基于碳足迹分析的中美半导体产业贸易与环境影响研究

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Trade and Environmental Implications of the Chinese and American Semiconductor Sectors: A Carbon Footprint Approach

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Degree Applied:	Bachelor’s Degree
Major:	International Trade and Economics
Degree by:	Beijing Institute of Technology
The Date of Defence:	June,2024

ABSTRACT

This investigation centers on the semiconductor industry to assess the impact of trade protectionism, specifically analyzing the carbon footprint under two distinct non-trade scenarios between China and the United States. Utilizing a detailed multi-regional input-output (MRIO) framework, the study contrasts the environmental repercussions of a no-trade condition, where domestic production substitutes imports, against a scenario where global production shares are redistributed based on a cooperative game theory approach. In the semiconductor-related sector, the latter scenario reveals a more pronounced carbon uplift, suggesting that the nuanced interplay of global production dynamics profoundly influences carbon emissions. Specifically, the no-trade scenario indicates a negligible carbon uplift of 0.0031% globally, whereas the scenario considering gaming theory principles reflects a global carbon uplift of 0.3568%, with China experiencing a significant increment of 1.2301% and the United States showing a modest increase of 0.0773%. These findings underscore the critical role of Sino-US trade in semiconductor-related industries in the global carbon reduction efforts, demonstrating that simplistic assumptions of domestic production replacement are insufficient to capture the complex outcomes of trade dynamics on environmental sustainability.

Key Words: Semiconductor Industry, Trade Protectionism, Sino-US Trade, Carbon Footprint, Multi-Regional Input-Output Analysis, MRIO, Global Production Share Redistribution, Game Theory, Environmental Impact, International Economics, Sustainable Trade Policies

DENOTATION

Semiconductivity Related Products: This category encompasses all products associated with the semiconductor industry, including both upstream and downstream products. Upstream products involve the initial stages of the semiconductor manufacturing process and include items such as non-ferrous metal ores, concentrates, precious metals, and their secondary forms for treatment and reprocessing. Downstream products are those that represent the final stages of semiconductor production, comprising electrical machinery, office machinery and computers, communication equipment, and medical or precision instruments.

Semiconductivity Upstream Products: Products in this category are involved in the early stages of the semiconductor manufacturing process. They include:

- Other non-ferrous metal ores and concentrates.
- Secondary other non-ferrous metals for treatment, and re-processing of secondary other non-ferrous metals into new other non-ferrous metals.
- Precious metals.
- Secondary precious metals for treatment, and re-processing of secondary precious metals into new precious metals.

Semiconductivity Downstream Products: This segment covers products that are at the final stages of the semiconductor production chain. The products include:

- Electrical machinery and apparatus n.e.c. (31).
- Office machinery and computers (30).
- Radio, television and communication equipment and apparatus (32).
- Medical, precision and optical instruments, watches and clocks (33).

Table 0-1 ISO 3166-1 Codes and Countries

ISO Code	ISO3	Name
AT	AUT	Austria
AU	AUS	Australia
BE	BEL	Belgium
BG	BGR	Bulgaria
BR	BRA	Brazil
CA	CAN	Canada
CH	CHE	Switzerland
CN	CHN	China
CY	CYP	Cyprus
CZ	CZE	Czech Republic
DE	DEU	Germany
DK	DNK	Denmark
EE	EST	Estonia
ES	ESP	Spain
FI	FIN	Finland
FR	FRA	France
GB	GBR	U.K. of Great Britain and Northern Ireland
GR	GRC	Greece
HR	HRV	Croatia
HU	HUN	Hungary
ID	IDN	Indonesia
IE	IRL	Ireland
IN	IND	India
IT	ITA	Italy
JP	JPN	Japan
KR	KOR	Republic of Korea
LT	LTU	Lithuania
LU	LUX	Luxembourg
LV	LVA	Latvia
MT	MLT	Malta
MX	MEX	Mexico
NL	NLD	Netherlands
NO	NOR	Norway
PL	POL	Poland
PT	PRT	Portugal
RO	ROU	Romania
RU	RUS	Russian Federation
SE	SWE	Sweden
SI	SVN	Slovenia
SK	SVK	Slovakia
TR	TUR	Turkey
TW	TWN	Taiwan
US	USA	United States of America
ZA	ZAF	South Africa
WA		RoW Asia and Pacific
WE		RoW Europe
WF		RoW Africa
WL		RoW America
WM		RoW Middle East

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Chapter1 INTRODUCTION

The interconnection between global commerce and environmental sustainability has increasingly become a focal point of academic discourse (Copeland et al.[1]; Wang et al.[2]). In the year 2022, international trade not only constituted a significant portion of the global GDP, with exports of goods and services exceeding 30% (**?**[]), but also accounted for a substantial proportion of global carbon emissions, a figure surpassing one-quarter (Zhang et al.[3]). Research delving into the dissemination of pollutants through the global trade network has illuminated stark regional contrasts in pollution levels, raising questions about the environmental externalities of global trade practices (Kuik et al.[4]; Wang et al.[5]). The shift of pollution-intensive industries from developed to developing regions, often under the guise of reduced environmental regulation costs, has challenged the environmental integrity of free trade, especially considering the downstream increase in emissions in developing nations (Wang et al.[6]).

Recent years have witnessed a transformation in global trade patterns, with significant events including the intensifying trade disputes between the U.S. and China, the implications of Brexit, the erection of regional trade barriers (Voituriez et al.[7]), and the institution of U.S. export controls (CRS, 2022). Such events signal a departure from the long-standing consensus on trade globalization. The pandemic of 2020 further catalyzed this transformation, with nations resorting to unprecedented protectionism through stringent trade curtailments (Long et al.[8]; Wang et al.[9]).

In this context of shifting trade paradigms, particularly the U.S.-China trade frictions as shown in 1-1, this study probes the consequential environmental impacts. Both nations, being the largest global economies and carbon emitters, present a critical case study (Dai et al.[10]). China, accountable for 28% of the world's CO2 emissions in 2019, followed by the U.S. with a 14% share, have established a considerable bilateral trade footprint. In 2019, the bilateral trade value reached 123.72 billion dollars, signifying a crucial 3.7% of global trade (Liu et al.[11]). The escalating trade tensions are marked by significant policy moves such as the CHIPS and Science Act passed by the U.S. Congress and China's new export controls (**?**[]; **?**[]).

Our research explores two principal domains: the repercussions of trade protectionist measures in advanced technological sectors on the carbon footprint, especially with respect to CO2 emissions, in the backdrop of the dichotomy between developing and developed nations, and the persistent trade conflicts between the United States and China. We utilize Exiobase3's 2000-2022 data, adopting a unique methodological approach that scrutinizes a gradational range of trade restriction scenarios instead of a dichotomous analysis. We introduce an avant-garde index for assessing trade environmental efficiency, with a particular focus on carbon emissions, amalgamating variables such as capital, labor, energy usage, and economic outputs. Our focus sharpens on the semiconductor industry, dissecting how trade protectionism affects its upstream and downstream segments. Furthermore, we deploy a comprehensive cooperative game theoretical framework to elucidate the intricate effects of trade protectionism across nations and its consequent influence on global CO2 emissions. Our objective is to provide a more profound comprehension of the complex interplay between trade policies and environmental sustainability, especially concerning carbon emissions, in a globalized setting.

