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Using input-output data to model the structure of export linkages in global value chains: A Brazil case study

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Abstract

This paper considers Global Value Chains by developing an open Leontief input-output model for which household consumption is endogenously determined—the Type II framework. Three specific contributions are: an extension of the Type II input-output model to a multi-country setting; its empirical modelling using trade-linked input-output tables; and a Brazil case study for exploring how the industrial structure of export linkages impact on employment. Policy dilemmas that emerge for Brazil's industrial strategy focus on its heavy reliance on primary-based industries, and how it might diversify its trading partners.

KEYWORDS

Brazil, export linkages, global value chains, input-output, Pasinetti, type 2 multiplier

1 | INTRODUCTION

For theories of structural change that focus on the importance of aggregate demand, increasing importance has been placed in recent years on the role of international trade. Inspired by the approach of Pasinetti (1981, 1993), a number of studies have modelled the relationship between the industrial composition of exports and structural change. In the approach of Araujo and Lima (2007), Thirlwall's (1979) balance of payments constraint is modelling by setting the composition of exports in a closed input-output system of the Pasinetti type. Alongside the modelling of interdependencies between industries, this approach is characterised by a Keynesian consumption function relationship between employment and household consumption. This pioneering multisectoral framework has promulgated an empirical literature in which export and import functions are estimated using econometric functions (see, for example, Blecker & Ibarra, 2013; Romero & McCombie, 2016).

Building on these foundations, but in contrast to the econometric literature, Trigg (2020) broadens these Pasinetti foundations to a (purely theoretical) multi-country system—described by Blecker (2021, p. 7) as an 'important recent extension'. By focussing on trade in intermediates, this theoretical framework models, under a detailed industrial and geographical decomposition, how sectors are inserted into Global Value Chains (GVCs). With these insights, this multi-country system provides an innovative attempt to link the export-led structural change literature (e.g. Araujo & Lima, 2007; Bértola et al., 2002; Britto & McCombie, 2009) with studies that examine GVCs and trade decomposition (Fana & Villani, 2022; Johnson & Noguera, 2012; Koopman et al., 2014; Timmer et al., 2014; Villani & Fana, 2021).

Three main specific contributions are advanced here.[1] First, though this multi-country system opens up the Pasinetti system to international trade, it is somewhat incomplete, still partly based within the confines of an input-output system under which household consumption is not fully endogenous. To develop an open input-output system fully closed with respect to households, the Type II model, originally devised by Bradley and Gander (1969), and later by Miyazawa (1976), will be employed. A new contribution for the input-output literature will be to adapt the one-country Type II system to a multi-country setting in a novel way.

A second contribution is to operationalise this export-led model of structural change using trade-linked input-output tables from the World Input-Output Database (WIOD) (Timmer et al., 2015). It will be shown that the Type II system provides a tractable method for exploring the structure of trade, using established secondary data. In this respect, we are interested in applying this framework to study international trade networks for a producer country. Following Pasinetti's targeting of full employment as a policy goal (Pasinetti, 1993), the overall aim and scope of this approach is to focus on the relationship between international trade and employment. A particular focus, using the vertical integration approach pioneered by Pasinetti (1973), is on the amount of employment activated (directly and indirectly) in the production of goods and services that are produced to satisfy foreign final demand. A further feature of this method is that it also an exploration of how industries participate in global production networks: the extent to which employment is involved in the production of final consumption goods and services or if it is activated to produce intermediate inputs that are embodied in the outputs of other countries, related to but different from the usual focus on value added in the GVC literature.

Finally, the potential contribution of this approach is illustrated using Brazil as an insightful case study. Brazil is the largest economy in Latin America, having undergone rapid post-war growth of its manufacturing sector. With, however, the opening up of world trade in the 1990s and the phenomenal rise of China as a manufacturing powerhouse, Brazil's relative

[1]This paper is dedicated to the memory of our co-author Jonathan Perraton. The authors are extremely grateful to the editors and to both anonymous referees, especially for proposing revisions along the lines of the Type II modelling approach. We also extend thanks to the Faculty of Arts and Social Sciences at The Open University for support from its strategic investment fund, in particular to Dave Wield and Theo Papaioannou for their encouragement and support.

position as a middle-income country has faltered in recent years, leading to claims that it has de-industrialised and undergone structural change towards primary resource-based production (Nassif et al., 2018). Furthermore, as observed by Sturgeon et al. (2013a, p. 6): 'In many respects, the explosion of GVCs in the 2000s passed Brazil by…', but with some evidence of their more recent importance. Although GVC participation is not considered to be a panacea for Brazil's economy, for Callegari et al. (2018, p. 1325) 'there are enough arguments to support the claim that the nation's integration into these chains is of great importance'. There is a need for Brazil to insert itself into global exports markets and GVCs form part of this policy aim. An export-led industrial strategy, it might be argued, is of particular importance to secure much needed employment growth in Brazil. For the World Bank (2013), export promotion has a key role to play in the development of high-quality wage-based employment; and for Grundke et al. (2021, p. 2): 'As Brazil is significantly less integrated into international trade than other emerging market economies, opening up to trade has significant potential to create jobs that are more productive and better paid'. By producing estimates of Brazil's sectoral linkages across countries—with a focus on vertically integrated labour—the method developed in this paper will provide insights into how employment in Brazil participates in global trade, including an emphasis on GVCs.

