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Trade Benefits and Environmental Costs of GVCS: A Case Study of the BRICS

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Abstract

As the international trading system has developed with the division of Global value Chains (GVCS), the export trade of Brazil, Russia, India, China, and South Africa (BRICS) has grown rapidly. The resulting growth of carbon emissions has drawn wide attention from the international community, necessitating the comparison of the trade benefits and environmental costs of the BRICS participation in GVCS. Based on the Eora database, this paper constructs a decomposition framework for the calculation of export value-added and embodied carbon, based on a multi-region input-output (MRIO) model. The trade benefits and environmental costs paid by the BRICS' total exports from 1990 to 2015 were measured and the imbalance was analyzed, along with the causes. The results show that the main value-added and carbon embodied in the BRICS' exports originate from their own countries, and the domestic value-added content of the BRICS' exports decreased while the foreign value-added content increased.

Keywords

BRICS, GVCS, Export Added Value, Carbon Embodied in Export, Source of Imbalance between the Trade Benefits and Environmental Costs

1. Introduction

The BRICS (Brazil, Russia, India, China, and South Africa) accounted for 24% of the world economy in 2019 and contributed more than 50% to world economic growth. The increasing economic volume and rapid economic growth also mean a large amount of energy consumption, and the carbon emissions of the BRICS have increased dramatically. According to the *BP Statistical Review of World Energy 2017* China, India, Russia, Brazil and South Africa ranked 1st, 3rd, 4th, 8th, and 23rd, respectively, in primary energy consumption, with a 36.7% combined share. They ranked 1st, 3rd, 4th, 13th, and 15th, respectively, in CO_2 emissions, with a combined share of 41.18%.

Their growth of carbon emissions is faster than their rate of economic growth, which has placed the BRICS under pressure to save energy and reduce emissions. Developed countries have violated obligatory promises made in Paris and pressured developing countries by imposing carbon tariffs and withdrawing from emissions reduction agreements, requiring developing countries to assume more obligations to reduce carbon emissions. To promote global climate governance, the international carbon emission reduction negotiations of post-Glasgow is inevitable, with the outcome affecting the process of global environmental protection.

The rapid growth of carbon emissions in BRICS is closely related to the international trade system characterized by the division of labor in GVCS (Pan, 2017). As international trade and the international division of labor have intensified, transnational production and international cooperation have become common, and the separation of production and consumption has deepened. Developed countries, by virtue of their advantages in technology and capital, occupy high value-added production links such as product research and development, and brand marketing, and meet domestic resource demand by importing pollution-intensive and energy-consuming products, thus transferring domestic carbon emissions to developing countries (Yin, 2018). Peters and Hertwich, (2008) note that, in 2001, the amount of carbon emission developed countries transferred to developing countries through international trade exceeded 5 billion tons. Wang and Watson, (2007) pointed out that 29% of Chinese carbon emissions is used to meet the consumption needs of other countries. As a result, developing countries are forcibly embedded in the lower end of the value chain, making less profit from trade and incurring higher environmental costs while taking on the responsibility to reduce emissions, while developed countries enjoy the high trade benefits and low environmental costs brought by the high-end link of the value chain, thus avoiding the responsibility of emissions reduction. This is undoubtedly detrimental to developing countries and has furthered injustice in global climate governance.

The BRICS are the most representative and vocal group among the developing countries. To actualize global climate governance, promote South-South cooperation in carbon emissions reduction, and increase the influence of developing countries in emissions reduction and trade negotiations, measuring and comparing the trade benefits and environmental costs of the BRICS' participation in GVCS are important.

This paper comparatively analyzes the trade benefits and environmental costs of exports in the BRICS' GVCS, by comprehensively considering the export value added and the embodied carbon of trade. This paper makes two contributions to the literature. First, it augments the literature by including data analysis on both value added and carbon embodied trade. Second, most such studies focus on comparing developing and developed countries, with few studies on developing countries. In contrast, developing countries have smaller technology and capital differences and are similarly positioned in the division of labor within the GVCS. Comparing the export value added and carbon embodied of developing countries will provide new ideas and methods for developing countries to change the imbalance between trade benefits and environmental costs.

2. Literature Review

Research on the BRICS and the trade benefits and environmental costs of GVCS can be divided into three parts: export added value, research on embodied carbon in trade, and the exploration of comparative research on trade benefits and environmental costs.

2.1. Value of Export-Added Trade

Zhong et al. (Zhong et al., 2021) and Xiong et al. (Xiong & Wu, 2021) believe that the traditional trade accounting method can't accurately calculate a country's trade added value, and select a single BRICS country for trade added value accounting. From the perspective of China, they use the multi-region input-output model to calculate the scale of China's trade added value. The results show that the traditional trade overestimates China's trade benefits. Wang et al. (Wang et al., 2013a) utilized OECD and UNCOMTRADE databases to measure the domestic export value added of manufacturing industry sectors in the BRICS and compared their structural differences in manufacturing industry exports. They found that the advantages of China's manufacturing exports are concentrated in low- and medium-tech industries; and India has the highest domestic export value-added ratio in the high-tech industry. Lin and Tang (Lin & Tang, 2015), using I-O modeling, measured and decomposed the value of the BRICS' export trade in GVCS and found that China and India have been confronting the risk of value-chain status solidification, while Brazil and Russia have little sustainability in gaining trade benefits, although their domestic value-added content for exports is high. Using I-O modeling, Guo and Zhao (Guo & Zhao, 2016) found that the contribution of foreign demands to the GVCS of the BRICS has been increasing. Li and Guo (Li & Guo, 2016) applied the Koopman export decomposition method to measure and decompose China's export value-added to Russia, Brazil, and India during the period 1995-2011. They found that China's exports to these countries have changed from primary commodities to manufactured goods, but the domestic value added of finished export products comprise a relatively small part, while exports of intermediate products account for a higher percentage, with value-added content of exports remaining high. Yang (Yang, 2019) compared the division status of the 56 industries in the BRICS' GVCS based on a value-added accounting framework, finding that China ranks first among the BRICS in terms of the length of global value chain and the size of value-added exports, and there are 19 industries in the BRICS with relatively similar positions of division of labor in global value chain. The above research shows that there are differences in the components of domestic added value in the BRICS.