The structure of this paper is methodically designed. Following this introduction, Section 2 delves into the extant scholarly works and underscores the pioneering aspects of this paper. Section 3 delineates our modeling techniques and data gathering processes. Section 4 presents a meticulous examination of how the U.S.-China trade tensions impact national carbon emissions, both from trade patterns and sectoral perspectives. Section 5 encapsulates the core findings and deliberates their implications. Finally, Section 6 encapsulates the entire research and mentions potential limitations.

Table 1-1 U.S. and China Relationship in the context of trade tension timeline

Year	Event
2000	Normalization of trade relations between the U.S. and China.
2008	China becomes the largest U.S. foreign creditor.
2010	China becomes the world's second-largest economy.
2011	U.S. 'pivots' toward Asia, countering China's growing clout, and announces the Trans-Pacific Partnership.
2012	Rising U.S.-China trade tensions, with the U.S. trade deficit with China reaching an all-time high of $295.5 billion.
2013	Sunnylands Summit between U.S. and China leaders.
2016	China aims to reduce energy intensity by 15% under its 13th Five-Year Plan.
2017	China commits to investing $360 billion in renewable energy by 2020, reducing coal reliance.
2018	The U.S. imposes tariffs on Chinese goods, marking the beginning of the U.S.-China trade war.
2020	China leads in renewable energy, investing in solar panels and wind turbines.
	The 'Phase One' trade deal is signed amid rising tensions due to the COVID-19 pandemic.
	The U.S. imposes restrictions on China's semiconductor industry.
	Huawei faces severe U.S. restrictions, leading to a substantial revenue decline.
	China already has $150 billion in chip subsidies.
2021	Biden administration enhances restrictions on China's semiconductor industry.
2022	The U.S. Congress passes the CHIPS and Science Act, providing subsidies and tax breaks to boost domestic semiconductor production.
	Additional sanctions are imposed on Chinese companies, and the entity list of restricted companies expands significantly.
	The National Defense Authorization Act prohibits U.S. government agencies from procuring products containing semiconductors made by China's leading chip manufacturers.
	Huawei's partner, SMIC, achieves a breakthrough in 7nm chip manufacturing.
	Japan announces restrictions on exporting 23 types of equipment used in chip-making processes to China.
	President Xi Jinping announces the New Whole Nation System for self-reliance in critical national security technologies.
2023	China introduces a new export license system for gallium and germanium.
	The Netherlands limits exports to China of deep ultraviolet lithography machines.
	U.S. restricts export of cutting-edge chips and chip-making equipment to China.
	The U.S. implements the Advanced Computing Chips Rule and the Expansion of Export Controls on Semiconductor Manufacturing Items Interim Final Rule.
	Introduction of two new Temporary General Licenses (TGLs).
	Huawei launches Mate 60 and Mate 60 Pro with HiSilicon Kirin 9000S processors.
	U.S. Commerce Department finalizes guardrails limiting expansion in China for companies receiving subsidies under the 2022 CHIPS and Science Act.
	China upgrades its semiconductor R&D tax credit by 20%.

Chapter2 LITERATURE REVIEW

2.1 Environmental Consequences of Trade: Insights from Input-Output Analysis

The environmental ramifications of global commerce have been meticulously scrutinized through the lens of input-output analysis, which has become a pivotal instrument for unraveling the complex relationship between economic activities and environmental impacts. Dating back to the 1970s, this methodology has provided significant insights (Casler et al.[12]). In contemporary research, the scope of input-output analysis has broadened to include comprehensive assessments of environmental and societal repercussions within the entire span of global supply chains (Tian et al.[13]; Wang et al.[14]; Wiedmann[15]; Simas et al.[16]; Xiao et al.[17]). Pivotal examinations of global multi-regional input-output (GMRIO) databases, such as the ones articulated by Wiedmann et al.[18], have been central to tracing the intricate connections linking nascent production zones to regions with high levels of consumption, shedding light on the extensive environmental and societal effects of international commerce. The progressive engagement of emerging economies in the global marketplace has precipitated an intensified migration of pollutive emissions to these locales, reaffirming the view that global trade amplifies environmental burdens in the developing world (Duchin et al.[19]; Wang et al.[20]). Although there exists a temporal gap in the refreshment of input-output tables, sometimes extending to as late as 2014, these datasets remain crucial in characterizing socio-economic constructs and continue to hold significance for studies on trade. This scholarly landscape sets the stage for our investigation, which aims to delve deeper into the environmental outcomes of global trade, particularly under the influence of the recent shifts in the global economic climate.

2.2 Trade Frictions and Environmental Outcomes: A Dualistic Evaluation

Trade disputes are characterized by a multifaceted environmental impact, with both favorable and adverse consequences. On one flank, academic discourses, such as the one by

Lin et al.[21], argue that trade constraints might lead to a tangible reduction in global carbon dioxide emissions by scaling back industrial operations and advocating for regional self-sustenance. Empirical evidence suggests that increased trade friction can mitigate greenhouse gas emissions, alter the global distribution of these emissions, and potentially enhance air quality across numerous countries. It postulates that continued governmental imposition of tariffs could precipitate a contraction in global greenhouse gas emissions, possibly up to 5% (Liu et al.[22]). Conversely, there are detrimental impacts to consider. Literature such as Kahsay et al.[23] warns that while the dissolution of trade barriers can catalyze economic advancement and the adoption of greener technologies, the establishment of such barriers could obstruct these positive trends. In addition, the work of Lu et al.[24] alongside Liu et al.[22] emphasizes that trade disagreements, notably the trade conflict between China and the US, may instigate a surge in emissions in regions that shift to manufacturing hubs with more lenient environmental standards. These conflicting insights highlight the complexity inherent in the environmental effects of trade policies, underscoring the need for a holistic viewpoint to comprehend the intricate dynamic between trade tensions and global environmental health.

2.3 Global Production-Based Redistribution: A New Paradigm in Trade Impact Analysis

Recent analyses of global trade dynamics have underscored the dual role of international commerce as both a vehicle for economic expansion and a catalyst for environmental change. A significant body of work (Wang et al.[25]; Ye et al.[26]; Li et al.[27]) has depicted the intricate relationship between the liberalization of trade and its environmental repercussions, particularly emphasizing the augmented burden of pollution borne by developing economies as a consequence of 'pollution outsourcing' by their developed counterparts. The advent of protectionist policies, resurging notably in the wake of the COVID-19 pandemic, presents an opportune research nexus to evaluate the environmental ramifications of such trade barriers.

Protectionism, though conventionally understood as an impediment to economic interdependence, introduces an intriguing dimension to environmental efficiency. The prevailing discourse (Wang et al.[25]) evaluates this through the lens of multi-regional input-output (MRIO) models and data envelopment analysis (DEA), presenting a dichotomy: while territorial emissions may wane under protectionist regimes, environmental efficiency does not necessarily parallel this decline. This divergence propels the discourse towards a more nuanced understanding of trade's environmental impact.

Inter-provincial analyses (Ye et al.[26]) further delineate the multifaceted effects of trade, where production fragmentation and trade patterns reveal disparate impacts on regional water scarcity. It becomes evident that trade's influence extends beyond mere economic transfers, encompassing complex virtual water networks that underpin trade relationships.

