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The Impact of the Environmental Clauses of Free Trade Agreements on the Hidden Carbon of Developing Countries

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Abstract

The environmental provisions covered by free trade agreements (FTAs) are one of the important external factors influencing trade embodied carbon. Based on the rule text of free trade agreements, this paper measures the depth of environmental clauses in free trade agreements between different countries and constructs an environmental clause depth index. Combined with the trade embodied carbon data of 255 different product codes of HS6 from 11 representative developing countries from 2008 to 2017, An empirical exploration is conducted based on the bilateral trade embodied carbon data from the production and consumption ends to explore the impact of the depth of environmental provisions in free trade agreements on trade embodied carbon. According to the empirical research results, it is found that the enhancement of the depth of environmental provisions in trade agreements can significantly reduce the trade embodied carbon at both the production and consumption ends. Heterogeneity analysis indicates that the environmental provisions of trade agreements at different dimensions have significant differences in their effects on promoting carbon reduction in trade. Compared with unilateral agreements, multilateral agreements are more effective in deeply curbing trade embodied carbon emissions through environmental provisions. The deepening of environmental provisions can more effectively reduce embodied carbon emissions in the trade of non-green products. The degree of inhibition of trade embodied carbon emissions by the depth of environmental provisions is more obvious when the importing country is a developing country. These conclusions can provide empirical evidence and decision-making references for developing countries to identify trade embodied carbon risks, strive for reasonable emission reduction space, and guide the green transformation of industries, helping them balance trade development and carbon emission governance.

Keywords

Trade Agreement; Environmental Clauses; Depth of Trade Hidden Carbon

1. Introduction

In recent years, against the backdrop of global economic integration, international connections have grown closer than ever. The number of free trade agreements (FTAs) entering into force has surged exponentially, with their provisions expanding and deepening continuously. Meanwhile, under the dual pressures of global warming and the advancement of Sustainable Development Goals (SDGs), "reducing trade-related carbon emissions and building a green, low-carbon society" has become a core issue for the long-term sustainable development of the global economy. Consequently, an increasing number of countries and regions are seeking to incorporate environmental rules into FTAs to balance trade liberalization with environmental protection. The flexibility of FTAs has garnered growing attention.

While nations are increasingly incorporating green clauses into trade agreements, the substantial variations in environmental provisions across regional trade deals—stemming from differing resource endowments and environmental standards—have impeded their practical implementation and effectiveness. Furthermore, the imbalance in negotiating power between developing and developed countries within Free Trade Agreement (FTA) negotiations means that developed nations still dominate the formulation of trade rules. This has resulted in high-standard agreements exerting "rule pressure" on developing countries, thereby raising the barriers to their participation in global economic integration.

Against this backdrop, optimizing trade rules, enhancing environmental regulatory capacities in developing countries, and promoting low-carbon collaboration in intra-country trade have become pivotal breakthroughs for reducing trade-related carbon emissions and achieving long-term sustainable development of the global economy. Building on this foundation, this study focuses on developing countries as the primary research subjects. Utilizing trade agreement data from the TREND database, we construct an in-depth index of environmental clauses in trade agreements. By collecting and analyzing 255 product codes of trade-related carbon data from 11 representative developing countries between 2008 and 2017, we empirically examine the impact of environmental clause depth in trade agreements on carbon emissions from both production and consumption perspectives. This research provides policy references and development guidance for refining environmental provisions in future trade agreements and facilitating the green and low-carbon transformation of global trade.

2. Literature Review

In the research field of in-depth measurement of environmental clauses in trade agreements, scholars at home and abroad have conducted explorations from multiple perspectives and achieved rich results. Morin et al. (2018) constructed the TRAC database using the clause coding method. By assigning binary values to over 60 environmental issues, they measured the depth of agreements from both the "procedural" and "substantive" obligation dimensions, providing an important foundation

for subsequent research. In recent years, Clara Brandi et al. (2017), with the help of the Trade and Environment Database (TREND), subdivided environmental provisions into 14 major categories and 295 dimensions. By integrating elements such as legal binding force and implementation time, they constructed fine indicators to measure the "breadth" and "strength" of the provisions. Other scholars have deeply analyzed the impact of the depth of environmental provisions on trade embodied carbon and the green transformation of industries from dimensions such as green technology cooperation and the improvement of environmental governance capabilities. Yin Ge, Fan Zhen, and Zhuang Rui (2024) systematically reviewed foreign measurement methods, and in combination with China's position in the global trade pattern and environmental policy goals, proposed the necessity of localizing the adjustment of measurement indicators. Fu Dahai and Cao Li (2023) constructed a depth index of environmental provisions in regional trade agreements. By applying an extended structural gravity model, they empirically analyzed the impact of environmental rules on the export of pollution-intensive products and green products from both trade creation and trade transfer perspectives. They found that environmental provisions with higher depth can effectively promote the green upgrading of industries.