2.2. Research on Embodied Carbon in Trade

Jiang (Jang, 2016) using I-O modeling and structural decomposition, measured and compared embodied carbon in trade between the BRICS, and found that Russia and China have an embodied carbon surplus in their export trade, becoming "pollution heavens". Brazil and India, meanwhile, have an embodied carbon deficit in export trade. Pan (Pan & Wei, 2015) and Zheng (Zheng et al., 2018), using input-output modeling, conducted a comparative analysis on embodied carbon flows in trade between the BRICS to ascertain if "carbon leakage" occurs within developing countries. Qiao et al. (Qiao et al., 2018) measured the embodied carbon in trade of total and segmented industries between China and the other BRICS from 1992 to 2013, using the Eora database and the Tapio decoupling model to investigate the relationships between trade development and carbon emissions. Zhao (Zhao, 2015), Guo (Guo, 2017), Zhang (Zhang, 2017), and Qiu (Qiu, 2018) measured and compared The BRICS' foreign trade embodied carbon based on the input-output model, studied the influencing factors of the BRICS' trade embodied carbon by using structural decomposition method and econometric model, and predicted the BRICS' import and export embodied carbon from 2015 to 2020 by using ARIMA model. Through literature review, it can be found that multi regional input-output model has been widely used in the field of trade embodied carbon measurement. However, most of the data used for the measurement of trade embodied carbon in the BRICS or other economies are based on traditional trade statistics, and there are few studies on the measurement of embodied carbon based on the value-added trade accounting framework. Under the unified framework, there are few studies on the calculation and comparison of the BRICS export trade benefits and environmental costs.

2.3. Research on Trade Benefits and Environmental Costs

Jiang and Liu (Jiang & Liu, 2013) compared the intensity of value-added content of exports between developed and developing countries. They used structural decomposition to study the reasons for the differences, creating an embodied carbon emissions index of unit export value added while considering the economic benefits that countries obtain from international trade and their corresponding carbon emissions. Zhang and Sheng (Zhang & Sheng, 2017) measured the emissions intensity of air pollutants from China's exports based on value added. They utilized structural decomposition to study the differences in the environmental costs of exports and their influencing factors between China and major developed countries. Ma and Chen (Ma & Chen, 2020) used value-added statistics to estimate the scale of bilateral trade between the US and China and the embodied carbon, finding that traditional customs statistics seriously overestimated the real trade scale between China and the United States, especially China's export and surplus to the United States. Although the comparison of pollution intensity of export unit added value reflects the difference of pollutant emissions that countries need to bear to obtain the same trade benefits, under the international division of labor system characterized by global value chain, the difference of export pollution intensity of countries is the result of the joint action of global division of labor and technical level, It is also difficult to distinguish the role of production technology and division of labor based on the structural decomposition of added value pollution intensity. The further research results of the value-added trade statistical framework provide conditions for the measurement and decomposition of export value-added and embodied carbon under a unified framework. The calculation and decomposition under the unified framework can compare the value-added sources and carbon emissions of each export path, and further explore whether the trade benefits and environmental costs obtained by countries in the process of participating in the global value chain are unbalanced and the specific sources of the imbalance. Meng (Meng et al., 2015) and Lv (Lv, 2017) compared the differences in export trade benefits and environmental costs between developed and developing countries, and provided empirical evidence for the transfer of high-carbon industries in developed countries and the locked low-end value in developing countries. However, based on the comparison within developing countries, there are few studies that measure and decompose a country's added value and embodied carbon under a unified framework. In addition, the research based on the BRICS lacks the research on the added value and embodied carbon in South Africa's exports. Therefore, based on the same database and under the same caliber, the research on export added value and embodied carbon of the BRICS is more scientific and comparable.

In summary, studies have measured and decomposed the added value of BRICS exports in GVCS and compared the domestic value creation and foreign value transfer by the BRICS based on input-output (I-O) models (Lv, 2017; Wang et al., 2013a; Pan et al., 2020). Studies have also used input-output models to measure the level of embodied carbon in the foreign trade of the BRICS to investigate if they have taken over the high carbon emission industries from developed countries. However, research has been conducted based on the single criteria of added or embodied carbon, fewer studies have measured and decomposed a country's value added and embodied carbon under a unified framework. The present article will extend the current literature by investigating both.

3. Model Introduction and Data Descriptions

3.1. Model Selection

WWZ is the main method of value-added trade accounting, which can meticulously measure and decompose the value added by countries at the sector, bilateral, and bilateral-sector levels while comparing the imbalance of trade benefits and environmental costs of participation in GVCS. This paper adopts the WWZ decomposition method proposed by Wang et al. (Wang et al., 2013b) to measure and analyze the data. The measuring base is a multi-region I-O model, which is similar to the method of measuring trade-embodied carbon. The measurement and decomposition of carbon embodied in exports and the export added value under one framework provides the conditions to accurately compare the trade benefits and environmental costs of participation in GVCS.

3.1.1. WWZ Decomposition Method

The I-O table is a balance sheet reflecting the relationship between inputs and outputs among various sectors of the national economy in a period of time; it can reveal the output of each sector and the production of these outputs into each sector or the final consumption, as well as the initial and intermediate input status of each sector in its own production process. A multi-region input-output (MRIO) model can clearly show the I-O state of product flow and product consumption among sectors in each region and is often used. Table 1 shows the MRIO model for the N sector in country G.

