248 (2.66)	1.282 (2.42)	1.4122 (2.64)
PCT	1.111 (1.12)	1.226 (1.46)	1.164 (2.88)	1.666 (2.68)
Cons.	2.246***	2.464***	2.826***	1.626***
R^2	0.622	0.612	0.648	0.686
N	242	242	221	221

Table 12
Impact of TPP on LCT across four different shipping segments.

Variable	(1) PSS	(2) DBS	(3) LSS	(4) CSS
TPP^2	−1.1111*** (2.46)	−1.1111*** (2.82)	−1.1111*** (1.66)	−1.1111*** (1.82)
TPP^2	1.1126*** (2.42)	1.1114*** (4.66)	1.1128*** (2.26)	1.1126*** (2.66)
TPP	−1.1222** (2.12)	−1.1114** (4.66)	−1.1224** (1.44)	−1.1266** (1.24)
POP	1.112** (2.86)	1.111** (2.46)	1.112** (2.26)	1.114** (2.42)
GDP	1.111*** (6.22)	1.111*** (4.46)	1.112*** (2.24)	1.112*** (1.48)
RDI	1.1111*** (6.14)	1.114*** (8.22)	1.112*** (6.42)	1.116*** (4.44)
EDR	1.282 (2.62)	1.182 (6.61)	1.228 (2.66)	1.224 (2.46)
PCT	1.111 (1.16)	1.214 (1.21)	1.224 (2.64)	1.142 (4.44)
Cons.	2.216***	2.244***	1.646***	1.412***
R^2	0.622	0.611	0.644	0.686
N	242	242	221	221

Table 13
panel-data unit-root tests.

Variable	LLC	Fisher-ADF	Robustness
lnC	−1.8622**	14.6242	Not
lnTBP	−1.8444*	22.2262	Not
lnTPP	−1.8188**	28.4648	Not
ΔlnCarbon	−8.6842***	46.2628**	Yes
ΔlnTBP	−11.2468***	46.2486	Yes
ΔlnTPP	−12.2268***	44.8082**	Yes

to the seventh period, suggesting that the effects of TBPs diminish over time. These findings illustrate that TBPs initially promote LCT, but their influence wanes as the economy expands and energy consumption increases. It is important to note that taxation alone cannot compel businesses to rely solely on traditional energy sources when they raise their operations Fig. 1.

The Chinese maritime industry's response to a one-standard-deviation shift in TBPs is manifested through the LCT [30,31]. The impact gradually becomes more consistent over ten periods, specifically after the initial five and the concluding five, which exhibit a linear pattern. This observation implies that the government should contemplate implementing regulations rather than taxes to promote LCT in the shipping sector, as shown in Fig. 2.

The reasons behind the two types of taxes within the TBPs, namely the boat and the pollution and emissions tax, differ. According to Figs. 3 and 4, it is evident that the pollution and emissions tax has a greater impact on LCT.

The assertion made in this statement is supported by the results of the Dynamic TBP and LCT experiments, which indicate that the government can potentially optimize the LCT benefits by adjusting the TBP level accordingly, as depicted in Fig. 5.

The response of the Chinese maritime industry's LCT is observed when TPPs shift by one standard deviation in Fig. 6. Initially, both LCT and TPP exhibit modest levels. However, the levels of LCT experience a significant drop after reaching their peak in the second phase. This indicates that LCT may achieve early success in the shipping sector. If the government increases subsidies for developing pollution control technology, which creates positive incentives, businesses are more likely to utilize LCT shortly. Nevertheless, until there are advancements in low-carbon technology, the shift will be less frequent, and its impacts will be negligible. Once the government establishes a stable position with appropriate subsidies and LCT levels, it will reduce the amount of TPPs.

Observe the response of LCT in Figs. 7–9 when three distinct types of TPPs are activated: specifically, the one aimed at advancing maritime innovation and research. Among these, Subsidy II, designed to incentivize using natural gas instead of oil in ships, engenders the most pronounced reaction from LCT.

The findings of the dynamic testing of TPPs and LCT support H2, indicating that the government should find a middle ground between the two, implementing them in stages.