In the research on environmental provisions of trade agreements, existing researchers hold two different views on the impact of environmental provisions in trade agreements. In studies suggesting that environmental provisions in trade agreements have a positive effect, Bastiaens and Postnikov (2017) found through empirical analysis that legally binding environmental provisions in trade agreements signed by Europe and the United States can significantly improve the environmental governance level of partner countries, especially in the fields of water pollution and biodiversity conservation. Martinez-Zarzoso and Oueslati (2018) proposed that the environmental provisions of trade agreements can effectively protect the domestic environment and reduce the emission of polluting gases. George and Yamaguchi (2018) found that enhancing the depth of environmental provisions in trade agreements could achieve better policy effects. Chinese scholars Peng Shuijun and LAN Rujia (2019) found through their research on China's free trade agreements that environmental provisions have promoted green technological innovation among domestic enterprises through technology spillover effects and standard improvement mechanisms, but the effects show industrial heterogeneity. However, some scholars believe that the terms of trade agreements can have negative effects. Morin and Rochette (2017) proposed that different countries tend to incorporate different environmental protection provisions in trade agreements, and conflicts in environmental provisions of trade agreements may lead to new trade protectionism. Brandi et al. (2020) also cautioned against the need to pay attention to the issue of the implementation gap of the provisions, that is, although some developing countries have committed to accepting environmental provisions, due to the limitations of regulatory capacity and insufficient funds, the actual environmental improvement effect may be lower than expected.

In recent years, as global attention to climate change and sustainable development has grown, a limited number of studies have examined the impact of environmental clauses on export trade's embodied carbon emissions. Baghdadi et al. (2013), using panel data from 182 countries between 1980 and 2008, pioneered an analysis of environmental clauses' effects on export-related carbon emissions through a difference-in-differences approach. Their findings revealed that nations with environmental clauses exhibited lower export carbon intensity compared to those without such provisions.

With the increasing prevalence of environmental clauses in trade agreements and the diversification of their textual forms, research has begun to focus on examining how the depth (heterogeneity) of these clauses impacts carbon emissions (2017). For instance, Abman et al. (2024) and Martinez-Zarzoso et al. (2018) found that specific environmental clauses often play unique roles in environmental governance areas such as carbon emissions. Yuan Wenhua et al. (2023), based on trade agreement rule texts and trade-related carbon data from 64 countries, investigated the impact of environmental clause depth on trade-related carbon emissions. The study revealed that environmental clauses significantly reduce trade-related carbon emissions through pathways like green technology cooperation and improved carbon productivity. Dai Xiang et al. (2024) explored how environmental clause heterogeneity influences export green transition, finding that environmental clauses effectively drive export green transformation.

To address these gaps, this study expands research in three key dimensions: First, while previous studies predominantly focused on environmental provisions in FTA frameworks developed by the US and EU, this paper shifts focus to developing countries. By examining how environmental clauses in FTAs profoundly impact trade-related embodied carbon in developing economies, we fill a critical research void in this field. Second, through dual perspectives of production and consumption, we analyze the mechanism by which environmental clause depth affects trade-related embodied carbon, offering new analytical dimensions for understanding trade-environmental dynamics in developing nations. Third, utilizing the first six-digit International Standard Classification (HS6) codes from APEC's Harmonized System of Classification of Goods, we achieve granular measurement of trade-related embodied carbon and precise identification of product-level heterogeneity. This approach provides micro-level data support for elucidating environmental clause mechanisms and formulating targeted policies. Through multidimensional analysis of "country-product pairs," we clarify the interplay between "export country characteristics, product attributes, and import demand," deepening our understanding of trade-related carbon driving mechanisms.

3. Theoretical analysis and research hypotheses

3.1. The Overall Impact of Environmental Clauses in Trade Agreements

on Trade-Embedded Carbon

Against the backdrop of global trade liberalization and growing environmental awareness, the impact of environmental clauses in Free Trade Agreements (FTAs) on trade-related embodied carbon has become a research hotspot. Trade-related embodied carbon encompasses both production-side and consumption-side carbon emissions. The former refers to direct and indirect carbon emissions during product manufacturing, while the latter involves carbon emissions in production processes triggered by consumption of goods.

