Bridging the gap between production and ecology: a multi-regional input-output analysis of current Brazilian and Chinese productive and ecological relations

Preenchendo a lacuna entre produção e ecologia: uma análise multirregional de insumo-produto das atuais relações produtivas e ecológicas brasileiras e chinesas

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RESUMO: A literatura emergente sobre Trocas Ecológicas Desiguais (TED) incorpora múltiplos elementos de vertentes pós-keynesianas, em particular a análise estruturalista das relações econômicas globais e da divisão centro-periferia. No entanto, ainda há pouca discussão na literatura sobre as sinergias e interligações dos aspectos produtivos e ecológicos da condição periférica. Este trabalho pretende entrar neste debate propondo uma análise multirregional de insumo-produto (MRIP) do padrão recente das relações econômicas entre Brasil e China, com foco na evolução e nas ligações entre os aspectos produtivos e ecológicos. Os resultados mostram uma crescente troca desigual de recursos biofísicos que flui do Brasil para a China, que está ligada a setores-chave do recente processo de recuperação chinês. Como conclusão, argumenta-se que as hierarquias produtivas e ecológicas implicam duas faces da mesma moeda da condição periférica.
PALAVRAS-CHAVE: Troca ecológica desigual; estruturalismo; análise multirregional de insumos e produtos ambientalmente ampliada.

ABSTRACT: The arising literature on Ecological Unequal Exchange (EUE) incorporates multiple elements of post-Keynesian strands, in particular the structuralist analysis of global economic relations and the center-periphery divide. Nevertheless, there is still little discussion in

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the literature on the synergies and interconnections of the productive and ecological aspects of the peripheral condition. This work intends to enter this debate by proposing a multi-regional input-output (MRIO) analysis of the recent pattern of economic relations between Brazil and China, focusing on the evolution and linkages between the productive and the ecological aspects. The results show a rising unequal exchange of biophysical resources that flows from Brazil to China which is tied to key sectors of the recent Chinese catching-up process. In conclusion, it is argued that productive and ecological hierarchies entail two sides of the same coin of the peripheral condition.
KEYWORDS: Ecological unequal exchange; structuralism; environmentally-extended multi-regional input-output analysis.
JEL Classification: C67; O53; O54; Q56.

INTRODUCTION

In the last years, ecological discussions have gained significantly more traction in Economics and the Social Sciences in general. However, there is still a relevant debate on whether the mainstream research agenda is ready to incorporate key contributions offered by the field of Ecological Economics. Moreover, while some alignment with ideas proposed by Ecological Economics is espoused, some of the main branches of heterodox economics have yet to fully integrate them into their research agenda. In the case of the post-Keynesian structuralist strand, most of its literature on the economic asymmetries, engendered by the relative position of countries within international structures of production, trade, and finance, still overlooks the inequality of ecological damage and resource distribution embedded in the exchange between countries or regions.

When considered together, some of the key ideas of the Structuralist, Post-Keynesian and Ecological Economics theories suggest that there is a historical net outflow of peripheral ("global south") biophysical resources, to the core countries ("global north"). While the latter group tends to specialize in more complex activities such as the manufacturing industry and modern services, peripheral countries maintain an extractive economic model with reduced productive diversity and are still structured around exporting raw materials. This suggests that the depletion of peripheral resources has been accompanied by the attainment of comparatively higher levels of income in core countries. Integrating the frameworks of both these research agendas can facilitate more effective policymaking in international and local organizations by simultaneously acknowledging the historical debt that core countries owe to the periphery while also assisting these countries in promoting structural change and ecological transition.

This paper aims to apply this combined framework to address the interconnections between the productive and ecological aspects of the peripheral condition. To achieve this, we examine the specific context in which Brazil, China, and their trade flows find themselves concerning the conjunct discussion of Ecologically Unequal Exchange and Heterodox development theory. In recent decades, China has become Brazil's most important economic partner. Although this has led to a recent increase in the volume of exports and has helped improve Brazil's foreign reserve accumulation, it is not possible to assert that both countries are following convergent paths in terms of development, environmental cost-sharing, and resource usage. While China has continuously shifted its productive structure toward complex economic activities, enabling an upgraded position in Global Value Chains (Palma, 2009) and better prospects for long-term economic growth, Brazil has experienced premature deindustrialization (Sugimoto & Diegues, 2022) and has struggled to achieve more substantial levels of sustained growth.