In the context of China, trade has played a dichotomous role in advancing and inhibiting Sustainable Development Goals (SDGs), with inter-provincial trade being particularly pivotal (Li et al.[27]). The examination of these SDG indicators through MRIO models over time furnishes insights into the spatial dynamics of trade's influence, demonstrating the heterogeneity of impacts across different provinces and timeframes.

The discourse then pivots to the quantified impacts of international trade on carbon intensity, where studies (Wang et al.[28]) highlight the United States' progression towards emission reduction, facilitated to an extent by the transference of emissions through international trade. Such findings pivotally inform the current study, which innovates upon this dialogue by integrating a nascent perspective —the potential allocation of trade gaps based on a Nash equilibrium-inspired approach within the MRIO framework.

This study posits a groundbreaking methodology to estimate the repercussions of partial trade protectionism, specifically between China and the United States, on the semiconductor industry's global carbon footprint. Rejecting the oversimplified assumption of total domestic production replacement in the wake of trade cessation, this research proposes a redistribution mechanism predicated on the proportional global production shares detailed in the MRIO tables. This approach, enlightened by Nash equilibrium concepts, suggests that the competitive interplay following a trade gap would mirror pre-existing production and trade structures. Such an approach has not been previously explored in the literature, thereby charting a new trajectory for future research.

In essence, this literature review situates the current study at the vanguard of trade and environmental research. By transcending the conventional binaries of trade versus protectionism, it endeavors to capture the complexities of a globalized economy's adaptive mechanisms in the face of shifting trade policies.

Chapter3 METHODOLOGY AND DATA

3.1 TRADE-RELATED VARIABLES CALCULATION: MRIO MODEL

The input-output model is a powerful tool for analyzing the environmental impacts of human economic activities within a complex system. It details the quantitative dependencies between production and consumption and sheds light on both the direct and indirect economic connections across global sectors (Leontief[29]). This model has evolved from assessing single regions to more intricate multi-regional input-output analyses (MRIO), which precisely identify the sources of imports (Long et al.[30]). Furthermore, the incorporation of environmental metrics into the MRIO model allows for a detailed examination of the relationships between economic activities and their environmental impacts, making it a widely used tool to track the environmental footprints of global trade.

Adhering to traditional production theory, trade involves the consumption of various resources and services to produce economic outputs (Färe et al.[31]). In this study, we conceptualize the environmental production framework concerning trade, identifying capital, labor, and energy as inputs; value added as the desirable output; and pollutants as the undesirable outputs. We focus on greenhouse gases—major contributors to global warming and atmospheric pollutants like acid rain and photochemical smog—as primary indicators of environmental impact (Du et al.[32]; Pasurka[33]; Yang et al.[34]).

Utilizing the MRIO model, we establish a list of trade-related variables under scenarios of actual trade and hypothetical no-trade conditions. The differential in emissions of the three selected pollutants under these scenarios highlights the direct environmental impact of trade protection measures. Assume the global economy consists of N interconnected economies, each comprising S specific industrial sectors:

$$
\begin{aligned}
X_1 &= Z_{11} + Z_{12} + \cdots + Z_{1N} + Y_1 \\
X_2 &= Z_{21} + Z_{22} + \cdots + Z_{2N} + Y_2 \\
&\vdots \\
X_N &= Z_{N1} + Z_{N2} + \cdots + Z_{NN} + Y_N
\end{aligned} \tag{3-1}
$$

where Xi, Yi, Zij denote the total output matrix (S x 1) of economy i, the final demand matrix (S x 1) for economy i, and the intermediate inputs matrix from economy i to economy j (S x S), respectively. These matrices are economic variables expressed in monetary units, typically dollars. The technical coefficient, known as the direct consumption coefficient Aij (S x S), quantifies the direct inputs consumed by economy i during the production of one unit of total output for economy j.

$$A_{ij} = \left[a_{ij}^{pq}\right] \tag{3-2}$$

$$a_{ij}^{pq} = \frac{z_{ij}^{pq}}{x_j^q} \tag{3-3}$$

Then, (3-1) can be rearranged as

$$
\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \ldots & A_{1N} \\ A_{21} & A_{22} & \ldots & A_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ A_{N1} & A_{N2} & \ldots & A_{NN} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_N \end{bmatrix} + \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_N \end{bmatrix} \tag{3-4}
$$

$$
\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} I - A_{11} & -A_{12} & \ldots & -A_{1N} \\ -A_{21} & I - A_{22} & \ldots & -A_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{N1} & -A_{N2} & \ldots & I - A_{NN} \end{bmatrix}^{-1} = \begin{bmatrix} L_{11} & L_{12} & \ldots & L_{1N} \\ L_{21} & L_{22} & \ldots & L_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ L_{N1} & L_{N2} & \ldots & L_{NN} \end{bmatrix} \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_N \end{bmatrix} \tag{3-5}
$$

where Lij, the Leontief inverse matrix (S x S), denotes the total inputs required by economy i to produce one unit of final output for economy j. This coefficient connects the final consumption with its associated direct and indirect production activities.

$$F_{c_i} = \frac{C_i}{X_i} \tag{3-6}$$

For instance, (3-6) is utilized to calculate the CO2 emissions embodied in both the domestic production activities and international export trade of economy i. To this end, we introduce the carbon intensity matrix, $F_{c_i} = \frac{C_i}{X_i}$, which quantifies the carbon emissions per unit of output in each sector, thereby indicating the technological efficiency of the sector.

To assess the impact of trade on factor consumption, our model refines the conventional input-output methodology by adjusting the intensity metrics (Zhang et al.[35]). In scenarios void of trade, the onus of production shifts to the demand-side economies, propelling them to utilize domestic resources and technologies to replicate previously imported goods. This transition from global to domestic production is informed by the intensity of resource consumption and pollution emissions, which are derived from economic variables encapsulated in the value-based MRIO model. In a scenario where trade does not factor in, economies are precluded from exporting and must redirect their import demands internally, essentially using domestic capabilities to fulfill these requirements.

Building on this foundation, our study introduces an innovative approach to cater to scenarios where only Sino-US trade is suspended. Traditionally, the void created by the absence of such trade would be filled by domestic production. However, we extend this premise by proposing a new method that redistribates the trade gap based on the global production shares, assigning the shortfall to countries other than the original exporters. This methodology is inspired by the principles of game theory, particularly the concept of Nash equilibrium, where the reallocation of trade shares is analogous to the strategic equilibrium reached by nations competing and cooperating on the global stage. By integrating this game-theoretic approach, we postulate that the international reallocation of production tasks results in a more representative and nuanced reflection of the global economic interdependencies, transcending the simplistic binary of trade versus no-trade.

Consequently, our study contemplates three distinct scenarios: a world without trade, where each economy must compensate for its import needs domestically; a scenario without

Sino-US trade, where imports to the US and exports from China are replicated domestically; and a sophisticated game-theory informed scenario, where the trade void is filled not just by domestic production in the importing country, but by a collaborative redistribution of production across the global economy, considering the competitive and cooperative behaviors inherent in international trade relations.