From the production perspective, strengthening environmental provisions in trade agreements imposes stricter ecological constraints on businesses. Under such regulations, companies face heightened environmental standards and associated costs. To meet these requirements, enterprises must invest in technological upgrades and cleaner production methods to reduce carbon intensity per unit output. Simultaneously, stringent environmental standards drive companies to restructure production by phasing out outdated, high-pollution facilities and transitioning to low-carbon, eco-friendly industries. For instance, environmental clauses in FTAs led by developed nations have prompted automotive manufacturers to increase investments in new energy vehicle R&D and production, reducing traditional fuel-powered vehicle output to lower embodied carbon at the source.

From the consumption perspective, comprehensive environmental clauses reshape consumer preferences. When consumers become aware of products' environmental attributes, they increasingly favor items meeting high environmental standards. This market shift compels companies to redesign products and optimize production processes to align with consumer demands for low-carbon, eco-conscious goods. For instance, in the textile trade, enhanced environmental clauses compel companies to adopt eco-friendly dyes and refine dyeing techniques, producing textiles that better meet environmental standards and thus reduce consumer-side embodied carbon. In conclusion, the following research hypothesis is put forward.

Hypothesis 1: Enhancing the environmental provisions in free trade agreements can significantly reduce trade-related embodied carbon, with both production and consumption sides showing inhibitory effects.

3.2. The Impact of FTA Environmental Clauses on the Heterogeneity of Implicating Carbon in Trade

The scope of environmental provisions in free trade agreements varies significantly across different types of clauses, as they encompass multiple dimensions including environmental objectives, implementation mechanisms, and regulatory approaches. Multilateral and unilateral agreements exhibit fundamental differences in rule attributes, implementation logic, and governance effectiveness, which may lead to divergent impacts on trade-related implicit carbon. Furthermore, product attributes create essential differences in the formation mechanisms of carbon footprints be-

tween green and non-green products, as well as in the sensitivity of environmental provisions. Variations in importing countries' economic development levels, environmental policy frameworks, and industrial structures substantially alter the pathways and intensity of environmental policy effects. Consequently, the depth of environmental provisions influences the impact of export-related implicit carbon emissions through heterogeneous factors.

Hypothesis 2: The coverage dimension and type of environmental clauses in FTAs, the types of export products, and the development level of economies will have heterogeneous impacts on trade-related carbon emissions.

4. Model Setting and Variable Explanation

4.1. Model Setting and Estimation Method

This study employs the PPMLHDFE (Poisson Pseudo-Maximum Likelihood Estimation with High-Dimensional Fixed Effects) method to construct a econometric model for measuring trade-related carbon emissions (co2p) at the production level, as outlined below:

$$co2p_{ijkt} = \alpha_0 + \alpha_1 ep_{ijkt} + \alpha_2 gdp_{ijkt} + \alpha_3 open_{ijkt} + \alpha_4 indus_{ijkt} + \alpha_5 \ln distw_{ij} + \alpha_6 col_{ij} + \alpha_7 contig_{ij} + \mu_{hs6} + \nu_{year} + \varepsilon_{ijkt} \quad (1)$$

Similarly, the econometric model for consumption-side trade-related embodied carbon ($co2c$) is defined as:

$$co2c_{ijkt} = \beta_0 + \beta_1 ep_{ijkt} + \beta_2 gdp_{ijkt} + \beta_3 open_{ijkt} + \beta_4 indus_{ijkt} + \beta_5 \ln distw_{ij} + \beta_6 col_{ij} + \beta_7 contig_{ij} + \mu_{hs6} + \nu_{year} + \varepsilon_{ijkt} \quad (2)$$

The formula specifies:

$co2p_{ijkt}$ represents the production-side trade-related implicit carbon between country i and country j under the hs6 product classification in year t, while $co2c_{ijkt}$ denotes the consumption-side trade-related implicit carbon. ep_{ijkt} serves as the core explanatory variable indicating the depth of environmental terms in free trade agreements, and gdp_{ijkt} represents the economic scale variable. $open_{ijkt}$ indicates trade openness, and $indus_{ijkt}$ reflects industrial structure variables. $lndistw_{ij}$ denotes the logarithm of the weighted distance between the two countries. col_{ij} is a dummy variable for colonial history, and $contig_{ij}$ indicates geographical adjacency. μ_{hs6} represents the fixed effect of the hs6 product classification, υ_{year} is the fixed effect of the year, ε_{ijkt} is the random disturbance term, α_0 is the constant term, and α_1-α_8 are the regression coefficients of the explanatory variables.