By employing data of selected years between 1995 to 2020 from EXIOBASE 3, we build an Environmentally-Extended Multi-Regional Input-Output Model (EEMIRIO) to demonstrate that the biophysical flows from Brazil to China have been increasing throughout recent years. Sectoral level data reveals that the increasing Chinese final demand came at the cost of a huge augmentation of Brazilian embodied land, and water withdrawal and CO_2 emissions in the Brazilian territory. In other words, China consumes more and more embodied Brazilian land, water withdrawal, and CO_2 emissions. Conversely, China's embodied land and CO_2 exports to Brazil were made in inferior amounts and Brazil's own demand composition for the same biophysical resources remained for the most part concentrated in extractive sectors like cattle farming and the processing of cattle meat.

The sectoral data also indicates that the Chinese sectors driving this increased biophysical footprint are some of the core leading industries of China's recent productive transformation, highlighting the intricate interconnection in the global economy between biophysical footprints and productive complexity. Therefore, our article's findings contribute to further articulating the research agenda on ecologically unequal exchange and structural change by helping characterize, in ecological and sectoral terms, the recent trajectory of the international trade pattern between Brazil and China.

The first section of this article aims to explore the contributions of Structuralist and Post-Keynesian literature to the study of international trade and development. We examine the implications of these theoretical perspectives on the ongoing deindustrialization process in Brazil, focusing on the role of the industrial sector in GDP and the patterns of exports. The following section briefly presents the theory of ecologically unequal exchange, highlighting empirical estimations of core-periphery biophysical flows and assessments of the particular position that Brazil and China have in global trade. Subsequently, we conduct an analysis of the evolution of Brazil-China economic biophysical resource exchange relations through Multi-Regional Input-Output analysis for the selected years of 1995, 2005, and 2020, employing EXIOBASE 3. Data and methodology are presented, followed by results, discussion, and conclusion.

DEVELOPMENT AND INTERNATIONAL TRADE IN STRUCTURALIST AND POST-KEYNESIAN PERSPECTIVES, AND THE PROCESSES OF DEINDUSTRIALIZATION AND REGRESSIVE SPECIALIZATION IN BRAZIL

Building upon the original contributions by important authors such as Raul Prebisch and Celso Furtado within the ECLAC (The United Nations Economic Commission for Latin America and the Caribbean), the structuralist literature continues to expand an already vast body of work that highlights the economic challenges faced by "peripheral" economies, in contrast to those of the "core" economies. As summarized by Bielschowsky (2009, p.173), the seminal contributions from ECLAC identified the peripheral regions as having the following characteristics: "(i) specialization in primary goods and lack of productive diversity (low levels of intersectoral complementarity and vertical integration); (ii) highly varied levels of sector productivity and an unlimited supply of labor with income close to subsistence level; and (iii) an institutional structure (State, agriculture sector, and business fabric, among others) that was poorly oriented towards investment and technical progress." Therefore, to achieve economic development, they recommended structural change through a state-led process of industrialization, which would promote technological catch-up while also spreading the benefits of productivity and economic growth more evenly.

For these authors, an important feature of the world economy is also the asymmetry between the sluggish growth of the global demand for commodities produced by the periphery, contrasted with the rising demand for manufacturing goods by the core countries. From this structuralist point of view, there is a tendency for a structural deficit in the balance of payments of peripheral countries, which in turn could interrupt episodes of growth by affecting the conditions necessary to import essential goods and services, maintain relative stability in exchange rates and inflation, and keep the external debt and its services under control.

In the same vein but through a different formulation, post-Keynesian economics also emphasizes the productive heterogeneity between countries and the impacts of this heterogeneity on international trade and growth differentials. Following Kaldor (1970), economic development must be understood as a process of cumulative causation, in which sectoral productivity is propelled by capital accumulation and sectoral growth itself. In this context, productivity is not entirely exogenous, and growth is not determined solely by supply but is instead demand-led in both the short and long run. Moreover, the effects of static and dynamic increasing returns to scale are more pronounced in sectors associated with complex activities, such as the manufacturing industry and technological services.