In Table 1, Z^{sr} is an N × N-dimensional matrix that represents the use of intermediate inputs from country *s* products in country *r*; Y^{sr} is an N × 1-dimensional vector that represents the final consumption of country *s* products in country *r*; X^s is also an N × 1-dimensional vector that represents the total output of country *s*; and Va^s describes the direct value-added (initial inputs) of country *s*, and is a 1 × N-dimensional vector. In addition, the superscript mark indicates transposition. According to the MRIO model, the following equilibrium equation exists:

$$\begin{bmatrix} A^{11} & A^{12} & \dots & A^{1g} \\ A^{21} & A^{22} & \dots & A^{2g} \\ \dots & \dots & \dots & \dots \\ A^{g1} & A^{g2} & \dots & A^{gg} \end{bmatrix} \begin{bmatrix} X^1 \\ X^2 \\ \dots \\ X^g \end{bmatrix} + \begin{bmatrix} Y^{11}+Y^{12}+\dots+Y^{1g} \\ Y^{21}+Y^{22}+\dots+Y^{2g} \\ \dots \\ Y^{g1}+Y^{g2}+\dots+Y^{gg} \end{bmatrix} = \begin{bmatrix} X^1 \\ X^2 \\ \dots \\ X^g \end{bmatrix} \quad (1)$$

In Equation (1), the input coefficient $A^{sr} = Z^{sr}\left(\widehat{X^r}\right)^{-1}$ denotes the amount of product from country *s* directly consumed in the intermediate inputs of a unit of output in country *r*. Equation (1) can be further transformed into $BY = X$, where $B = (I - A)^{-1}$ is the Leontief inverse matrix and B^{sr} denotes the sum of the amount of products of country *s* consumed directly or indirectly in intermediate

Table 1. Multi-region input-output.

Input	Output	Intermediate Use				Final demand				Total Output
		1	2	…	*G*	1	2	…	*G*	
Intermediate Input	1	Z^{11}	Z^{12}	…	Z^{1g}	Y^{11}	Y^{12}	…	Y^{1g}	X^1
	2	Z^{21}	Z^{22}	…	Z^{2g}	Y^{21}	Y^{22}	…	Y^{2g}	X^2
	⋮	⋮	⋮	…	⋮	⋮	⋮	…	⋮	⋮
	G	Z^{g1}	Z^{g2}	…	Z^{gg}	Y^{g1}	Y^{g2}	…	Y^{gg}	X^g
Initial Input/Value added		Va^1	Va^2	…	Va^g					
Total Input		$(X^1)'$	$(X^2)'$	…	$(X^g)'$					

Data: authors.

inputs per unit of final output in country r. A country's total output can be expressed as the sum of the intermediate use and final demand for that country by each country:

$$X^s = \sum\nolimits_r^g A^{sr} X^r + \sum\nolimits_r^g Y^{sr} = A^{ss} X^s + \sum\nolimits_{r \neq s}^g A^{sr} X^r + Y^{ss} + \sum\nolimits_{r \neq s}^g Y^{sr} \tag{2}$$

where $\sum\nolimits_{r \neq s}^g A^{sr} X^r$ denotes the export of intermediate products from country s to other countries, and $\sum\nolimits_{r \neq s}^g Y^{sr}$ denotes the exports by country s of final goods to other countries. Therefore, the total export E^s of country s can be expressed as the sum of intermediate and final product exports:

$$E^s = \sum\nolimits_{r \neq s}^g A^{sr} X^r + \sum\nolimits_{r \neq s}^g Y^{sr} \tag{3}$$

According to the WWZ, the total export E^s of country s can be decomposed into 16 terms with different economic meanings depending on the source of value added, the final place of absorption, and the absorption path:

$$\begin{aligned} E^s &= \sum_{r \neq s}^{G} E^{sr} \\ &= \left(V^s B^{ss}\right)' \# \sum\nolimits_{r \neq s}^G Y^{sr} + \left(V^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} B^{rr} Y^{rr} + \left(V^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} \sum\nolimits_{r \neq s,r}^G B^{rt} Y^{tt} \\ &\quad + \left(V^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} B^{rr} \sum\nolimits_{r \neq s,r}^G Y^{rt} + \left(V^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} \sum\nolimits_{r \neq s,r}^G \sum\nolimits_{u \neq s,t}^G B^{rt} Y^{tu} \\ &\quad + \left(V^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{rs} B^{rr} Y^{rs} + \left(V^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} \sum\nolimits_{r \neq s,r}^G B^{rt} Y^{ts} \\ &\quad + \left(V^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} B^{rs} Y^{ss} + \left(V^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} \sum\nolimits_{r \neq s,r}^G B^{rs} Y^{st} \\ &\quad + \left(V^s B^{ss} - V^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} X^r + \sum\nolimits_{r \neq s}^G \left(V^r B^{rs}\right)' \# Y^{sr} \\ &\quad + \sum\nolimits_{r \neq s}^G \left(V^r B^{rs}\right)' \# A^{sr} L^{rr} Y^{rr} + \sum\nolimits_{r \neq s}^G \left(V^r B^{rs}\right)' \# A^{sr} L^{rr} E^r \\ &\quad + \sum\nolimits_{r \neq s}^G \sum\nolimits_{t \neq s,r}^G \left(V^t B^{ts}\right)' \# Y^{sr} + \sum\nolimits_{r \neq s}^G \left(\sum\nolimits_{t \neq s,r}^G V^t B^{ts}\right)' \# A^{sr} L^{rr} Y^{rr} \\ &\quad + \sum\nolimits_{r \neq s}^G \left(\sum\nolimits_{t \neq s,r}^G V^t B^{ts}\right)' \# A^{sr} L^{rr} E^r \end{aligned} \tag{4}$$

In Equation (4), $V^s = Va^s \left(X^s\right)^{-1}$ is the matrix of the coefficients of value added; $L^{ss} = \left(I - A^{ss}\right)^{-1}$ is the domestic Leontief inverse matrix; and # indicates the matrix point multiplication.