4.2. Variable Selection

4.2.1. Explained variable

The dependent variable in this study is defined as trade-related embodied carbon, representing the indirect carbon emissions generated throughout the entire production, distribution, and consumption chain of goods and services. The data originates from the Trade-Related Carbon Emissions Database (TRCE) published by the Organisation for Economic Co-operation and Development (OECD) in 2021. The simplified calculation formula for trade-related embodied carbon is:

$$C=e(I-A)-1\times T \quad (3)$$

Here, C denotes the country-by-sector trade-related carbon emissions, e is the diagonalized matrix of carbon emission multipliers per unit of production. Considering the availability of data and the pertinence of the research questions, this paper selects the trade embodied carbon data from 2008 to 2017 from the above-mentioned OECD trade embodied carbon database as samples, and based on the trade embodied carbon variables of "production end (co2p) - consumption end (co2c)" in two dimensions, The heterogeneous impact of the depth of FTA environmental provisions on the trade embodied carbon emissions of member countries in the Global South was examined respectively, thereby comprehensively revealing the mechanism of FTA environmental provisions in regulating carbon reduction at the production end and responding to the pressure of carbon transfer at the consumption end in developing countries. .

4.2.2. Core Explanatory Variable

The core explanatory variable in this study is the environmental clause depth (denoted as ep) of free trade agreements (FTAs) in developing countries, with raw data sourced from the TREND Trade Agreement Database. The environmental clause depth between two countries is defined as the proportion of legally binding environmental clauses in their signed trade agreements relative to the total number of environmental clauses in the trade agreement sample database. A value of 1 is assigned to a specific environmental clause dimension if it exists in any valid agreement between the two countries, while 0 is assigned otherwise. The 48 environmental clause dimensions are then aggregated with equal weighting. To account for the "dynamic evolution" and "lagged impact" characteristics of environmental clauses, the depth metric is time-accumulated to reflect the cumulative process of clause development from non-existence to presence and from superficial to profound.

4.2.3. Controlled variable

In order to obtain relatively reliable estimation results, the factors influencing trade embodied carbon emissions have been controlled. Among them, the economic scale (gdp) is measured by the gross domestic product (GDP). The degree of trade openness (open) is calculated as "(total imports + total exports) /GDP×100%". The industrial structure (indus) is measured as "value added of the secondary indus-

try/GDP×100%" (Antweiler et al., 2001). Weighted Geographical Distance (lndistw) characterizes the true trade distance between two countries through a population-weighted approach. The historical colonial relationship (col) is a dummy variable. If there is a bilateral colonial relationship, it is taken as 1; otherwise, it is taken as 0 (Rose, 2004). Common boundary (contig) : It is a dummy variable. If the two countries are geographically adjacent, it takes 1; otherwise, it takes 0 (Anderson & van Wincoop, 2003).

4.3. Data Sources

The empirical analysis in this study utilizes panel data from Global South countries covering 2008-2017, with the sample scope strictly adhering to the United Nations Conference on Trade and Development (UNCTAD) 's official classification criteria for "Global South nations." Regarding variable data sources, the dependent variable "trade-related carbon intensity" is derived from global input-output databases (e.g., OECD-ICIO, WIOD) and the OECD's 2021 Trade-Related Carbon Emissions Database. Control variables reflecting macroeconomic characteristics—including economic size, trade openness, and industrial structure—are sourced from the World Bank's World Development Indicators (WDI) database. Geographical and historical correlation factors (population-weighted geographic distance, historical colonial ties, and shared borders) are analyzed using the GeoDist database developed by the Centre for International Economic Research (CEPII). By integrating these authoritative multi-source databases, the empirical framework ensures comprehensive data integrity, accuracy, and consistency, providing a robust foundation for subsequent econometric model estimation and result interpretation. Descriptive statistics of the sample are presented in Table 1.