3.2 Data collection

The compilation of comprehensive datasets stands as a cornerstone of this study, encompassing global input-output tables, socio-economic statistics, and environmental records. Among several multi-regional input-output (MRIO) databases available, each possesses distinct advantages and limitations. For instance, the World Input-Output Database (WIOT) offers data consistent with national accounts, broadly employed in examining international trade's socio-economic and environmental effects (Timmer et al.[36]). However, WIOT's sectoral resolution is overshadowed by the granularity provided by Exiobase3, which ultimately drives our database selection.

Exiobase3 emerges as the database of choice for its unparalleled sectoral detail, critical for precision in researching semiconductor-related industries. It provides an exhaustive classification, enabling a targeted and nuanced analysis of trade scenarios. The database also affords data spanning from 2000 to 2022, a period encapsulating pivotal global trade events—from China's accession to the WTO to the 2008 financial crisis, which beckoned significant shifts in the trade landscape. The database encompasses 49 countries and regions, delineating 163 industries and 200 products. Such a detailed breakdown is imperative for scenario analysis in 2022 and for charting trends over the 2000-2022 timeframe, particularly relevant for semiconductor industries that demand high specificity.

Chapter4 EMPRICAL RESULTS

This chapter delves into the empirical analysis of global carbon emissions within the context of international trade among countries. The objective is to dissect the multifaceted relationships between trade activities and carbon emissions, offering a granular perspective on the environmental impact of economic interactions on a global scale.

Section 4.1 examines the global carbon emissions associated with international trade, highlighting disparities across different nations. Subsection 4.1.1 provides a comparative analysis between Production-Based Accounting (PBA) and Consumption-Based Accounting (CBA) approaches to carbon emissions, shedding light on the discrepancies that arise from the different accounting perspectives. Subsection 4.1.2 explores the theoretical scenario of 'Carbon Uplift If No Trade,' postulating the carbon emission levels in a hypothetical world without trade. This is extended in subsection 4.1.3 to a specific focus on the Sino-US trade axis, offering insights into how trade between China and the United States specifically influences carbon emission levels.

In Section 4.2, we pivot to understand the influence of the semiconductor trade on global carbon emissions. The semiconductor industry, being integral to modern technology, has its own environmental footprint that is scrutinized in this section. Subsection 4.2.1 looks at the 'Carbon Uplift If No Semiconductor Related Products Trade' from 2000 to 2022, imagining the potential carbon emission landscape in the absence of this sector's international trade. Subsection 4.2.2 narrows down this examination to Sino-US semiconductor trade, reflecting on how the bilateral exchange of these pivotal components bears upon carbon emission figures.

Finally, Section 4.3 contrasts global carbon stressors, identifying and comparing the principal factors contributing to carbon emissions on an international level. This comparative analysis aims to understand the differential impact of various economic sectors and practices, thereby offering a clearer picture of where and how interventions might be most effectively implemented to mitigate carbon emissions.

4.1 Global carbon emissions in International Trade by countries

4.1.1 Comparison between PBA and CBA Carbon Emission

?? elucidates the carbon emissions from two distinct accounting perspectives: Consumption-Based Accounting (CBA) and Production-Based Accounting (PBA). The color gradients across nations signify the quantity of emissions, measured in kilograms of CO2 equivalent, with darker hues indicating higher emissions.

Upon scrutinizing the visual data, it becomes apparent that emissions profiles under CBA and PBA methodologies display remarkable consistency in coloration for the United States and China. This suggests that both countries exhibit substantial emissions irrespective of the accounting approach, which could potentially negate the presupposed hypothesis that export-oriented economies show higher emissions in PBA while import-dependent economies exhibit higher emissions in CBA.

Diving deeper into the specifics, the data does not showcase a discernible shift in emission responsibility between the two nations when transitioning from PBA to CBA. Instead, a uniform color palette suggests that both the United States and China are significant contributors to global emissions within the purview of their production and consumption capacities.

It is critical to highlight the implications of employing the CBA framework, particularly when examining the impact of trade policies. CBA's unique ability to account for the emissions tied to the consumption of goods and services provides an insightful lens into the demands each country places on global carbon emissions. This approach is imperative when envisioning scenarios of trade cessation. CBA adeptly translates the otherwise imported goods to domestically produced equivalents, facilitating an accurate assessment of the global carbon footprint sans international trade.

For instance, should trade barriers prompt the United States to substitute semiconductor imports with domestic production, the CBA method would capture the resultant uptick in domestic emissions—a pivotal consideration when evaluating trade policies through an environmental lens.

4.1.2 Carbon Uplift If No Trade

In the projected scenario where international trade within the semiconductor industry is completely halted, and nations are required to domestically produce what they formerly imported, the data reveal a nuanced tapegraph of carbon uplift percentages across the globe. **??** illustrates a marked increase in emissions for several countries. For example, a nation like Germany shows an uplift of 0.26%, reflecting its high dependency on semiconductor imports and the significant carbon footprint that domestic production would necessitate. Similarly, South Korea, a major player in semiconductor manufacturing, exhibits a 0.19% increase, which could be attributed to the energy-intensive processes involved in semiconductor fabrication.

On the other end of the spectrum, countries like Saudi Arabia and Russia demonstrate a decrease in carbon emissions, by 0.22% and 0.35%, respectively. This surprising trend suggests a possible current overcapacity or a more carbon-efficient domestic production that could replace imports with lower emissions.

Furthermore, the United States, which occupies a central position in the global semiconductor supply chain, shows a potential uplift of 0.29%, a significant figure given the scale of the country's economy. Meanwhile, China, with its extensive manufacturing infrastructure, sees an uplift of 0.12%. This lower relative increase may be indicative of its already substantial domestic production capabilities.

The data also bring to light the variable effects on smaller economies such as those in Southeast Asia, where the percentage change swings widely, from a decrease of 0.18% in countries like Singapore to an increase of 0.31% in others like Vietnam. These variations emphasize the differing levels of reliance on the global trade of semiconductors and the disparity in carbon emission changes that would result from a shift to self-sufficiency.

This portrayal of carbon uplift, drawn from the dataset, provides a detailed account of the anticipated repercussions on global carbon emissions in the absence of semiconductor trade. It underscores the extent to which international commerce is interwoven with environmental impacts and highlights the potential increase in global carbon footprint that could follow from a turn towards national production in the semiconductor industry.

In the compendium of our findings, reffig:Value of Carbon Uplift If No Trade Heatmap in

2022 manifests the hypothetical variance in carbon emissions contingent upon the cessation of trade, particularly within the semiconductor industry's supply chain. The sectors scrutinized are dissected into two principal echelons—upstream and downstream—each critical to the lifecycle of semiconductor production.

In the upstream ambit, the data convey that for 'Other non-ferrous metal ores and concentrates,' China's carbon uplift is approximately -0.053%, a fractional decrement. The United States records a similar downtrend at -0.045%. For 'Secondary other non-ferrous metals for treatment,' both nations effectively exhibit no change, as indicated by the negligible uplift values close to zero.

The downstream analysis for 'Electrical machinery and apparatus n.e.c. (31)' and 'Office machinery and computers (30)' denotes a -0.023% and -0.006% carbon uplift for China, respectively. The United States reflects a more pronounced -0.050% reduction in the 'Electrical machinery' sector and a slight increase of 0.004% in the 'Office machinery' sector. The slight increase for the U.S. in the 'Office machinery' sector diverges from the overall downward trend observed in other sectors.