3.1.2. Extending the WWZ Decomposition Method to the Decomposition of Carbon Embodied in Exports

The carbon embodied in exports (TCEs) of country s can be decomposed into 16 terms with different economic meanings depending on the source carbon embodied, the final absorption place and the absorption path:

$$\begin{aligned} TCE^s &= \sum_{r \neq s}^{G} TCE^{sr} \\ &= \left(EI^s B^{ss}\right)' \# \sum\nolimits_{r \neq s}^G Y^{sr} + \left(EI^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} B^{rr} Y^{rr} + \left(EI^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} \sum\nolimits_{r \neq s,r}^G B^{rt} Y^{tt} \\ &\quad + \left(EI^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} B^{rr} \sum\nolimits_{r \neq s,r}^G Y^{rt} + \left(EI^s L^{ss}\right)' \# \sum\nolimits_{r \neq s}^G A^{sr} \sum\nolimits_{r \neq s,r}^G \sum\nolimits_{u \neq s,t}^G B^{rt} Y^{tu} \end{aligned}$$

$$
\begin{aligned}
&+\left(EI^{s}L^{ss}\right)'\#\sum\nolimits_{r\neq s}^{G}A^{rs}B^{rr}Y^{rs}+\left(EI^{s}L^{ss}\right)'\#\sum\nolimits_{r\neq s}^{G}A^{sr}\sum\nolimits_{r\neq s,r}^{G}B^{rt}Y^{ts}\\
&+\left(EI^{s}L^{ss}\right)'\#\sum\nolimits_{r\neq s}^{G}A^{sr}B^{rs}Y^{ss}+\left(EI^{s}L^{ss}\right)'\#\sum\nolimits_{r\neq s}^{G}A^{sr}\sum\nolimits_{r\neq s,r}^{G}B^{rs}Y^{st}\\
&+\left(EI^{s}B^{ss}-EI^{s}L^{ss}\right)'\#\sum\nolimits_{r\neq s}^{G}A^{sr}X^{r}+\sum\nolimits_{r\neq s}^{G}\left(EI^{r}B^{rs}\right)'\#Y^{sr}\\
&+\sum\nolimits_{r\neq s}^{G}\left(EI^{r}B^{rs}\right)'\#A^{sr}L^{rr}Y^{rr}+\sum\nolimits_{r\neq s}^{G}\left(EI^{r}B^{rs}\right)'\#A^{sr}L^{rr}E^{r}\\
&+\sum\nolimits_{r\neq s}^{G}\left(\sum\nolimits_{t\neq s,r}^{G}EI^{t}B^{ts}\right)'\#Y^{sr}+\sum\nolimits_{r\neq s}^{G}\left(\sum\nolimits_{t\neq s,r}^{G}EI^{t}B^{ts}\right)'\#A^{sr}L^{rr}Y^{rr}\\
&+\sum\nolimits_{r\neq s}^{G}\left(\sum\nolimits_{t\neq s,r}^{G}EI^{t}B^{ts}\right)'\#A^{sr}L^{rr}E^{r}
\end{aligned}
\tag{5}
$$

where $EI^{s}=CO^{s}\left(X^{s}\right)^{-1}$ is the direct carbon emissions coefficient representing the direct carbon emissions per unit of output, and CO is the carbon dioxide emissions vector.

Equations (4) and (5) decompose a country's export value added and carbon embodied in exports into 16 components under the same decomposition framework. For convenience, this paper combines the 16 decompositions into two levels for analysis, the specific meanings of which are shown in Table 2. If trade benefits (export added value) are the positive output of a country's participation in GVCS, then the output of domestic carbon emissions resulting from commodity exports is negative, i.e., the environmental cost of a country's participation in GVCS. The domestic value added (DVA) absorbed by foreign countries (export value added), is the real trade benefit of a country's participation in the global value chain's division of labor. Accordingly, the domestic carbon emissions (DCE) absorbed by foreign countries is the domestic carbon emissions caused by the trade benefits of a country participating in the division of the global value chain—that is, the environmental cost.

3.2. Data Sources

Currently the Eora database only provides MRIO data covering 189 countries with 26 sector classifications and data for 35 environmental indicators matched with MRIO tables from 1990 to 2015, including greenhouse gas emissions, air pollution, and energy use. Based on data completeness and time length, the time span of this study is 1990-2015. Because the EDGAR database is more detailed for fuel classification and methodology and relatively more accurate in terms of carbon emissions accounting, the CO_2 emissions data for subsectors are obtained from the EDGAR database from the Eora database.

4. Decomposition Results

4.1. First-Level Decomposition

As shown in Table 3, the share of DVA in the BRICS' exports is above 80%, and the corresponding share of DCE ranges from 70% to 90%, with the preponderant value added and carbon embodied in exports originating in their own countries. Along with the deepening of international trade and international division, the

Table 2. Meaning of each level decomposition of export value added and embodied carbon.

	First-level Decomposition	Meaning	Second-level Decomposition	Meaning
Domestic Value Added/Domestic Carbon Emissions	DVA/DCE (items 1 - 5)	Domestic Value Added absorbed by foreign countries/ Carbon Emissions	DVA_FIN/DCE_FIN (item 1)	Domestic Value Added/Domestic Carbon Emissions contained in final product exports
			DVA_INT/DCE_INT (item 2)	Domestic Value Added/Domestic Carbon Emissions contained in intermediate product exports
			DVA_INTrex/DCE_INTrex (items 3 - 5)	Domestic Value Added/Domestic Carbon Emissions contained in intermediate product exports ultimately consumed by the third country
	RDV/RDE (items 6 - 8)	Returned Domestic Value Added/ Returned Domestic Carbon Emissions	RDV/RDE (items 6 - 8)	Domestic Value Added/Domestic Carbon Emissions of re-imported goods contained in intermediate product exports ultimately consumed domestically
Foreign Value Added/Foreign Carbon Emissions	FVA/FCE (items 11 - 12, 14 - 15)	Foreign Value Added/Foreign Carbon Emissions	MVA_FIN/MCE_FIN (item 11)	Foreign Value Added/Foreign Carbon Emissions contained in intermediate product exports ultimately consumed by importing countries
			MVA_INT/MCE_INT (item 12)	Foreign Value Added/Foreign Carbon Emissions contained in intermediate product exports
			OVA_FIN/OCE_FIN (item14)	Value Added/Foreign Carbon Emissions of the Third Country contained in final product exports
			OVA_INT/OCE_INT (item 15)	Value Added/Foreign Carbon Emissions of the Third Country ultimately consumed by importing countries contained in intermediate product exports
	PDC/PDE (items 9, 10, 13, 16)	Double-calculated Value Added/ Double-calculated Carbon Emissions	PDC/PDE (items 9, 10, 13, 16)	Double-calculated Value Added/Double-calculated Carbon Emissions