Table 1. Descriptive statistics

VarName	Obs	Mean	SD	Min	Median	Max
co2p	284868	0.0770	0.3307	0.0000	0.0012	2.7633
co2c	284868	0.0800	0.3420	0.0000	0.0011	2.8503
ep	284868	1.3423	1.4913	0.0000	0.9474	9.3158
gdp	284868	0.8120	0.9405	0.0104	0.3620	2.6200
open	284868	67.4838	54.0637	0.0000	34.9710	191.8726
indus	284868	34.0481	15.7436	10.0519	25.2588	74.1130
lndistw	284868	7.6014	0.9119	4.8810	8.0697	9.7296
col	284868	0.5024	0.5000	0.0000	1.0000	1.0000
contig	284868	0.3369	0.4726	0.0000	0.0000	1.0000

5. Empirical Results and Analysis

5.1. Regression Result of Base Line

This study employs the Poisson Pseudo Maximum Likelihood (PPML) estimation method to empirically examine the relationship between the depth of environmental clauses in trade agreements and trade-related embodied carbon. By constructing

a dual-perspective framework (production-side and consumption-side) for measuring trade-related embodied carbon, we comprehensively evaluate the impact of environmental clause depth on trade-related embodied carbon. The baseline regression results are presented in Table 2.

The analysis of Table 2's baseline regression results reveals that the environmental clause depth (ep) in free trade agreements significantly suppresses both production-side and consumption-side trade-related carbon emissions. Both production-side and consumption-side environmental clause depth coefficients are negative and statistically significant at the 1% level, remaining significantly negative even after controlling for variables. On the production side, as environmental clause depth increases, participating enterprises face stricter compliance requirements. To mitigate compliance costs, companies reduce production-related carbon emissions through technological innovation, process optimization, and material substitution, thereby lowering production-side trade-related carbon. On the consumption side, enhanced environmental clauses not only promote eco-consciousness through agreement terms but also strengthen environmental disclosure via consumer protection provisions. This drives increased consumer awareness of environmental issues, compelling companies to adjust product structures and ultimately reducing consumption-side trade-related carbon. Overall, the increased environmental clause depth in trade agreements exerts a dual suppression effect on production-side and consumption-side trade-related carbon. This effectively reduces carbon emissions in Global South countries, validating Hypothesis 1 of this study and aligning with expectations.

Table 2. Regression result of base line

	(1) co2p	(2) co2c	(3) co2p	(4) co2c	(5) co2p	(6) co2c
ep	-0.151***	-0.167***	-0.088***	-0.088***	-0.203***	-0.218***
	(0.006)	(0.006)	(0.008)	(0.009)	(0.012)	(0.013)
gdp			-0.026*	-0.001	0.290***	0.288***
			(0.014)	(0.014)	(0.018)	(0.018)
open			-0.007***	-0.007***	-0.004***	-0.005***
			(0.000)	(0.000)	(0.000)	(0.000)
indus			-0.008***	-0.009***	-0.009***	-0.011***
			(0.001)	(0.001)	(0.001)	(0.001)
lndistw			0.113***	0.136***	0.245***	0.252***
			(0.017)	(0.018)	(0.015)	(0.016)
col			-0.651***	-0.682***	-0.261***	-0.329***
			(0.026)	(0.027)	(0.026)	(0.027)
contig			-0.226***	-0.203***	-0.153***	-0.146***
			(0.017)	(0.017)	(0.014)	(0.014)
_cons	-2.382***	-2.327***	-2.485***	-2.606***	-2.422***	-2.444***
	(0.010)	(0.010)	(0.161)	(0.163)	(0.134)	(0.137)
N	284868	284868	284868	284868	284739	284739
Hs6	No	No	No	No	Yes	Yes
Year	No	No	No	No	Yes	Yes

r2_p	0.005	0.005	0.049	0.061	0.408	0.420

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

5.2. Robustness Test

This paper mainly conducts robustness test from four aspects, such as changing model estimation method, changing regression sample, multi-period sample division and endogeneity problem.

5.2.1. Change The Model Estimation Method

This study employs Poisson Pseudo-Maximum Likelihood Estimation (PPML) for the benchmark regression, which effectively handles count data and heteroscedasticity but has inherent limitations. To address these shortcomings, we utilize Systematic Generalized Moment Estimation (xtdpdsys) for robustness testing. The xtdpdsys method incorporates lagged terms of the dependent variable as explanatory variables, effectively addressing endogeneity issues in dynamic panel data while controlling for individual heterogeneity and serial correlation. The results show that the sign and significance of the core explanatory variable, environmental term depth (ep), in the production side (co2p) and consumption side (co2c) regression are consistent with the benchmark regression, which verifies the reliability of the benchmark conclusion and enhances the robustness of the research conclusion.