A significant repercussion of Kaldor's ideas was the development of a series of models in which growth is constrained by the balance of payments (Thirlwall, 1979). An important feature that these models aim to consider is that peripheral countries cannot sustain significant current account deficits for extended periods (Vernengo & Caldentey, 2020). Assuming that exports and imports must grow at the same rate to avoid balance of payments issues, Thirlwall (1979) demonstrates that given the rate of growth of world income, the long-term performance of an individual economy depends on the ratio between the income elasticity of exports and the income elasticity of imports (Setterfield, 2011). As demonstrated in the empirical literature survey conducted by Magacho (2017), manufacturing products exhibit higher income elasticity than primary goods, suggesting that promoting structural change toward these sectors is advantageous as it allows for the capture of a larger portion of increases in world income. In this context, Palma (2008) offers evidence that economic growth is "product-specific," implying that specialization in internationally high-demand products with significant dynamic scale returns propels the economy along a growth trajectory. Therefore, an important takeaway from this literature for policymaking in developing countries is that international trade may not equally benefit everyone. Furthermore, how countries produce, import, and export goods matters for economic development.

In light of these perspectives, Brazil has been experiencing concerning trends as its economy has undergone a process of deindustrialization and regressive specialization since the 1980s. Morceiro (2018), analyzing data (1947-2017) provided by the Brazilian Institute of Geography and Statistics, revealed that the real manufacturing value added as a share of real GDP reached its peak at 20.7% in 1981 but declined to 11.8% by 2017 (Table 1).

Table 1: Real manufacturing value added as a share of real GDP (1981-2017)

Year	1981	1987	1993	1999	2005	2011	2017
Share	20.7%	19%	16.8%	15.2%	15.7%	14%	11.8%

Source: Morceiro (2018).

Distinct from the deindustrialization observed in most developed countries, which is characterized by a decrease in the industry's share of GDP without a reduction in the absolute aggregate value of its products, the deindustrialization in Brazil does not entail a shift towards more productive service sectors. Instead, it has manifested as a shift towards low knowledge-intensive commodity sectors (Sugimoto & Diegues, 2022). This phenomenon can also be observed in Brazilian exports. Taking data from the Atlas of Economic Complexity of Total Exports, the share of Material Manufacturers, Machinery, and Other Manufacturers fell from 22.3%, 15.5%, and 5.32% in 1981 to 7.69%, 8.31%, and 1.35%, respectively, in 2020. On the other hand, the share of low knowledge-intensive commodity sectors like Crude Materials and Fuels increased from 13.57% and 3.6% to 31.25% and 10.21%, respectively, in the same period.

Although deindustrialization and regressive specialization began before the exponential increase in Chinese demand, which started at the end of the 20th century, the trade pattern with this partner accentuated these processes (Idem, 2022). This can be observed by utilizing the aforementioned data and contextualizing the trade partnership with China. The share of Material manufacturers fell from 15.01% in 1981 to 3.95% in 2020, while Crude Materials and Fuels rose from

27.02% and less than 1% to 66.20% and 16.68%, respectively. When observing the data of Brazilian exports to China in current USD value, it is noteworthy that Brazil sent 28 million USD worth of Crude Materials in 1981 and 44.8 billion USD in 2020. This amount represents 61% of the country's total exports of Crude Materials, amounting to 73.3 billion USD.

The available data, in conjunction with the aforementioned theories, support the idea that Brazilian international integration is moving towards under-positioning in the Global Value Chains, as the country has experienced processes of deindustrialization and regressive specialization towards low-added value goods, resulting in its assumption of a peripheral condition. The current trade pattern with China reflects and further exacerbates this trend.

THE THEORY OF ECOLOGICALLY UNEQUAL EXCHANGE, CORE-PERIPHERY RELATIONS, AND THE INTERNATIONAL INSERTION OF BRAZIL AND CHINA

Despite the significant critiques leveled against conventional mainstream models, heterodox theory on international trade and growth has, at least in terms of the topics discussed by pioneering contributions, largely overlooked the inequality of environmental damage and resource distribution embedded in the exchange between countries or regions (Fontana & Sawyer, 2016).

As stated by Saes (2023), the theory of ecologically unequal exchange (EUE) and the Barcelona School also begins with the core-periphery division as a fundamental category. However, the emphasis is placed on biophysical indicators such as greenhouse gas emissions, land area used, volumes of water, volumes of materials, expended energy, invested labor time, and so on. Considering the environmental pressures of trade and economic activities involves recognizing a variety of potential social and environmental costs that cannot be fully captured in monetary terms (Hornborg, 2021). This approach also enables a more accurate measurement of the pressure that the economic activity of each country or region truly exerts on the ecosystem, allowing for a more robust specification of the ecological debt that core countries owe to the periphery (Hornborg & Martinez-Alier, 2016).