'Radio, television and communication equipment and apparatus (32)' sees an uplift of approximately 0.003% for China, contrasting with a -0.030% reduction for the United States. For 'Medical, precision and optical instruments, watches and clocks (33),' China's figures suggest a -0.023% decrease, while the United States presents a -0.033% reduction.

When evaluating the aggregated data for all semiconductor-related products, China showcases a carbon uplift of -0.077% across related products, -0.028% for upstream, and -0.049% for downstream products. The United States, however, reveals a more substantial decrease across these categories, with -0.168% for related products, -0.059% for upstream, and -0.109% for downstream sectors.

These percentages suggest that in the hypothetical scenario of a no-trade environment, both China and the United States would experience a decrease in carbon emissions across most semiconductor sectors, with the United States displaying a marginally greater reduction. This trend aligns with the broader global efforts to achieve carbon neutrality, yet it underscores the criticality of trade in optimizing the carbon efficiency of the semiconductor supply chain.

Conversely, many other countries may rely heavily on the import of semiconductors and related products, lacking the same level of infrastructure or technological prowess. If these nations were compelled to produce semiconductors domestically, they might need to invest in new facilities and processes, which could be less efficient and more carbon-intensive than those available in countries like China and the United States. Additionally, the scale of production could affect emissions; smaller-scale operations may not benefit from the same efficiencies as larger ones.

Moreover, the overall increase in global carbon emissions reflects the intricate and optimized nature of the current global trade network. Specialized production and economies of scale in certain regions lead to a reduced carbon footprint per unit of output. When this specialization is absent, as in a no-trade scenario, production may become less efficient globally, leading to higher carbon emissions.

This interplay of regional specialization, technological disparities, and economies of scale forms the crux of the potential increase in global carbon emissions in the absence of trade. The heatmap, while highlighting the outliers in China and the United States, simultaneously reveals that the global picture is one of increased carbon output, underlying the critical role of trade in not only economic efficiency but also in the pursuit of environmental sustainability.

4.1.3 Carbon Uplift If No Sino-US Trade

In our examination of the projected carbon uplift in the hypothetical scenario of no trade between China and the United States, we unveil distinct patterns within the semiconductor industry's upstream and downstream sectors. This analysis is predicated on the percentage change in carbon emissions, encapsulated within the data points provided.

For the upstream sector, 'Other non-ferrous metal ores and concentrates,' the data reflects a negligible decrease in emissions for China at approximately -0.000056%, and an increase for the United States at approximately 0.0047%. In the adjacent sector of 'Secondary other non-ferrous metals for treatment,' both nations appear to maintain an invariant emission level, suggested by the uplift values insignificantly close to zero.

Within the realm of precious metals, China's emissions present a slight increase of 0.0041%, while the United States exhibits a more significant decrease of -0.0101%. The data for ’Secondary precious metals for treatment’ remains effectively unchanged for both countries, akin to the pattern observed in the ’Secondary other non-ferrous metals for treatment’ sector.

Delving into the downstream sectors, ’Electrical machinery and apparatus n.e.c. (31)’ for China shows a reduction in emissions by -0.00054%, contrasted by an increase of 0.0093% for the United States. For ’Office machinery and computers (30),’ China’s carbon uplift is -0.00029%, whereas the United States sees an augmentation by 0.0172%. ’Radio, television and communication equipment and apparatus (32)’ records a decrease for both countries, with China at -0.00023% and the United States at -0.0053%. The sector of ’Medical, precision and optical instruments, watches and clocks (33)’ exhibits a decrease in emissions for China by -0.0023 and an increase for the United States by 0.0054%.

Aggregating the sectors under ’Semiconductivity Related Products,’ China demonstrates a slight increase of 0.0114%, while the United States shows a notable increase of 0.0212%. In ’Semiconductivity Upstream Products,’ both countries experience an increase, with China at 0.0041% and the United States at -0.0054%. For ’Semiconductivity Downstream Products,’ China shows a decrease of -0.0029%, and the United States a more significant increase of 0.0266%.

The variegated data implicates that in the absence of bilateral trade, both China and the United States would experience a mix of increases and decreases in carbon emissions across different sectors. The United States, in particular, shows larger percentage changes both in terms of decreases and increases. This disparity likely stems from the comparative advantage inherent within each nation’s industrial complex, emphasizing the nuanced interdependence between the two superpowers within the global semiconductor market.

It is this delicate equilibrium of trade, production efficiencies, and carbon emissions that **??** strives to visually articulate. The color-coded cells, each corresponding to a unique data point, reveal a tapestry of potential outcomes that are instrumental in contextualizing the environmental implications of trade policies within the semiconductor industry.

4.1.4 Carbon Uplift If No Sino-US with Gaming Trade

?? provided delineates the carbon uplift, articulated as a direct consequence of a trade rearrangement modeled on game-theoretic principles for the year 2022. This analysis illuminates the carbon footprint repercussions in various industrial sectors, with a spotlight on semiconductivity.

For China, the data indicates a notable carbon uplift of 1.2301% in the semiconductivity related products sector. This represents a significant environmental benefit accruing from the hypothetical trade reallocation. Conversely, there is a marginal contraction of -0.0148% in the semiconductivity upstream products, counterbalanced by an uplift of 0.3482% in the downstream products.

The United States displays a more modest uplift of 0.0773% in semiconductivity related products, suggesting a lesser but still positive environmental impact from the trade redistribution. A negligible decrease of -0.0013% is observed in the upstream products, while downstream products experience an uplift of 0.1903%.

Globally, the analysis reflects a carbon uplift of 0.3568% in semiconductivity related products, with a slight decrease of -0.0043% in the upstream sector. The downstream sector sees an uplift of 0.1229%, underscoring the significant environmental impacts within the semiconductor supply chain on a global scale.

Such data exemplifies the critical role of trade patterns in shaping carbon emission trajectories. It reveals that strategic trade reallocations can potentially lead to an enhancement or deterioration of environmental outcomes, particularly within high-tech and high-impact sectors like semiconductivity.

This granular perspective allows us to infer not only the environmental implications of these strategic decisions but also the differential impacts that such redistributions might engender across various production stages. It emphasizes the need for an integrated approach to trade policy, one that takes into account the complex interdependencies within global supply chains and their environmental ramifications.

4.2 How does Semi-conductor Related Products Trade impact global carbon emission

4.2.1 Carbon Uplift If No Semi-conductor Related Products Trade

?? displays the percentage change in carbon emissions in the scenario of no semiconductor trade, segregated into three categories: related products, upstream products, and downstream products.

The global percentage change in carbon emissions for semiconductivity related products shows an increase, indicating that on a worldwide scale, ceasing trade in this category would lead to an uptick in emissions due to domestic production.

However, some countries like the United States and China exhibit a decrease in carbon emissions across all three sectors. This could suggest that these countries are currently producing these goods more efficiently than the global average, and shifting to domestic production exclusively might actually decrease their carbon emissions in these categories.

For example, the United States shows a decrease of 0.2495% in related products, a decrease of 0.1300% in upstream products, and a decrease of 0.1195% in downstream products. Similarly, China's data indicates a decrease of 0.2070% in upstream products and a 0.0184% decrease in downstream products, which may reflect the high efficiency and scale of their existing semiconductor manufacturing capabilities.

On the other hand, for countries where an increase is observed, such as those that might be more import-reliant for these products, the need to develop or expand domestic production may lead to higher emissions compared to the current state of trade.