5.2.2. Change Regression Sample

To address potential biases in the distribution of export-related carbon emission intensity and ensure robustness of the test results against extreme sample distortions, this study applies tail-trimming (1% and 5%) and capping (1% and 5%) methods to the dependent variable. The results demonstrate that the core explanatory variable ep consistently yields significantly negative estimates for trade-related carbon emissions across both production and consumption sectors, regardless of treatment. This confirms the conclusions 'robustness to outliers and highlights that the environmental clause depth's carbon emission suppression effect is systematic, observed across diverse distribution intervals.

5.2.3. Multi-Period Sample Partitioning

Following changes in trade policies, the adjustment period for trade flows typically exceeds one year, and the performance of trade-related carbon emissions also requires a certain adjustment period. This study covers the sample period from 2008 to 2017. To verify the temporal stability of the results, the sample was divided into two sub-periods for regression analysis: 2008-2012 and 2013-2017. The results show that the sign and significance of the core explanatory variable ep remained consistent across both periods, indicating that the baseline conclusions are robust and unaffected by the segmentation of the sample period.

5.2.4. Identification and Treatment of Endogenous Problems

This study further analyzes and addresses potential reverse causality issues related to endogeneity. As the implementation of global free trade agreements (FTAs) is not instantaneous but rather a gradual and prolonged process, markets that have already implemented FTAs require a certain period of adjustment. Current carbon emissions hardly contribute to the signing of historical FTAs, but existing FTAs continue to influence bilateral trade, thereby affecting carbon emissions. Therefore, the lagged treatment of FTAs can partially mitigate reverse causality and facilitate the exploration of long-term effects. To enhance the reliability of conclusions, this paper conducts regression analysis with all variables lagged by one period. The results show that the coefficient of environmental clause depth remains significantly negative and passes the 1% significance test, indicating that even after accounting for lag effects, the environmental clause depth in FTAs still exerts a suppressive effect on trade-related carbon emissions across both production and consumption sectors.

5.3. Heterogeneity analysis

5.3.1. Environmental conditions exhibit heterogeneity

Environmental clauses encompass multiple dimensions including environmental objectives, implementation mechanisms, and operational frameworks. Different types of clauses exhibit significant variations in regulatory intensity, focus areas, and implementation approaches. Conducting heterogeneity analysis on these clause categories enables a more nuanced understanding of the complex mechanisms through which environmental provisions influence trade-related embodied carbon. This approach facilitates policymakers' targeted refinement of environmental clauses. The seven major categories of environmental clauses include: environmental objectives, balancing environmental goals with trade/investment objectives, implementation mechanisms, external assistance, general environmental protection, compliance with multilateral environmental agreements, and participation in promoting environmental objectives. However, since the external assistance category contains only a single clause and the sample size is insufficient, potential estimation biases may arise. Therefore, this category was excluded from the empirical analysis.

The findings demonstrate that enhancing the depth of environmental provisions across both production and consumption sectors generally contributes to reducing trade-related carbon emissions, though the extent of impact varies. Specifically, clauses such as environmental objectives and compliance with multilateral environmental agreements (MEAs) show more pronounced effects in curbing trade-related carbon emissions. This highlights the critical importance of clear environmental targets and adherence to MEAs in mitigating carbon emissions from trade activities. Conversely, certain provisions like those balancing environmental goals with trade/investment objectives exhibit moderate curbing effects but

demonstrate relatively weaker impacts.

Table 3. Trade-embedded carbon in production

	(1) co2p	(2) co2p	(3) co2p	(4) co2p	(5) co2p	(6) co2p
ep1	-0.387***					
	(0.072)					
ep2		-1.138***				
		(0.162)				
ep3			-1.425***			
			(0.126)			
ep4				-0.230***		
				(0.035)		
ep5					-13.352***	
					(0.939)	
ep6						-0.369***
						(0.093)
cons	-2.606***	-2.525***	-2.570***	-2.361***	-2.843***	-2.698***
	(0.133)	(0.133)	(0.139)	(0.130)	(0.128)	(0.141)
N	284739	284739	284739	284739	284739	284739
CVs	Yes	Yes	Yes	Yes	Yes	Yes
Hs6	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
r2_p	0.406	0.406	0.407	0.406	0.408	0.406