The main argument of EUE is that there exists a historical and ongoing asymmetric net outflow of peripheral biophysical resources that is obscured by the apparent reciprocity of international trade (Dorninger, 2015; Givens & Huang, 2021; Hornborg, 2021; Saez, 2023). Since crucial aspects of economic development, such as capital accumulation, are necessarily reliant on these environmental resources (Hornborg, 2021), it can be argued that if such an asymmetric flow has indeed occurred historically, it has contributed to the relatively higher levels of development in core countries. To investigate these patterns, researchers on EUE have employed various methods, with material flow analyses and environmentally-extended multi-regional input-output modeling (EEMIRIO) being among the most prominent.

Dorninger & Hornborg (2015) conducted a review of the empirical literature, demonstrating that current research using EEMIRIO and the most updated data available in 2015 revealed a context in which there were net inflows (imports) of raw material equivalents, embodied energy, embodied land, and embodied labor to the USA, Japan, and the countries of the EU27 treated as a single unit. Dorninger et al. (2021) demonstrated a temporal persistence in the unequal exchange pattern. Specifically, from 1990 until the 2008 financial crisis, the amount of biophysical resources transferred towards the group of high-income countries displayed a rising trajectory. After a slight reduction between 2007-2010, it remained stable at a high level. Additionally, the group of high-income countries throughout the period was the only one that had a net inflow of all resources while also maintaining significantly higher ratios of Trade in value added per unit of embodied resource exported (TIVA).

China's special position regarding EUE has also been a particularly discussed subject in many studies. When analyzing the commercial flows with traditional core countries, it is important to notice that there is relevant evidence of EUE[1] with China in a subordinate position. However, regarding the relationship with peripheral countries, it appears as a net importer of many biophysical resources. Yu et al. (2014) shows that in 2010, China emitted significantly more SO_2 and CO_2 to cope with the export demand from core regions than it imported from these same groups. Additionally, it was also a net exporter of embodied water and land while net transferring value added in all resource categories. In a different sense, the trade with peripheral countries shows a scenario that is mostly the opposite but with more nuances depending on the object of the analysis. For instance, China exported more SO_2 and CO_2 to Latin America but received net transfers of water and land.

In fact, the EUE that China increasingly experiences with different regions of the world, depending on the biophysical resource flow in analyses, must be considered by peripheral countries. These countries are exerting extensive pressure upon their environment without gaining "compatible" socioeconomic benefits. This is especially true for Brazil's raw materials export structure, as empirical evidence demonstrates that agricultural and mining exports from low and middle-income nations to China are related to increased forest loss in these exporting nations (Shandra et al., 2020). Another important feature highlighted by this empirical literature is the massive increase since 1990 in the biophysical flows that South America the region exports to China. As shown by Dorninger & Eisenmenger (2016), China has increased its percentage as an export destination and is already the second biggest partner of Argentina and the main destination for Brazil's raw material exports.

[1] In their estimation, Dorninger et al. (2021) demonstrate that China is a net exporter to the rest of the world of almost all embodied resources. From a bilateral trade perspective, Dai et al. (2021) shows that there is unequal exchange in trade involving carbon emissions with the EU, while Zhao et al. (2016) demonstrate the same process holds in trade with the US.

Despite the ongoing debate on whether China is effectively catching up to the core while building conditions to reduce its ecological footprint and trade-induced ecological impact, it is important to note that a remarkable counterpart of the biophysical resources transferred from other global South countries was the high growth and recent structural change that it has experienced. As already pointed out, this was not the case for Brazil, which suffered from premature deindustrialization, and like many other peripheral countries, saw increased pressure upon the domestic environment mainly due to a trade insertion based on an extractivist model. In what follows, this article intends to contribute to the literature that discusses ecological exchange between China and Brazil, highlighting not only the evolution of the biophysical flows but also the sectoral dynamics associated with these flows. By analyzing how resource usage is associated with the productive structure and integration within Global Value Chains (GVCs), this articulation helps to paint a clearer picture of the relationship among trade, structure (especially when studying bilateral relations that are more nuanced than the traditional core-periphery case studied in EUE theory), and the socioeconomic results it engenders.

A MULTI-REGIONAL INPUT-OUTPUT ANALYSIS OF THE EVOLUTION OF BRAZIL-CHINA RELATIONS

Combining the structuralist view with an EUE approach requires the ability to track environmental footprints at a sectoral level. Following several of the works aforementioned, this paper will employ Environmentally-Extended Multi-Regional Input-Output (EEMRIO) tables for this task. Based on the works of Leontief (1991[1928]; 1970) and Leontief & Strout (1963), EEMRIO models can produce a detailed snapshot of the economy, tracing the origin of direct and indirect inputs needed for the production of goods and services. These models depict the extensive industrial network of productive dependency formed by the direct and indirect interconnection of all sectors, containing information about the natural resources used in production, the pollution generated by this process, and the amount of natural resources and pollution embodied in the goods and services consumed (Guilhoto, 2021).