Data: authors.

share of DVA in export products follows a decreasing trend while the foreign value-added (FVA) from foreign countries is increasing. The share of value-added (RDV) of the export-over-import component of BRICS' exports is small in all countries. India and South Africa occupy less than 1%, while China has a faster growth, with its share increasing from 0.24% in 1990 to 3.08% in 2015. In the export-over-import component, the trade pattern is one country producing products by participating in the upper-stream segment of the global value chain and then reimports these products that have been processed by other countries to meet the domestic consumption needs, which laterally reflects a country's position in the upper-stream segment of GVCS and, to some extent, reflects the disadvantageous position of India and South Africa in the upstream link and China's efforts to upgrade its embedded position. Except for Russia, the BRICS' FVA in exports and the share of its resulting foreign carbon emissions (FCE) both follow an increasing trend. The Russian share of FVA is the lowest,

Table 3. Decomposition results of the BRICS' value-added and embodied carbon 1990-2015[a].

Year	Country	Name	DVA/DCE			RDV/RDE			FVA/FCE			PDC/PDE		
			Value Added	Embodied Carbon	Intensity	Value Added	Embodied Carbon	Intensity	Value Added	Embodied Carbon	Intensity	Value Added	Embodied Carbon	Intensity
1990	Brazil	Contents	257.82	20.41	0.79	0.88	0.07	0.83	16.72	2.07	1.24	3.99	0.50	1.25
		Proportion	92.27	88.52		0.32	0.32		5.98	9.00		1.43	2.16	
	Russia	Contents	550.94	407.43	7.40	9.56	7.64	8.00	43.12	33.52	7.77	14.88	12.86	8.64
		Proportion	89.08	88.29		1.55	1.66		6.97	7.26		2.41	2.79	
	India	Contents	181.45	50.37	2.78	0.25	0.07	2.95	10.21	1.60	1.56	2.28	0.36	1.58
		Proportion	93.44	96.12		0.13	0.14		5.26	3.05		1.17	0.69	
	China	Contents	780.50	399.79	5.12	2.01	1.20	5.96	34.87	4.35	1.25	8.82	1.33	1.51
		Proportion	94.47	98.31		0.24	0.29		4.22	1.07		1.07	0.33	
	South Africa	Contents	155.25	56.57	3.64	0.33	0.13	3.83	16.30	1.82	1.12	5.58	0.63	1.12
		Proportion	87.48	95.64		0.19	0.22		9.19	3.08		3.14	1.06	
1995	Brazil	Contents	2176.64	66.82	0.31	32.23	1.08	0.33	278.90	15.16	0.54	79.34	4.21	0.53
		Proportion	84.79	76.57		1.26	1.23		10.86	17.38		3.09	4.82	
	Russia	Contents	3791.48	470.31	1.24	94.78	12.14	1.28	261.82	25.42	0.97	161.28	17.58	1.09
		Proportion	87.98	89.51		2.20	2.31		6.08	4.84		3.74	3.35	
	India	Contents	2758.09	487.25	1.77	16.89	3.11	1.84	380.69	25.28	0.66	113.56	7.95	0.70
		Proportion	84.37	93.06		0.52	0.59		11.64	4.83		3.47	1.52	
	China	Contents	16869.99	2099.28	1.24	624.31	83.77	1.34	1949.32	101.95	0.52	814.72	55.24	0.68
		Proportion	83.27	89.70		3.08	3.58		9.62	4.36		4.02	2.36	
	South Africa	Contents	994.42	148.35	1.49	2.62	0.41	1.56	160.61	7.85	0.49	65.12	3.20	0.49
		Proportion	81.33	92.83		0.21	0.26		13.13	4.91		5.33	2.00	

Data: authors. [a]Due to limited space, this paper only shows the total decomposition data for 1990 and 2015. The meaning of each data set in Table 3 is shown in the following table.

Value Added (unit; 100M USD)	Embodied Carbon (unit; 1K Ton)	Carbon Emission Intensity (unit: 1K Ton/1M USD)
Percentage of added value in total exports (unit; %)	Percentage of embodied carbon in total export embodied carbon (unit; %)	

at only 6.08% in 2015; South Africa is the highest at 13.13%. This low share is due to the fact that Russia mainly focuses on production in the upper-stream segment of the global value chain and exporting primary products using its own advantages. The Russian import substitution policy, from its spontaneous formation to ultimate role as a national security strategy, is the root cause of the discrepancy. Under the influence of economic crisis and pressure at home and abroad, the voluntary import substitution policy at the beginning of 1998 was promoted by the financial crisis in 2008 and became Russia's national development strategy in 2014. To attenuate foreign economic dependence and break Western economic sanctions, Russian import substitution policies spread from the food industry to the military industrial sector (i.e., aviation, shipping), replacing imports with domestic products and achieving self-sufficiency in production. As a result, the use of imported intermediate goods in Russian exports has gradually decreased and the share of DVA remains high.