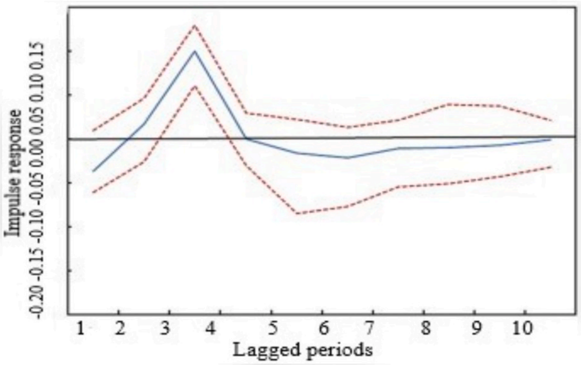

Fig. 1. Link between TBPs and LCT

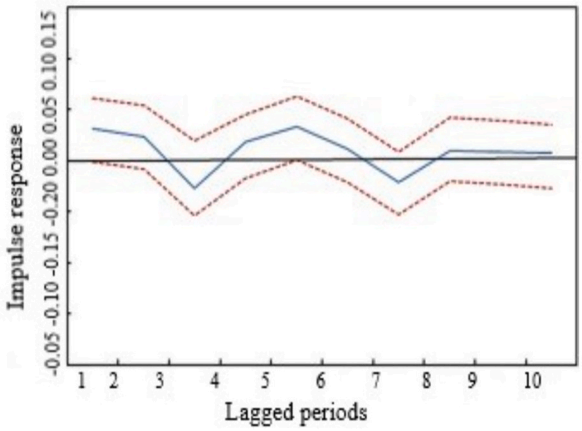

Fig. 2. Link between TBPs and LCT

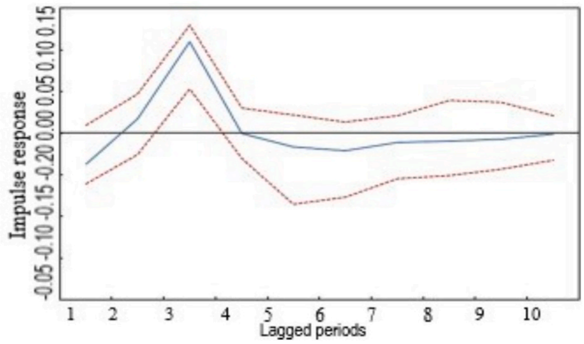

Fig. 3. Link between tax of vessels with LCT.

5. Conclusions

5.1. Conclusions

Based on empirical evidence, this study has yielded three significant findings.

The multiple regression analysis indicates a U-shaped relationship between TBP and LCT in the Chinese shipping sector, with an optimal turning point in the middle. Before reaching this threshold, TBP appeared to enhance LCT within the industry. However, beyond this point, shippers may prioritize expanding their operations over improving LCT on their vessels. Consequently, TBP could impede the industry's progress in promoting LCT. In the maritime domain, the relationship between LCT and TPP is represented by N-

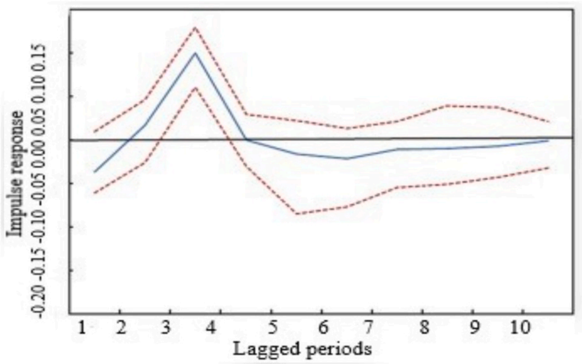

Fig. 4. Impact of pollution and emissions tax on LCT.

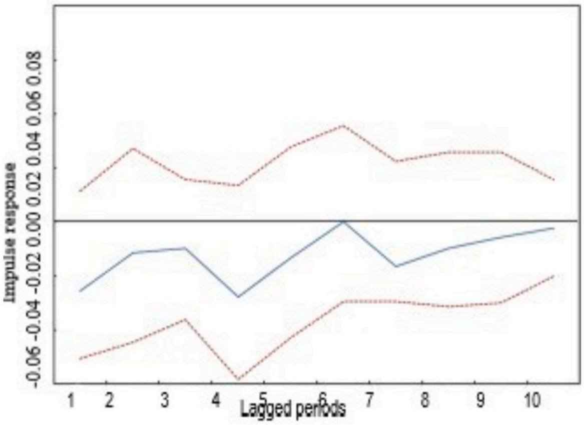

Fig. 5. Link between TPPs and LCT

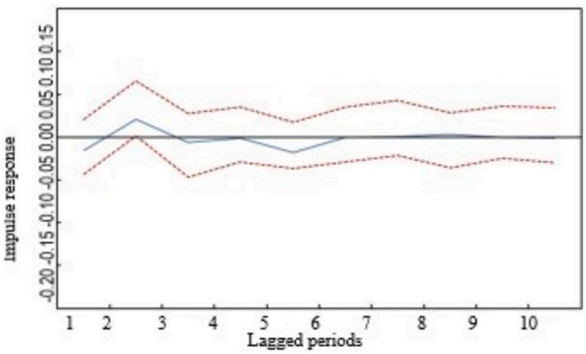

Fig. 6. Link between TPPs with LCT

shaped curves. Enterprises demonstrate a swift adoption of low-carbon technology, even with limited government subsidies, resulting in remarkable initial benefits regarding vessels' LCT.