Moreover, these models can indicate the trade balances in monetary value and material measure among countries in terms of which ones are consuming products and services produced with national nature and from which countries goods and services with a high level of embodied nature and pollution generation are being imported from (Idem, 2021). Consequently, Env-MRIO allows not only the study of general macroeconomic and ecological characteristics of an economy but also of detailed sectoral and inter-sectoral dynamics of upstream and downstream global chains of production (Godin & Hadji-Lazaro, 2020).

Data and Methodology

EXIOBASE 3 is the EMMRIO table selected for this study due to its higher sector granularity compared to other MRIO tables available, and its comprehensive information about the Brazilian and Chinese economies. These two countries are among the 44 countries with individual data in the dataset (Stadler et al., 2018). The biophysical indicators chosen for assessing the ecological footprint are land use in km2, blue water withdrawal in Mm3, and GHG emissions in CO_2 kg equivalents. These three indicators are available in EXIOBASE 3's environmental extension account[2].

Our data curatorship aims to highlight the periods of expansion in China's demand for international goods. For this purpose, the timeframe of our analysis is demarcated by three points: 1995, 2005, and 2020. The initial demarcation in 1995 was chosen because it represents the earliest available data in our database prior to a series of actions taken by the Chinese Communist Party (CCP) to expand the country's international trade at the beginning of the new millennium. In turn, as the early 2000's represents a period demarcated by big government strategies for international economic integration, such as China's accession to the World Trade Organization (WTO) in 2001 and the Go Global initiative (2000), 2005 was elected as a point of observation because it showcases the initial effects on the Chinese economy of this strategies. Finally, 2020 was selected because it outlines the maturation of these aforementioned strategies and others started after 2010, such as the Belt and Road Initiative (2013) and Made in China (2015).

The exercise focuses mainly on identifying the output that Brazilian sectors need to produce to satisfy the Chinese final demand and the ecological impacts associated with these sectors. By looking at the upstream network of production needed to satisfy the Chinese final demand it is possible to identify the amount of output that each Brazilian sector needs to produce so that China can keep its current consumption pattern. To spot this, one should start by manipulating the final demand matrix (FD) so that the values of the Chinese final demand are kept while all the other countries' final demand is set to zero. This can be achieved by multiplying element-wise the FD matrix by a matrix of the same size of ones and zeros in which "one" values are attributed to the Chinese final demand and "zeroes" for the rest. To account for all the direct and indirect sectoral production necessary for satisfying the Chinese final demand, the transformed FD matrix (FD') has to be pre-multiplied by the Leontief-inverse matrix (L):

$$X_{chn} = L \,.\, FD' \qquad (1)$$

The resulting X_{chn} matrix contains information concerning how much each sector in the world needs to produce to supply the level of Chinese final demand.

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[2] Their complete names are: Land use Crop, Forest, Pasture (Km2); Water Withdrawal Blue – Total (Mm3) and GHG emissions (GWP100) | Problem oriented approach: baseline (CML, 2001) | GWP100 (IPCC, 2007).

The output of the Brazilian sectors can be easily identified by looking at their corresponding rows.

Concerning the ecological footprint in Brazil of "supplying" this Chinese final demand, the strategy adopted in this work is similar: to study the backward linkages of the Chinese final demand that are traceable back to Brazilian sectors and their ecological impacts. Thereafter, the ecological impacts of these Brazilian sectors are measured, being measurements of China's final demand ecological footprint on Brazil.

For this to be done the satellite account matrix (*Q*) from EXIOBASE 3, which contains the indicators of land use, blue water withdrawal and GHG emissions, must be first multiplied by the inverse of the diagonalized output vector (x^{-1}). This operation results in the *U* matrix of direct ecological footprints. Each value in this matrix represents the amount of direct land use, blue water withdrawal and GHG emissions needed for each sector to produce one unit of output.

$$U = Q \cdot x^{-1} \qquad (2)$$

Since we want to study only the ecological impacts that take place in Brazil, i.e., the ones caused directly by Brazilian sectors, it is necessary to alter the *U* matrix so that all the values are zero except those of the Brazilian sectors. This can be done by multiplying element-wise the *U* matrix by a matrix of ones and zeros in which "one" values are attributed to Brazilian sectors and "zeroes" for the rest. The resulting matrix is a matrix of the Brazilian direct ecological footprint (U_{bra}).