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4. Carbon embodied in consumer trade

	(1) co2c	(2) co2c	(3) co2c	(4) co2c	(5) co2c	(6) co2c
ep1	-0.472***					
	(0.074)					
ep2		-1.260***				
		(0.168)				
ep3			-1.578***			
			(0.134)			
ep4				-0.250***		
				(0.036)		
ep5					-13.038***	
					(1.005)	
ep6						-0.470***
						(0.098)
_cons	-2.695***	-2.583***	-2.581***	-2.420***	-2.875***	-2.809***
	(0.137)	(0.136)	(0.144)	(0.134)	(0.132)	(0.144)
N	284739	284739	284739	284739	284739	284739
CVs	Yes	Yes	Yes	Yes	Yes	Yes
Hs6	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
r2_p	0.418	0.418	0.419	0.418	0.419	0.418

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.3.2. Protocol type heterogeneity

From an international governance perspective, multilateral and unilateral agreements exhibit fundamental differences in their rule attributes, implementation logic, and governance effectiveness, which establishes the theoretical basis for their distinct impacts on trade-related carbon emissions. Multilateral agreements are centered on collaborative governance among multiple countries. Through multi-round negotiations and interest balancing, they establish rule frameworks that are both binding and feasible, embedded in multi-tiered constraint and supervision systems. These agreements typically contain stricter enforcement mechanisms and oversight clauses, with multilateral institutions ensuring the fairness and enforceability of their implementation. In contrast, unilateral agreements are driven by the policy objectives of a single economy. Their rule design is autonomous and exclusive, lacking provisions for reciprocal rights and obligations or cross-entity supervision channels. This unilateral approach grants stronger autonomy to one party, often leading to "selective implementation" and resulting in inefficiency.

This study categorizes trade agreements into multilateral and unilateral types based on data from the WTO Trade Agreement Database. Columns (1)-(2) in Table 5 demonstrate the effects of multilateral agreements on trade-related implicit carbon emissions (production-side co2p and consumption-side co2c), while columns (3)-(4) illustrate the impacts of unilateral agreements. The regression analysis reveals that environmental provisions in both multilateral and unilateral agreements suppress trade-related carbon emissions. Notably, the environmental provision depth (ep) in multilateral agreements significantly reduces emissions across both production and consumption sides. In contrast, the environmental provision depth in unilateral agreements shows no significant inhibitory effect on trade-related carbon emissions.

Table 5. Protocol type heterogeneity

	(1) multilateral co2p	(2) multilateral co2c	(3) unilateral co2p	(4) unilateral co2c
ep	-0.185***	-0.201***	-0.172	-0.191*
	(0.019)	(0.021)	(0.105)	(0.110)
_cons	-2.602***	-2.726***	3.787*	4.461**
	(0.273)	(0.281)	(2.050)	(2.075)
N	74145	74145	1923	1923
CVs	Yes	Yes	Yes	Yes
Hs6	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
r2_p	0.433	0.446	0.571	0.583

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

5.3.3. Product Heterogeneity

In international trade and environmental studies, carbon emissions from the production and consumption of different products exhibit significant variations, with differing sensitivities to environmental regulations. Green products, leveraging low-carbon technologies, renewable materials, and lifecycle optimization, demon-

strate reduced environmental impacts and lower carbon emissions throughout their production, use, and disposal cycles. In contrast, non-green products often rely on energy-intensive materials and conventional production methods, lacking carbon reduction strategies that create a "high-carbon lock-in." However, they demonstrate greater flexibility in meeting environmental emission reduction requirements.

Therefore, this study categorizes products into green and non-green groups based on the HS6 product coding system for heterogeneity analysis. Columns (1)-(2) in Table 6 demonstrate how environmental clause depth (ep) affects trade-related carbon emissions for green products at both production (co2p) and consumption (co2c) stages, while columns (3)-(4) show similar impacts for non-green products. Regression results indicate that environmental clause depth significantly reduces trade-related carbon emissions for both green and non-green products, with a more pronounced effect on non-green products. This may be attributed to the fact that non-green products often rely on energy-intensive raw materials and traditional technologies, resulting in higher carbon emissions and lower environmental standards. Consequently, trade-related carbon emissions for non-green products are more sensitive to environmental clause depth. Therefore, increasing environmental clause depth can more effectively reduce carbon emissions in non-green product trade.