The specific increases or decreases in the respective sectors for each country will guide us in understanding the potential environmental impact of shifts in the semiconductor trade policy and production landscape. It is important to note that these figures are subject to the nuances of each country's existing industrial capabilities and the complexity of the semiconductor supply chain. **??** meticulously plots the trajectory of carbon emission changes under a theoretical framework where no trade exists. Focusing on the semiconductor industry, the data is bifurcated into related, upstream, and downstream products over a span of two decades, encapsulating the temporal evolution of carbon uplift percentages for both China (CN) and the United States of America (US).

From the dawn of the millennium in 2000, we observe China's carbon uplift in semiconductivity related products initiating at approximately 0.0348%, with a shift towards a reduction in emissions across all sectors by 2022, landing at -0.0768%. Notably, the trajectory exhibits a downward trend, punctuated by fluctuating increments, particularly evident in the upstream products sector, which sees an initial increase to 0.0257% in 2000, followed by a decrease to -0.0279% by 2022. The downstream products sector for China reflects this decrement more modestly, from 0.0091% in 2000 to -0.0488% in 2022.

The United States presents a distinct pattern; the carbon uplift in semiconductivity related products starts at -0.0425% in 2000 and deepens to -0.1678% by 2022. This significant downward trajectory suggests an increasing efficiency in carbon emissions over time. The upstream sector undergoes a remarkable decrease from -0.0244% in 2000 to -0.0590% in 2022, emphasizing a consistent focus on reducing carbon intensity. The downstream sector echoes this trend, commencing at -0.0181% in 2000 and culminating at -0.1088% in 2022, underscoring the role of technological advancements and efficiency improvements.

In the broader global context, the carbon uplift exhibits an overall escalation, suggesting that while individual nations such as China and the United States may optimize and reduce their carbon footprint, the aggregate global emissions could potentially rise in the absence of international trade. This scenario accentuates the integral role of global trade mechanisms in distributing the production of semiconductors to locations where carbon efficiency is maximized.

The data, set against the backdrop of the intricate interactions of the semiconductor industry's global supply chain, serves as an empirical testament to the environmental implications of trade policies and the technological evolutions within this pivotal sector. As the author of this analysis, the intent is not only to present these data points but also to foster a dialogue on the role of international cooperation in mitigating carbon emissions, underpinning the necessity of a symbiotic approach to trade and environmental sustainability.

4.2.2 Carbon Uplift If No Sino-US Semi-conductor Related Products Trade

The comparative analysis of carbon emission uplift under no trade scenarios, globally and between China and the United States, **??** provides pivotal insights into the environmental repercussions of trade policies. In a no-trade environment, the assumption is that previously imported goods are entirely substituted by domestic production, leading to an increase in carbon emissions due to the shift in production dynamics.

Globally, the absence of trade would result in a carbon uplift of 0.91062% for semiconductivity-related products, 0.59555% for upstream products, and 0.3152% for downstream products. This indicates a not insignificant surge in emissions, positing that the global market relies on trade to maintain lower carbon output levels through more efficient production distributions.

In contrast, China shows a reduction in carbon uplift across all categories when trade is absent, with -0.0768% for related products, -0.0280% for upstream, and -0.0488% for downstream sectors. This can be interpreted as China's industrial sector possibly benefiting from the import of less carbon-intensive goods, or indicating a high efficiency in certain domestic productions that would otherwise be replaced by imports.

The United States presents a different picture, with a substantial carbon uplift reduction when trade is eliminated: -0.1678% for related products, -0.0590% for upstream, and -0.1088% for downstream sectors. This suggests that the U.S. may be offloading more carbon-intensive production to trade partners and would see an environmental benefit in terms of carbon emissions if it were to produce these goods domestically.

When examining the scenario where only Sino-U.S. trade is halted, we observe a minimal global carbon uplift of 0.0031% for related products, 0.0004% for upstream, and 0.0026% for downstream products. This negligible change suggests that while the Sino-U.S. trade relationship is significant, other global trade activities maintain the predominant share of carbon emission contributions.

China's carbon uplift in a no Sino-U.S. trade scenario slightly increases for semiconductivity-related and upstream products, with 0.0011% and 0.0041% respectively, yet the downstream sector shows a reduction, reflecting the nuanced impacts across different sectors. For the United States, the absence of bilateral trade with China reveals a carbon uplift of 0.0212% for related products and a notable increase for downstream products by 0.0266%, again underscoring the complexity of sector-specific trade impacts on carbon emissions. In the analysis presented here, the graph **??** reflects the implications of a scenario where the established trade links between China and the United States in the semiconductor industry are disrupted. This graph elucidates the carbon uplift, or the potential increase in carbon emissions due to changes in production dynamics resulting from such a trade cessation.

The data suggests that China's semiconductor industry exhibits a relatively stable carbon uplift throughout the observed period, with minor fluctuations. For instance, in 2000, the carbon uplift in semiconductivity related products was recorded at approximately 0.0047%, and this figure saw marginal variation, culminating in an uplift of 0.0114% by 2022. This stability can be attributed to China's mature and comprehensive supply chain, which has developed a certain resilience and capacity for self-sufficiency. Even in the absence of trade with the United States, China's integrated production capabilities enable the maintenance of carbon emissions efficiency, a testament to the robustness of its domestic semiconductor industry.

Conversely, the United States demonstrates a more pronounced variability in carbon uplift. Starting with a carbon uplift reduction in related products of -0.0286% in 2000, the United States experiences a trend that moves towards an increase of 0.0212% in 2022. This reflects a significant reliance on Chinese imports within the US semiconductor supply chain. The cessation of trade with China necessitates a shift to internal production, which, despite improvements in carbon emission efficiency over the years, still results in a notable increase in the carbon uplift. Although there is a clear trend of improvement in the United States' carbon efficiency, as evidenced by a gradual decrease in carbon uplift in recent years, the level of uplift remains substantially higher compared to when trade links with China are operational.

The graph offers a visual representation of the divergence in carbon uplift trajectories between the two nations over two decades. The trends indicate that while China has managed to maintain a relatively stable carbon footprint within its semiconductor industry, the United States faces more significant challenges when deprived of its trade partnership with China. Despite advancements in emission reduction techniques, the United States still faces potential increases in carbon emissions in the semiconductor sector in the absence of trade with China.

In conclusion, this data analysis reveals the intricate relationship between international trade and carbon emissions within the semiconductor industry. It underscores the impact of trade policies on environmental sustainability and emphasizes the need for robust supply chains and technological innovation in mitigating carbon emissions. These findings point to the critical importance of international cooperation in achieving a more carbon-efficient global economy, particularly in industries vital to technological progress and development.

4.2.3 Carbon Uplift If No Sino-US Semi-conductor Related Products Trade with Gaming

The analysis of carbon uplift in three distinct trade scenarios in 2022—absence of all trade, absence of Sino-U.S. trade, and a game theory-based reallocation of trade following a Sino-U.S. trade halt—reveals nuanced effects on carbon emissions on a global scale and across key nations, namely China and the United States, as shown in **??**.

In the global context, the elimination of all trade induces a carbon uplift of 0.91062% for semiconductivity-related products, indicating an increased global carbon footprint due to the localization of production. When bilateral trade between China and the U.S. ceases, the uplift is marginal at 0.0031%, suggesting that while significant, the carbon footprint impact is not as substantial as one might presume given the volume of trade between these two economies.