Given the large network of backward linkages in production, it is also necessary to account for indirect ecological footprints. In this sense, although some sectors that supply the Chinese final demand may not leave any direct ecological footprint in Brazil, they may purchase their inputs from sectors that do leave a very high footprint. To account for all the indirect backward linkages, the U_{bra} matrix of direct ecological footprints must be multiplied by the Leontief inverse matrix (*L*). The result is a matrix Q_{tbra} *of* direct and indirect ecological footprints in Brazil for each sector.

$$Q_{tbra} = U_{bra} \cdot L \qquad (3)$$

Finally, the Q_{tbra} matrix has to be multiplied by a diagonalized final demand vector (*f*). This operation results in a final matrix Q_{dbra} where it is possible to identify the ecological footprint in Brazil caused by the final demand of each Chinese sector.

$$Q_{dbra} = Q_{tbra} \cdot f \qquad (4)$$

It is possible to reproduce the same operation from a Chinese perspective and look at the Brazilian industries that leave ecological footprints in China. By aggregating the values of the different sectors in both countries it is possible to compare the ecological footprint value of the Brazilian and Chinese final demands for the indicators selected.

Results

By employing the EXIOBASE 3 and following Equation (1) above described, it was possible to identify the output that Brazilian sectors needed to produce in order to satisfy the Chinese final demand in the year 2020. The results displayed in Table 2 show the Top 10 Brazilian sectors that produce the most (measured in millions of Euros) to satisfy the Chinese final demand.

Table 2: Brazilian Sector's Output Needed to Directly and Indirectly Satisfy the Chinese Final Demand in 2020 (Top 10)

Brazilian Sectors	Sector Output in M.EUR
Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	21,166.56
Mining of iron ores	13,141.75
Chemicals	3,995.02
Wholesale trade and commission trade, except of motor vehicles and motorcycles	2,711.43
Other business activities	2,627.68
Computer and related activities	2,497.58
Cultivation of oil seeds	2,425.61
Processing of meat cattle	2,337.31
Support and auxiliary transport activities; activities of travel agencies	2,308.10
Petroleum refinery	2,145.23

Tables 3, 4 and 5 show the ecological footprint in Brazil – in terms of land use, blue water withdrawal and CO2 emissions respectively – of each Chinese sector's final demand for the selected years of 1995, 2005 and 2020. As expected, the results show increasing resource use in Brazil by the Chinese final demand.

Table 3: Evolution of Total Brazilian Land Used to Directly and Indirectly Satisfy Chinese Sectors' Final Demand (Km2) (Top 10)

Chinese Sectors	1995	2005	2020
Construction	818.34	18,850.71	59,640.96
Health and social work	170.45	5,286.09	37,583.60
Processing of food products	543.49	6,105.09	16,603.60
Hotels and restaurants	1,898.00	7,545.55	16,184.67
Public administration and defence; compulsory social security	295.12	3,938.32	14,288.41
Manufacture of fish products	997.73	8,614.95	12,931.73

Manufacture of machinery and equipment	200.92	3,726.96	10,133.03
Manufacture of wearing apparel; dressing and dyeing of fur	82.20	3,281.14	10,072.09
Education	101.82	3,604.14	10,015.49
Manufacture of motor vehicles, trailers and semi-trailers	41.37	2,449.20	8,814.71

Table 4: Evolution of Total Brazilian Blue Water Withdrawal to Directly and Indirectly Satisfy Chinese Sectors' Final Demand (Mm3) (Top 10)

Chinese Sectors	1995	2005	2020
Construction	9.58	55.12	167.77
Health and social work	0.70	7.73	83.87
Manufacture of machinery and equipment n.e.c	2.92	16.65	30.72
Manufacture of electrical machinery and apparatus n.e.c	0.81	8.93	29.10
Manufacture of wearing apparel; dressing and dyeing of fur	0.38	5.65	25.44
Public administration and defence; compulsory social security	1.42	7.19	24.74
Processing of food products	3.46	4.67	24.71
Paper	0.25	1.75	24.63
Manufacture of motor vehicles, trailers and semi-trailers	1.03	7.70	22.99
Education	0.49	5.18	22.07