Table 6. Product heterogeneity

	(1) green product co2p	(2) green product co2c	(3) Non-green products co2p	(4) Non-green products co2c
ep	-0.181***	-0.183***	-0.203***	-0.218***
	(0.041)	(0.045)	(0.013)	(0.013)
_cons	-3.778***	-3.855***	-2.401***	-2.425***
	(1.063)	(1.108)	(0.135)	(0.138)
N	6811	6811	277928	277928
CVs	Yes	Yes	Yes	Yes
Hs6	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
r2_p	0.286	0.312	0.411	0.422

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

6. Conclusion and Policy

6.1. Research Conclusions

Against the backdrop of global economic integration, deepening free trade agreement (FTA) integration, and the combined advancement of global climate change and Sustainable Development Goals (SDGs), this study utilizes the TREND trade agreement database to quantify environmental rule texts across different types of trade agreements. By constructing an indicator for measuring the depth of environmental clauses, we systematically investigate their impact on the trade-related embodied carbon in both production and consumption sectors of developing countries through empirical research. The findings are as follows.

First, enhancing the depth of environmental provisions in free trade agreements can significantly reduce trade-related carbon emissions, demonstrating substantial inhibitory effects on both production-side and consumption-side embedded carbon. This conclusion remains robust across multiple stability tests, including model estimation method modifications, regression sample adjustments, multi-period sample segmentation, and endogeneity issues resolution, further validating its reliability. Second, heterogeneity analysis reveals that environmental objectives and compliance with multilateral environmental agreements exhibit more pronounced inhibitory effects through environmental clause depth. Compared to unilateral agreements, multilateral agreements demonstrate superior effectiveness in suppressing trade-related carbon emissions via environmental provisions. Since non-green products exhibit higher emission reduction elasticity toward environmental clauses, the inhibitory impact of environmental clause depth is more pronounced for non-green products. Additionally, when the importing country is a developing nation, the inhibitory effect of environmental clause depth on trade-related carbon emissions becomes more significant due to characteristics such as "high carbon elasticity" in production processes and lower domestic environmental standards and regulatory capacity.

6.2. Policy Recommendations

Against the backdrop of global warming, progress toward the Sustainable Development Goals (SDGs), China's experience as a representative developing country, and its "dual carbon" targets, this paper offers targeted policy recommendations for developing countries to balance trade growth and carbon reduction. These recommendations address core challenges including weak rule-making discourse power, gaps in green technology, and insufficient environmental governance capacity, building on prior research conclusions:

First, enhance discourse power in environmental clause rule-making. China should collaborate with regional economic blocs such as ASEAN and the African Union to establish a FTA negotiation cooperation mechanism for developing countries, unifying collective positions on environmental clause issues and advancing proposals that align with the industrial structure characteristics of developing nations. Meanwhile, an evaluation mechanism for the implementation effectiveness of environmental clauses should be set up to regularly track their impacts on trade-related carbon emissions and industrial employment, ensuring that rule-making balances environmental protection requirements with development needs.

Second, break low-carbon bottlenecks and construct a green trade system. Developing countries need to build a "technology-industry-trade" low-carbon transformation chain through transnational technology cooperation and local capacity cultivation. China should take the lead in launching a Green Technology Sharing Platform for Developing Countries, integrating mature technological resources in fields

like photovoltaics, energy storage, and low-carbon agriculture, and providing adaptive technical support to partner countries via technology licensing and joint research and development. It is also critical to strengthen local technology absorption and innovation capabilities, and establish an industry-academia-research-application collaboration mechanism through multilateral cooperation to realize the shift from simple technology introduction to localized innovation. Additionally, efforts should be made to promote the establishment of a mutual recognition system for green trade product certification, jointly developing unified low-carbon product standards and certification procedures with fellow developing countries to reduce trade barriers for green products.

Third, consolidate environmental governance foundations to align trade and emission reduction goals. China and other developing countries should draw on high-standard environmental provisions in international FTAs and formulate phased environmental legislation plans based on their respective national industrial transformation stages. Green financial instruments should be leveraged to guide capital flows toward low-carbon sectors and optimize market resource allocation, while a trade carbon footprint accounting and disclosure system should be established to require key export enterprises to disclose their product carbon footprints, driving industrial emission reduction through market-oriented mechanisms. At the societal level, new media and community outreach initiatives should be used to popularize knowledge on the links between low-carbon consumption and green trade, laying solid institutional safeguards for developing countries to explore a development path that integrates trade decarbonization and economic sustainability.

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