The third scenario presents a game-theoretical distribution of trade voids left by halted Sino-U.S. trade, adjusted according to existing production structures and the proportional value output within industry supply chains. Here, a notable shift occurs: the global carbon uplift for related products pivots to 0.35677%, a figure more pronounced than the no bilateral trade scenario but still less than the no trade scenario. This shift can be attributed to the strategic redistribution of production to regions that may not match the carbon efficiency of the previous Sino-U.S. configuration.

China's unique position as both a massive producer and consumer plays a pivotal role in these scenarios. Under game-theoretic reallocation, China experiences an increase in carbon uplift for related products to 1.23009%, suggesting that the reallocation may lead to less carbon-efficient production processes taking over the supply void. Conversely, the U.S. sees an uplift of 0.77308% for related products, hinting at potential increases in carbon emissions due to adjusted trade patterns and possibly less efficient domestic production filling the gap. In the scenario framed by game theory distribution **??**, the strategic reallocation of trade shares between the United States and China shows an upward trajectory in carbon uplift over the years. This model, which diverges from a simplified binary trade or no-trade paradigm **??**, suggests a more complex interaction within the global supply chain, where the interdependence of international trade plays a crucial role.

The analysis reveals that the carbon uplift in the gaming scenario substantially exceeds the uplift in the simple scenario of domestic production replacing imports. This outcome challenges the notion that ceasing Sino-US trade would lead to a straightforward transition to domestic production for either country. Moreover, the fact that the uplifts are more pronounced under the gaming scenario may imply that the simplified scenario fails to capture the dynamic efficiencies and the clean production structures already present in the Chinese and American industries, which are among the most carbon-efficient on the global stage.

A closer look at the data from 2000 to 2022 reflects this trend. For instance, in the year 2022, China's carbon uplift for semiconductor-related products under the gaming scenario was 1.23009%, marking a stark contrast to a more modest uplift in the no-trade scenario. Similarly, the United States also exhibited an uplift in the gaming scenario, with figures like 0.77308% for the year 2022 for semiconductor downstream products. These specific numbers indicate that the advantages of trade in carbon efficiency are not fully realized when trade is simply redistributed without considering the underlying economic and environmental efficiencies.

The larger carbon uplifts observed in this game theory-informed scenario suggest that a hypothetical redistribution of trade shares may lead to less optimal environmental outcomes than the current state of trade. It underscores the potential misalignment between economic strategies and environmental goals, highlighting the importance of considering the full spectrum of supply chain dynamics when assessing the environmental impacts of trade policies.

4.3 Comparison of Global carbon stressors

4.3.1 Rank of Carbon Stressors in 2022

In our scholarly discourse examining the semiconductor industry's carbon footprint, we center upon the segmentation of upstream and downstream sectors. **??** provides a granular perspective on the environmental costs of semiconductor production.

For the upstream segments, 'Other non-ferrous metal ores and concentrates' denote significant carbon stressors, with China presenting approximately 221,397 kg CO2 per M EUR, juxtaposed against the United States' higher output of around 360,391 kg CO2 per M EUR. In the arena of 'Precious metals,' another upstream category, China again indicates a robust emission figure of roughly 304,336 kg CO2 per M EUR, while the United States showcases a lower, yet substantial, figure of approximately 75,648 kg CO2 per M EUR.

Transitioning to the downstream analysis, we observe in the sector 'Electrical machinery and apparatus n.e.c. (31),' China's carbon stressor is noted at about 10,232 kg CO2 per M EUR, in contrast to the United States' figure of around 18,798 kg CO2 per M EUR. In the domain of 'Office machinery and computers (30),' the carbon emission intensity for China is captured at nearly 9,244 kg CO2 per M EUR, with the United States reflecting a higher emission intensity of approximately 18,205 kg CO2 per M EUR. Moreover, within 'Radio, television and communication equipment and apparatus (32),' China's carbon stressor stands at around 25,205 kg CO2 per M EUR, with the United States slightly elevated at 22,833 kg CO2 per M EUR. Lastly, in the 'Medical, precision and optical instruments, watches and clocks (33)' sector, the data delineate China at roughly 5,285 kg CO2 per M EUR and the United States at about 22,749 kg CO2 per M EUR.

The visualization method adopted in the paper, the "Rank of Carbon Stressor Heatmap in 2022," is predicated upon a ranking-based depiction rather than raw numerical values. This analytical choice is made to circumvent the limitations posed by the disparate magnitude of raw data, ensuring a more coherent and comparative visual comprehension of the carbon stressors across various sectors and countries.

4.3.2 Carbon Stressor Trends (2000-2022)

The intricate graph **??** delineates the carbon stressor in kilograms of CO2 equivalent per million EUR of product value (kg CO2 eq./M EUR) for China, the United States, and globally, across all products and within the semiconductor sector, including both its upstream and downstream components.

Beginning the analysis with the year 2000, China's carbon stressor in the semiconductor industry's related products was 140,031 kg CO2 eq./M EUR, which, when compared to the upstream and downstream sectors—1,466,154 and 63,334 kg CO2 eq./M EUR, respectively—indicates a significant carbon efficiency in the production of specific semiconductor-related outputs. Over the subsequent years, a downward trend is evident, with fluctuations that suggest adjustments and improvements in production efficiency, concluding with the 2022 figures of 24,511 kg CO2 eq./M EUR for related products, and 141,159 kg CO2 eq./M EUR for downstream, against an upstream value of 271,619 kg CO2 eq./M EUR.

For the United States, the year 2000 starts with a carbon stressor of 433,602 kg CO2 eq./M EUR for related products, and 372,360 and 405,985 kg CO2 eq./M EUR for the downstream and upstream sectors, respectively. This highlights a greater initial carbon stressor compared to China. Over the years, the US shows a trend of reducing this stressor across all sectors, particularly in the related and downstream products, culminating in 2022 with values of 22,343 and 21,392 kg CO2 eq./M EUR for related and downstream products, and a higher but reduced upstream stressor of 83,254 kg CO2 eq./M EUR.

The global trends mirror this reduction, starting from 71,282 kg CO2 eq./M EUR for related products and 53,260 and 658,171 kg CO2 eq./M EUR for downstream and upstream sectors in 2000, to 46,830 and 35,374 kg CO2 eq./M EUR for related and downstream products, and 344,678 kg CO2 eq./M EUR for upstream products in 2022. The general trend shows a global drive towards higher carbon efficiency, albeit with regional disparities.

The relationship between these carbon stressors and the previously discussed carbon uplift in a no-trade scenario is telling. The carbon stressor is a measure of the efficiency of production—a lower figure suggests a higher carbon efficiency. In the absence of trade, especially between China and the US, we see the carbon uplift—representing an increase in carbon emissions—reducing over time, which could imply that the efficiency of local production is increasing, thus lessening the potential negative environmental impacts of trade disruptions. This supports the initial analysis that suggests that the semiconductor industry, particularly in China and the US, is advancing towards greater carbon efficiency. Despite this progress, the complexities of global trade and production processes indicate that continuous improvements and collaborations are necessary to further mitigate the carbon footprint of this vital sector.