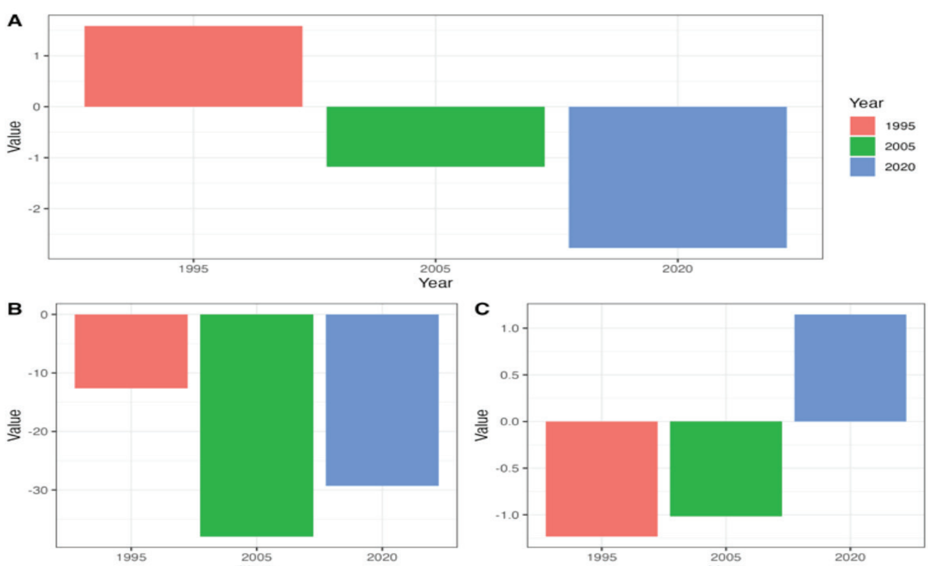
Table 5: Evolution of Total Brazilian GHG Emissions to Directly and Indirectly Satisfy Chinese Sectors' Final Demand (Kg CO2 equivalents) (Top 10)

Chinese Sectors	1995	2005	2020
Construction	199,833,062	2,915,047,396	15,589,242,491
Health and social work	15,070,179	392,735,696	6,300,495,546
Hotels and restaurants	110,323,796	379,537,233	4,033,313,300
Public administration and defence; compulsory social security	29,003,188	333,735,429	3,408,692,912
Manufacture of machinery and equipment n.e.c	57,940,824	928,080,606	3,314,933,984
Processing of food products	75,606,703	332,040,577	2,650,437,675
Manufacture of electrical machinery and apparatus	16,298,638	480,290,592	2,622,056,599

Manufacture of motor vehicles, trailers and semi-trailers	18,210,715	404,038,379	2,107,316,879
Petroleum refinery	130,122	50,042,823	1,738,594,309
Education	9,658,323	266,314,671	1,724,870,047

A similar exercise was carried out from the Brazilian final demand perspective and the values were compared for each indicator. Figure 1 shows this comparison from a Brazilian perspective and in net and ratio values comparing the bigger value to the smaller one. For instance, Chart A shows the evolution of the net value of CO_2 Emissions caused by the Brazilian and Chinese final demands in the other country. In 1995 the Brazilian final demand generated around 1.58 times more CO_2 emissions in China than the Chinese final demand generated in Brazil. In 2005 the situation was reversed as the Chinese final demand generated 1.17 times more CO_2 emissions in Brazil than the Brazilian final demand generated in China. Finally, in 2020 the Chinese final demand generated 2.78 times more CO_2emissions in Brazil than the Brazilian final demand in China.

Figure 1: Net Values in Ratio of CO_2 Emissions (A), Land Use (B) and Blue Water Withdrawal (C) needed to Satisfy Brazilian and Chinese final demands



DISCUSSION: THE PRODUCTIVE AND ECOLOGICAL ASPECTS OF THE PERIPHERAL CONDITION

A first glance at Table 2, detailing the Brazilian sectors' output to meet Chinese final demand in 2020, reveals a strong alignment with the propositions of the structuralist approach. The Top 10 list contains primary sectors that lack large potential for devising internal processes of cumulative causation and increasing returns of scale. The inclusion of sectors such as oil, petrol, ores, cattle, and oil seeds alongside sectors like chemicals and computer activities paints a picture of Brazil as a peripheral country with a heterogeneous productive structure (Furtado, 2009) currently experiencing premature deindustrialization.