Figure 1 and Figure 2 display the changes of domestic added value (DVA) of The BRICS and the absolute amount of domestic embodied carbon (DCE) in export. On the whole, from 1990 to 2015, the domestic added value of the BRICS export trade showed a growing trend (Figure 1). From 1990 to 2002, the export trade and domestic added value of the BRICS increased steadily. After 2002, with the deepening development of international trade and international division of labor, the export trade of the BRICS accelerated, and the domestic added value climbed all the way to 2008. Affected by the financial crisis in 2009, the domestic added value of export trade of the BRICS decreased to a certain extent, and the growth trend gradually recovered in the next three years. After 2011, the growth rate of export trade and domestic added value of the BRICS slowed down, showing a steady growth trend. Individually, China plays a leading role in the export

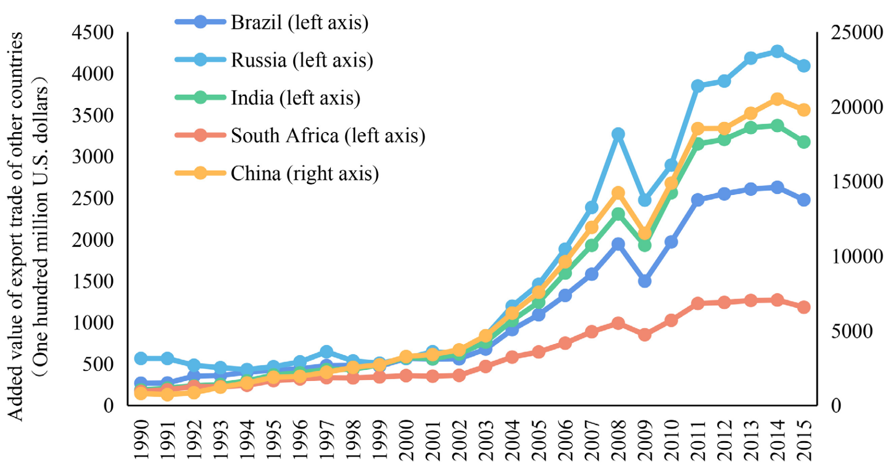

Figure 1. The added value of export trade of The BRICS from 1990 to 2015. Data: Eora Database, authors-calculated.

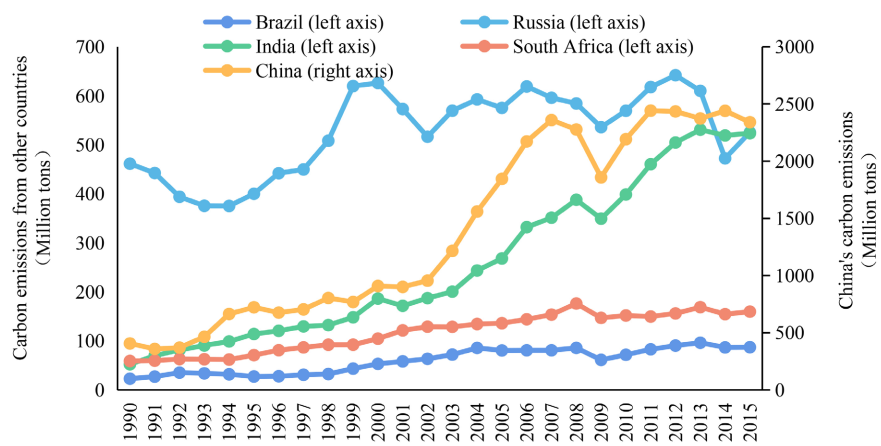

Figure 2. The total embodied carbon in exports of The BRICS from 1990 to 2015. Data: Eora Database, authors-calculated.

trade of the BRICS. Russia is the second largest country among the BRICS to obtain the domestic added value of export trade. The growth rate of Domestic added value of India's export trade is second only to that of China. The domestic added value of Brazil's export trade grew slowly. South Africa has the smallest growth rate of domestic added value of export trade among the BRICS, and the gap with other BRICS has gradually widened.

Since 1990, the change of embodied carbon in export trade of the BRICS is shown in Figure 2. On the whole, the total carbon embodied in BRICS exports shows a rising trend. Individually, different from the change of total export trade, the trend of total carbon embodied in export trade varies among the BRICS. From 1990 to 2015, the carbon embodied in Brazil and South Africa's exports was generally low and showed a trend of steady increase. The carbon embodied in exports of China and India showed a trend of rapid increase. China's export of embodied carbon increased rapidly from 1990 to 2015, becoming the country with the largest total export of embodied carbon of BRICS. India is the country with the fastest growth rate of export embodied carbon. The carbon embodied in Russia's exports showed a trend of fluctuation. From 1990 to 1994, due to domestic political turmoil, economic recession and other reasons, Russia's export trade decreased, so did the export embodied carbon. From 1995 to 1999, the domestic political situation gradually stabilized, and the carbon embodied in Russia's export rose rapidly. After entering the 21st century, the carbon embodied in Russia's export stabilized at around 570 million tons.

There are also differences in the carbon emission intensity of domestic production in the the BRICS. As shown in Figure 3, although the domestic carbon intensity of each country tends to decrease, Brazil's carbon emission intensity has always been at a low level, and Russia's carbon emission intensity has gradually converged with the other three countries after a steep increase in the period of 1997-1999. The Asian financial crisis that started in 1997 dealt a huge blow to Russia's export trade, and both the market prices of major export resources (energy and metals) and the export trade earnings plummeted, which led to a

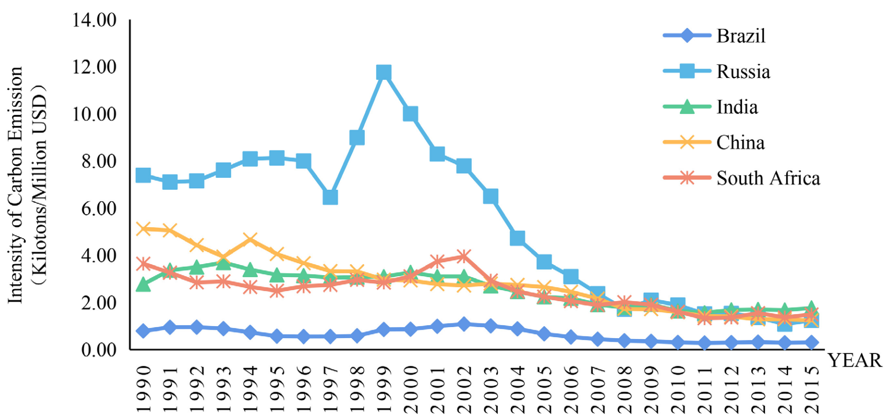

Figure 3. Changes in the domestic carbon emission intensity of exports from The BRICS from 1990 to 2015. Data: Eora Database, authors-calculated.

sharp increase in the carbon emission intensity of Russian exports. The fact that Brazil's export carbon emission intensity is significantly lower than that of other BRICS is due to its dominant position in the global value chain.