4.3.3 Carbon Stressor in Different Sectors 2022

?? reveals the heterogeneous nature of the carbon stressor across regions and sectors, underscoring the complex interdependencies and varied stages of development. The metric, measured in kilograms of CO2 equivalent per product value, illuminates the environmental cost of economic activities.

Africa's substantial carbon stressor figures (approx. 249,685 kg CO2 eq./M EUR for related products) hint at the potential for improvement in production efficiencies or the necessity for technology transfer to reduce the environmental impact of its burgeoning semiconductor industry.

Focusing on the Americas, the data depicts a relatively low carbon stressor in the related products sector at approximately 27,254 kg CO2 eq./M EUR, which, juxtaposed with the significant figure in the upstream sector (approx. 178,097 kg CO2 eq./M EUR), indicates a remarkable discrepancy between the different stages of semiconductor production.

China (CHN), a key player in this narrative, shows a carbon stressor of approximately 24,511 kg CO2 eq./M EUR for related products and 141,159 kg CO2 eq./M EUR for downstream products. These figures, when aligned with its upstream carbon stressor of about 271,619 kg CO2 eq./M EUR, suggest a more efficient downstream production relative to the upstream processes.

When we consider the United States (USA), the carbon stressor in related semiconductor products is approximately 22,343 kg CO2 eq./M EUR, with the upstream value at 83,254 kg CO2 eq./M EUR, and downstream at about 21,392 kg CO2 eq./M EUR. This denotes a more balanced carbon stressor across the sectors compared to other regions, reflecting perhaps a more mature market with optimized production processes.

The global view encapsulates these variances, with a general carbon stressor in semiconductor-related products at approximately 46,830 kg CO2 eq./M EUR, indicating the worldwide impact of this industry. This serves as a critical indicator for policymakers and industry leaders to assess and strategize for a sustainable progression of the semiconductor industry.

Chapter5 CONCLUSION

The culmination of this study into the effects of trade protectionism, particularly within the semiconductor industry, underscores the nuanced implications for carbon emissions on a global scale. The analytical results, as shown in 5-1, suggest that the current Sino-US trade, under the prevailing global production framework, contributes substantially to the reduction of global carbon footprint, an insight previously obscured by simplistic substitution methodologies.

Our data reveals that the global carbon uplift percentage, which signifies the increase in the carbon footprint under the modelled scenarios, paints a telling picture of the benefits of current trade patterns. For instance, the no-trade carbon uplift globally for semiconductor-related products was marked at 0.9106%, while the no Sino-US trade with gaming scenario exhibited a significantly higher uplift of 0.3568% in China and 1.2301% in the United States, signifying the substantial carbon mitigation benefits accrued through the current trade relations. This is contrasted with a global uplift of merely 0.0031% under the no Sino-US trade scenario, which does not account for the more complex and realistic inter-country competitive dynamics.

Similarly, for upstream and downstream semiconductor products, the no-trade scenario indicates potential global uplifts of 0.5955% and 0.3152%, respectively. However, when incorporating a gaming trade redistribution approach, the results showcase an intriguing shift with a carbon uplift of -0.0043% globally for upstream products, and a more pronounced uplift for downstream products at 0.1229%. These variations underscore the intricate interplay between trade policies and environmental outcomes.

In conclusion, our comprehensive and granular approach to modeling trade restrictions and their impact on carbon emissions provides a more accurate representation of the potential environmental repercussions. The data-driven insights confirm that trade between China and the United States has been a key driver in mitigating carbon emissions, challenging the notion that protectionism could be a boon for environmental sustainability. As we navigate the complexities of global trade and its environmental impact, it becomes increasingly evident that collaboration, rather than protectionism, is pivotal in fostering a global reduction in carbon

Table 5-1 Summary of Carbon Uplift and Stressor Data for Semiconductivity Products

Products	**Global**	**China**	**United States**
Semiconductivity Related Products			
No Trade Carbon Uplift	0.9106%	-0.0768%	-0.1678%
No Sino-US Trade Carbon Uplift	0.0031%	0.0011%	0.0212%
No Sino-US Trade with Gaming Uplift	0.3568%	1.2301%	0.0773%
Carbon Stressor (kg CO_2 eq./M.EUR)	46,830.10	24,511.12	22,343.31
Net Export Rate	0.0000%	25.4251%	-26.6277%
Semiconductivity Upstream Products			
No Trade Carbon Uplift	0.5955%	-0.0280%	-0.0590%
No Sino-US Trade Carbon Uplift	0.0004%	0.0041%	-0.0054%
No Sino-US Trade with Gaming Uplift	-0.0043%	-0.0148%	-0.0013%
Carbon Stressor (kg CO_2 eq./M.EUR)	344,677.88	271,619.23	83,254.16
Net Export Rate	0.0000%	21.3270%	65.2615%
Semiconductivity Downstream Products			
No Trade Carbon Uplift	0.3152%	-0.0488%	-0.1088%
No Sino-US Trade Carbon Uplift	0.0026%	-0.0029%	0.0266%
No Sino-US Trade with Gaming Uplift	0.1229%	0.3482%	0.1903%
Carbon Stressor (kg CO_2 eq./M.EUR)	35,373.63	14,159.19	21,392.43
Net Export Rate	0.0000%	25.5608%	-27.0224%

emissions.

Chapter6 DISCUSSION

In the discourse of global trade and its environmental impact, our discussion unfolds multiple layers of complexity. The findings from the conclusion section, indicating a stark contrast in carbon uplift across different trade scenarios, propel us into a deeper examination of the underlying dynamics at play.

The nuanced scenario of Sino-US trade, particularly under a gaming redistribution, reveals a paradox within the realm of protectionism and its perceived environmental benefits. While the cessation of trade between China and the United States may intuitively suggest a decrease in carbon emissions due to localized production, the empirical evidence from our analysis suggests otherwise. The intricate fabric of global production and trade cannot be unraveled without significant repercussions. It becomes evident that the cessation of trade could inadvertently escalate the carbon footprint, thereby undermining the environmental strides achieved through current trade synergies.

This counterintuitive finding beckons a reevaluation of trade policies from an environmental standpoint. The inclination towards protectionism, which has gained traction in certain political discourses, is revealed through our study to be potentially detrimental to the collective goal of reducing global carbon emissions. In particular, the semiconductor industry, with its deeply intertwined global supply chains and high carbon mitigation potential, serves as a poignant case study reflecting the broader trade-environment nexus.

The discussion also brings to light the role of advanced economies in leveraging their technological prowess to produce goods more efficiently, with a lesser environmental toll. In the wake of trade protectionism, this efficiency could be lost, transferring production to regions with less stringent environmental regulations or less efficient technologies, thereby exacerbating global emissions.

It is imperative to consider that while trade agreements and policies are often driven by economic and political factors, their environmental implications are profound and far-reaching. Our study challenges policymakers to integrate environmental efficiency into the heart of trade negotiations, transcending the traditional paradigms of protectionism to foster a trade environment that is both economically viable and environmentally sustainable.

Hence, the discussion leads us to advocate for a collaborative approach to international trade, one that is cognizant of the global environmental imperatives and is structured around sustainable practices. The nuanced understanding of the carbon uplift trends across various scenarios presented in this study could serve as a foundational block for future research and policy-making, steering the global community towards more informed and environmentally conscious trade decisions.

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