This condition of the Brazilian economy starkly contrasts with that of the Chinese economy. The remarkable Chinese catching-up process has been characterized by a strong initial export-led dynamic that gradually combined with an investment-led one, and more recently, is moving towards a consumption-led dynamic (Jabbour, 2020). The success of China has been attributed to its ability to couple intense structural change with spillover effects over its industrial structure and within its national territory (Idem, 2020). The manufacturing and construction sectors have been pivotal in the process of infrastructure development and upgrading in global value chains. The significant increase in the Chinese final demand footprint in Brazil across the selected indicators between 1995 and 2020 unveils another aspect of the story of the Chinese catching-up. The examination of the sectors presented in Tables 3, 4, and 5 reveals that the Top 10 are composed predominantly of manufacturing or infrastructure sectors, with construction leading in all three indicators. Furthermore, sectors such as food processing, health and social work, and hotels and restaurants are associated with the rising consumption-led dynamic of the Chinese economy.

It becomes evident, therefore, that sectors driving the recent Chinese catching-up process are also driving the increasing ecological footprint in Brazil over the past years. There is a clear intricate interconnection between the Chinese upgrade in its productive complexity and the rising biophysical footprints in Brazil, as the increase in resource usage is sectorally unequal between both countries. This suggests that similar to development, biophysical footprints might be sector- and product-specific and associated with manufacturing and infrastructure industries.

The net values in the ratio of the biophysical indicators between Brazil and China displayed in Figure 1 contribute more for asserting the points of contact between EUE and heterodox/structuralist approaches. In the period between 1995 and 2020, Brazil has become a huge net exporter of land and CO_2 emissions to China, as the Chinese final demand needs 2.77 times Brazilian CO_2 emissions and 30 times Brazilian land more than the Brazilian final needs from China.

While Brazil is a net importer of blue water withdrawal from China, the Brazilian final demand only requires 1.15 times the amount that the Chinese final demand needs from Brazil. This value is relatively small compared to the differences observed for other biophysical indicators. As explained by Dorninger & Hornborg

(2015), EUE analysis should focus on aggregates rather than single values. Additionally, China is a well-known global water exporter, as supported by studies such as those by Magacho, Espagne & Santos Carneiro (2023) and Yu et al. (2014).

A key insight from the analysis conducted is that the peripheral status of the Brazilian economy is evident not only through premature deindustrialization and struggles with catching up, but also through persistent unequal ecological exchanges. The trajectory of biophysical exchanges between Brazil and China exemplifies this dual aspect of the periphery. As China's catching-up process intensified and Brazil experienced a loss of productive complexity, the net flow of biophysical resources from China to Brazil, particularly in terms of land and CO_2 emissions, intensified, with Brazil increasingly becoming a major net supplier of biophysical resources to China. In essence, this signifies a greater extraction of natural resources in Brazil, their transformation, and consumption in China. The primary drivers of this trend were Chinese sectors that played pivotal roles in its export-, investment-, and now consumption-led growth.

Instead of questioning Brazil's position as a peripheral country, the fact that Brazil has become a net importer of blue water withdrawal from China fuels the debate about whether China should still be considered as peripheral, central, or classified in an in-between position of semi-periphery.

CONCLUSION

In their own right, the EUE and structuralist literature represent significant research agendas that critique formulations overly reliant on the idealization of free trade and its purported benefits. By respectively highlighting core-periphery asymmetries regarding the impacts of heterogeneous productive structures and biophysical resource transfers, they offer important starting points for an alternative framework on development and sustainability. However, there is still much research to be done on the complementarities and differences between both approaches, as well as on other themes such as prevailing south-south trading patterns and the policies, both local and international, that can best serve the goals of assisting the periphery while also promoting sustainable trajectories.

In this regard, our article contributes to the literature by examining the evolution of EUE between China and Brazil and the sectoral demand for resources that underpinned it. We demonstrate that from 1995 to 2020, the embodied land transfers and CO_2 emissions originating from Brazil and utilized to meet final demand in China remained substantial. While China's net blue water transfers partly offset this, the origins of the final demand drivers revealed two distinct sectoral dynamics.

China used Brazilian biophysical resources to help in the achievement of larger socio-economic goals such as structural change and the increase in mass consumption and growth. However, the Brazilian sectors involved in the trade with China were for the most part sectors associated with an extractive model that cannot provide adequate conditions for long-run development. Therefore, the Brazilian south-south trade flow exhibited the twofold characteristics of the peripheral condition manifesting itself both in a recurrent EUE and a regressive specialization. In this sense, although China might have important concerns regarding the efficiency of its productive development strategy in terms of further value capture in GVC's and specially in reducing the ecological deficit with core countries and the domestic footprint, from a bilateral perspective the relationship with Brazil highlights many core-like features.

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