4.2. Second-Level Decomposition

To further understand the main sources of trade benefits from the BRICS participation in GVCS and the corresponding differences, we further decompose DVA/DCE and FVA/FCE to provide additional information for the reasons behind the imbalance between trade benefits and environmental costs. As shown in Table 4, the sum of DVA (DVA_INT) of intermediate goods exported by the BRICS and then finally consumed by importing countries and the DVA (DVA_INTrex) of intermediate goods exported for final consumption in third countries ranges from 50% to 80%, and the sum of the corresponding carbon ratio is also at this level with most of DVA and DCE of exported products coming from intermediate goods. As countries become more involved in GVCS, the share of DVA_INT has been decreasing, and the DVA_INTrex of the BRICS (minus Brazil) has been increasing.

Table 4. The proportion of BRIC countries' export value added and embodied carbon DVA/DCE and FVA/FCE (Unit: %).

Year	Country	Name	DVA_FIN/ DCE_FIN	DVA_INT/ DCE_INT	DVA_INTrex/ DCE_INTrex	MVA_FIN/ MCE_FIN	OVA_FIN/ OCE_FIN	MVA_INT/ MCE_INT	OVA_INT/ OCE_INT
1990	Brazil	Value Added	29.61	44.13	18.54	0.26	2.34	0.34	3.05
		Embodied Carbon	30.11	41.16	17.25	0.39	3.47	0.51	4.62
	Russia	Value Added	16.23	49.38	23.48	0.07	2.01	0.22	4.67
		Embodied Carbon	15.04	49.41	23.84	0.07	1.81	0.23	5.15
	India	Value Added	39.90	36.14	17.40	0.16	2.73	0.11	2.26
		Embodied Carbon	40.56	37.20	18.36	0.07	1.59	0.05	1.34
	China	Value Added	37.95	39.50	17.02	0.21	2.00	0.18	1.83
		Embodied Carbon	38.42	40.45	19.44	0.04	0.51	0.03	0.50
	South Africa	Value Added	18.97	46.48	22.03	0.11	2.64	0.36	6.08
		Embodied Carbon	19.38	50.61	25.65	0.03	0.94	0.08	2.03
2015	Brazil	Value Added	29.50	36.85	18.44	0.32	5.08	0.39	5.07
		Embodied Carbon	28.19	32.13	16.24	0.53	8.21	0.65	7.99
	Russia	Value Added	12.83	42.96	32.20	0.07	1.59	0.20	4.21
		Embodied Carbon	12.35	43.58	33.57	0.08	1.08	0.21	3.47
	India	Value Added	32.74	32.35	19.28	0.23	5.97	0.23	5.22
		Embodied Carbon	35.49	35.83	21.74	0.07	2.50	0.11	2.15
	China	Value Added	35.78	29.66	17.84	0.30	5.10	0.23	4.00
		Embodied Carbon	37.91	31.59	20.20	0.10	2.32	0.08	1.86
	South Africa	Value Added	19.83	37.38	24.12	0.13	4.97	0.33	7.70
		Embodied Carbon	21.25	42.31	29.27	0.04	1.93	0.15	2.80

Data: authors.

The DVA (DVA_FIN) contained in the final goods exports of the BRICS accounts for a relatively large share, especially for India and China, which profit the most from direct exports of final products and are in the downstream link of the global value chain. The FVA in exports in each country is mainly composed of OVA_FIN and OVA_INT, and the sum of the two ratios in the BRICS (except Russia) has increased, which indicates that, with economic and production globalization, BRICS have inevitably participated in the international division of labor and international cooperation. However, the structure of Russia's export goods and national policies differ from the other four. The proportion of added value of importing country (MVA_FIN) in final goods export and added value of importing country (MVA_INT) in intermediate goods export is less than 0.5%. Especially in Russia, both values are less than 0.1%, which evidences that Russia's exports have a small import component and are mostly resource-based primary products.

The main source of export gain for Russia and South Africa is exporting intermediate goods, while India and China mainly profit by exporting final goods, with Brazil profiting mainly by exporting intermediate goods to meet the final demand of importing countries. The sources and patterns of export gains evidence that Russia and South Africa are mainly in the upstream link of the global value chain compared to Brazil, while China and India are in the downstream segment.

4.3. Third-Level Decomposition

The trade benefits and environmental costs of the BRICS' participation in GVCS are imbalanced, but the direction of this imbalance differs. As can be seen from **Figure 4**, the share of trade benefits of Brazil's exports is higher than its corresponding share of carbon emissions, and its advantage is expanding; the share of trade benefits of exports for India, China, and South Africa is much lower than the share of their carbon emissions; the imbalance of China has been alleviated, but the imbalance of India and South Africa has become more serious. Although the overall share of trade benefits of Russia's exports is lower than their share of carbon emissions, the gap is relatively small and tends to be balanced.

The main sources of trade benefits and environmental cost imbalances also differ across the BRICS. **Figure 5** depicts the contribution of each component of export value added and carbon embodied DVA/DCE to the trade imbalance. The export of intermediate goods is the main source of the share of Brazilian export value added being larger than the corresponding carbon emissions share. China and India have similar sources of imbalance, with a variety of products being exported and the exporting pathways not being clean enough. South Africa's main source of imbalance is the export of intermediate products. Finally, Russia's production of final product exports is cleaner, while the export pathway through the export of intermediate goods processed in direct importing countries to meet the final demand of the third country is heavily polluted. This suggests that exports of intermediate products are the main reason for the larger