Nevertheless, the subsequent costs of developing new technologies gradually strain their corporate budgets. This and the cost-benefit analysis of conventional energy sources increase carbon dioxide emissions as the shipping industry experiences unsustainable growth. However, the performance of LCT may improve in later stages as shippers once again embrace new technologies supported by increasing government subsidies. The emergence of DTAs significantly augments the impact of fiscal measures on LCT within the maritime industry. Integrating digital and low-carbon technologies catalyzes the industry's pursuit of LCT. Evidence from the shipping sector indicates that government regulations and LCT have a moderating effect. DTAs have the potential to amplify the positive influence of fiscal policies while mitigating their negative consequences. Therefore, it is imperative for the government to

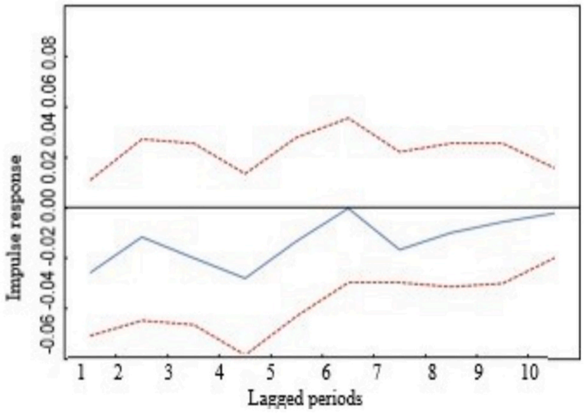

Fig. 7. Link between subsidy I and LCT

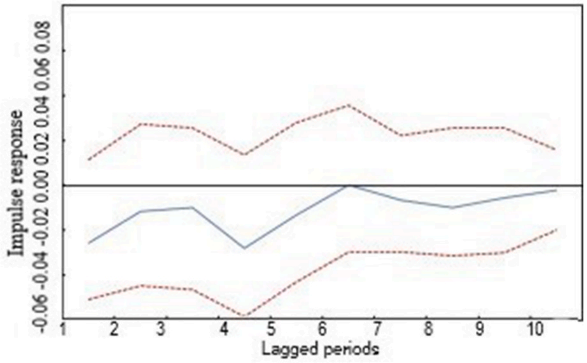

Fig. 8. Link between subsidy II and LCT.

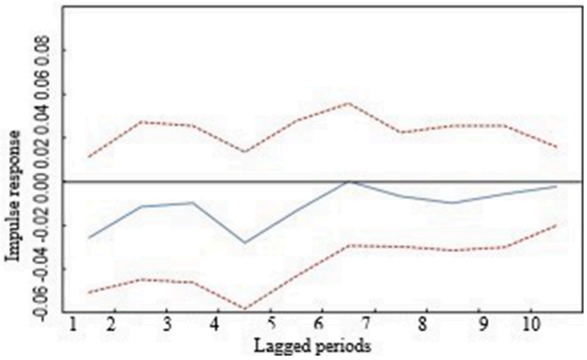

Fig. 9. Link between subsidy III and LCT.

strongly encourage the utilization of digital technology in the marine industry.

5.2. Suggestions for administrators

Like other sectors, the shipping industry also embraces Low Carbon Technology (LCT) tactics, in line with the global emission management agreement. Our research on LCT in the shipping sector has led us to identify four key managerial takeaways.

(1) To address any unintended consequences of overly stringent regulations, it is recommended that the government sets tax rates at an optimal level. Governments can balance promoting environmental preservation and ensuring sustainable economic development in the shipping industry by considering the specific industrial circumstances and regional economic growth.
(2) The consequences of the Trans-Pacific Partnership (TPP) are complex and unfold in multiple stages. While government subsidies can initially support the adoption of LCT in the maritime sector, excessive reliance on subsidies can hinder technical innovation and the development of LCT. However, gradually increasing subsidies in the later stages can mitigate these negative effects. To accelerate the adoption of LCT across different vessels, governments can design an ideal TPP framework and encourage using low-carbon technologies and improved management practices.

5.3. Limitations

While this study has examined empirical evidence on fiscal policies LCT and DTA in China's shipping sector, there are still certain gaps that can be addressed through future experiments. To initiate this process, forthcoming research will utilize a larger sample size. This research draws conclusions using panel data collected from all transport boats registered in 20 provinces across China between 2010 and 2022. Nonetheless, extending these findings to other countries and vessels is imperative to uncover additional heterogeneity across ships. Conducting research at the enterprise level would offer fresh insights, as shipping companies are the primary entities embracing digital technology and enhancing LCT. Since these advancements are occurring on a small scale within individual vessels, investigating how fiscal policies impact these micro-level operations could be a fruitful avenue for future research.

Ethics approval and consent to participate

Not applicable.

Consent for publication

All of the authors consented to publish this manuscript.

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Data availability

We collected relevant data from World Bank open data available at https://data.worldbank.org/. For any further query on data, corresponding author at email address zmjust@163.com may be approached.

CRediT authorship contribution statement

Wei Wu: Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Min Zhao:** Visualization, Investigation, Data curation, Conceptualization. **Zheng Ji:** Visualization, Investigation, Formal analysis, Conceptualization. **Muhammad Haroon:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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