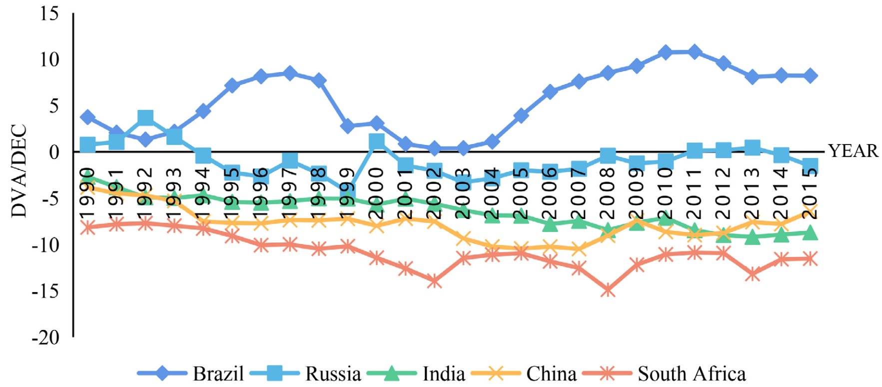

Figure 4. The imbalance of trade benefits and environmental costs of the The BRICS from 1990 to 2015. Data: Eora Database, authors-calculated.

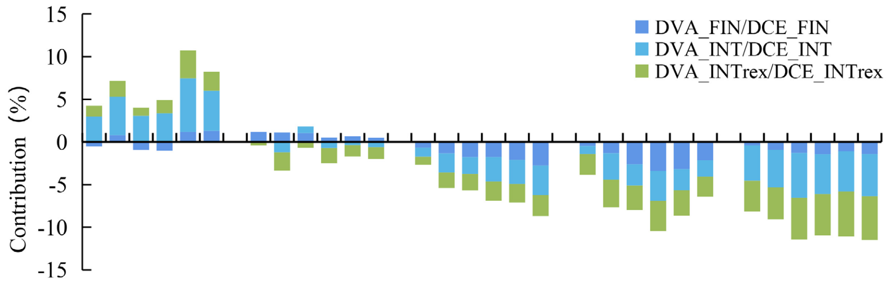

Figure 5. The contribution of each part of the BRIC countries' export value added and embodied carbon DVA/DCE to trade imbalances from 1990 to 2015[1]. Data: Eora Database, authors-calculated.

share of carbon embodied within Russia's total exports than the share of DVA. The above analysis suggests, in general, that Brazil is in a dominant position within GVCS, while India, China, and South Africa are in disadvantageous positions.

5. Conclusions and Policy Recommendations

5.1. Main Conclusions

The BRICS' value added and embodied carbon for exports mainly originate from their own countries, while the proportion of value added for domestic exports is declining and the value added content of exports is increasing. There is an imbalance between the trade benefits and environmental costs of each country's total exports, but the directions are different. Brazil's export revenue is higher than the environmental costs, with its advantages expanding. For India, China, and South Africa, export revenue is lower than the environmental costs, with the imbalance situation in Indian and South Africa deteriorating consistently. Russia's export revenue is slightly lower than the environmental costs and the two tend to be balanced. The main source of export trade benefits for Russia and South Africa is intermediate goods, while India and China gain benefits mainly

[1]The histogram corresponding to each BRIC country in Figure 5 is drawn by the data of 1990, 1995, 2000, 2005, 2010, 2015.

from exporting finished goods, and Brazil mainly profits by exporting intermediate goods. The sources and methods of obtaining trade benefits reflect the fact that, compared to Brazil, Russia and South Africa are in the upper link of the global value chain, while India and China are in the lower link. Assessing the source of imbalance reveals that the export of intermediate goods is the main source of imbalance between export trade benefits and environmental costs in Brazil and South Africa; the export of intermediate goods drives Brazil's exports revenue beyond the induced environmental costs, but it has opposite impact in South Africa and Russia. The imbalances in China and India come from similar sources, with less-clean exports of both final and intermediate goods.

5.2. Policy Recommendations

To promote cooperation in carbon reduction within the BRICS and to improve the imbalance between trade benefits and environmental costs, this article proposes several policy recommendations.

First, it is necessary to continue increasing investment in scientific research, improve production technology, develop cleaner production, and reduce the carbon emissions intensity of export production. Energy efficiency and productivity are the main factors influencing carbon emissions. There is a large gap in the carbon emissions intensity of exports and domestic production amongst the BRICS at similar development stages and value chain status, where space for further reductions in carbon emissions intensity through technological improvements still exists. Compared with Russia, which is in the same upstream link, South Africa has a higher DCE intensity in total exports; compared with the same middle and lower link country (China); India also has a higher DCE intensity in total exports. South Africa and India should therefore focus on the DCE at the central governmental level, to promote the improvement of production technology with policy guidance and other methods, and to pursue green and low-carbon development.

Second, to promote the expansion of the industrial value chain toward high-end links, it is necessary to strengthen the servicing of the manufacturing industry and increase the added value of production. The decomposition outcome shows that, compared to Russia and Brazil (which are in the middle and upper link, respectively), the imbalance of trade benefits being lower than the environmental costs is more severe. The decomposition outcome of major trading countries also shows that, compared with the developed countries in the upper link, the BRICS have to pay more environmental costs to gain the same export revenue. In addition to the production technology differences, the differentiated position and status in GVCS is the main reason for the differences in the imbalance between trade benefits and environmental costs between developing and developed countries. The export sector of the BRICS is concentrated in secondary industries, especially manufacturing, which has more production links and longer production processes. Promoting the manufacturing industry's upward research and development in the participation of division of labor in GVCS, the design link's climb, and the downward extension of services such as marketing and after-sale services will improve the GVCS status of the BRICS and upgrade the production value chain.

Third, it is necessary to be wary of technology blockades by developed countries and reduce domestic production's dependence on foreign technology through import substitution to ensure the normal operation of national economic systems. Both the differentiated reasons for the imbalance between export trade benefits and the environmental costs of the two upper link situated countries, Russia and South Africa, and the impact on China's manufacturing industry development caused by the US technology blockade on China have underscored the importance for developing countries of mastering core production technology and transforming the manufacturing industry from imported innovation to independent innovation. The BRICS should strengthen their independent innovation capabilities in the technical field and improve their ability to deal with sudden risks in global trade.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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