After this introduction, Section 2 will briefly review some of the issues concerning how Brazil's industrial sectors relate to global trade, and establish empirical research questions for the case study. Setting up the method employed in this study, Section 3 will develop an export-led multi-country system using the Type II input-output model. Data from the WIOD is introduced in Section 4, showing how the model can be estimated. Sections 5 and 6 provide results from the operationalisation of the Type II system, considering the key country and sectoral linkages associated with Brazil and global production networks. Some conclusions and a summary of the contribution of the paper are provided in the final part (Section 7).

2 | INSERTION OF BRAZIL INTO GLOBAL TRADE

For Brazil, there are two main dimensions to consider in relation to its industrial development and the formulation of industrial strategy. The first concerns its trading partners. Since the first administration of Lula da Silva (2003–2010), there has been a strategic move towards the diversification of Brazil's international relations, away from its traditional trading partners (the US and European Union) towards other partners—the most of important of which is China (Cardoso, 2013). Following China's accession to the World Trade Organisation in 2001, and under pronounced diplomatic engagement, by 2009 it had replaced the US as Brazil's main trading partner.

This diversification has the advantage of helping to shield Brazil from US-related volatilities, as exemplified by the 2008 Global Financial Crisis. However, the arrival of China as such a major partner also introduced a new set of issues for Brazil: including increasing competition for its exports (especially in Latin America) and penetration into Brazil of Chinese imports (see Durán Lima & Pellandra, 2017; Jenkins, 2015).

The emergence of China also highlights a second dimension to be considered in relation to Brazil's industrial strategy: its choice of which sectors to focus on. The flow of trade between Brazil and China has a distinctive sectoral composition. As observed by Trindade et al. (2016, p. 282), for Brazil the 'trajectory of export expansion has been increasingly dominated by agro-industry and is indicative of policy initiatives oriented towards the primary goods sector'. The growth of exports to China of primary commodities such as soya beans (as part of what has been called primarization) has coincided with a stagnation of manufacturing (referred to as de-industrialisation) where it loses its share of overall economic activity (see de Melo et al., 2015; Gale et al., 2019).

It has been estimated that the share of primary/primary-based exports for Brazil increased from 40.3% in 2000 to 62.5% in 2014; alongside, for example, a drop from 32.2% to 23.2% of scale-intensive manufacturing (Nassif et al., 2018, pp. 373–374). To reverse this structural change and re-industrialise the Brazilian economy, a targeting of manufacturing sectors has been proposed: as for example, attempted by the first Lula government's Productive Development Policy which prioritised 25 industrial sectors (Suzigan et al., 2020, p. 805); and the more recent Nova Indústria Brasil, by Lula's second government, which again attempts to reverse de-industrialization by prioritising innovation for particular sectors, for example, including the Mover sustainability programme for automotive production (Presidência da República, 2024).

For an in-depth analysis of the sectoral composition of exports, an additional form of structural change comes to the fore: the increasing importance of GVC linkages in world trade. Though often associated with the supply of high-tech inputs, the primarization of Brazil's exports can also be interpreted as increasing GVC linkages. Since, for example, China's investment in its own processing facilities in the 1990s, it now imports unprocessed soybeans, as inputs for processing of soybean flower (Jenkins, 2015, p. 1349). As observed by Sturgeon et al. (2013a, p. 3): 'About 95% of Brazil's soybean exports to China in 2009 were unprocessed beans'. There has been a similar issue with Brazilian exports of unprocessed iron ore, with, for example, the mining company Vale setting up a steel mill in China despite protestations that it should have been located in Brazil (Cooney, 2021, p. 134).

As a possible way forward for industrial strategy in resource-based economies, Kaplinsky and Morris (2016) have argued for a densification (thickening) of domestic value chain linkages, introducing more processing of primary goods. Ghana is suggested as an example of how successful government policy has encouraged industrial development based on the processing of cocoa beans. Moreover, this densification approach can have substantial employment impacts: 'It creates logistic and service jobs and activities' (Kaplinsky & Morris, 2016, p. 642). In this regard, for Nassif et al. (2018, 365): 'The argument in favour of sectoral policies should also consider that, in economies endowed with vast and diverse resources, economic exploitation of these resources requires some moderate degree of intention to stimulate the sectors that relate to them, such as chemical, biochemicals and pharmaceuticals…'. A similar argument for the densification of agro-industry supply chains has been made by the US Agency for International Development in relation to the production of avocados in Chile (Taglioni & Winkler, 2016, p. 18). How exports of particular products are targeted by industrial policy depends critically on the type of participation in GVCs involved, and the potential strength of domestic value chains.

This latter approach, though it emphasises an active role for government in industrial policy, bears some resemblance to a more market-led comparative advantage perspective in which countries, such as Brazil, are recommended to specialise in the use of resource-based endowments.[2] This can be contrasted with a more production-centred approach, often associated with the ideas promulgated by the Cambridge economist, Nicholas Kaldor, focussing more on advanced manufacturing sectors (see Andreoni et al., 2018).

For a production-centred industrial strategy, policy makers also need to consider how Brazil's manufacturing operations fit into GVCs. Brazil faces a significant challenge in

[2]See Cooney (2021, Chapter 8), however, for important insights into the environmental implications of Brazil's focus on primary and primary-based sectors.

participating in GVCs. Its potential participation is restricted by its long distance from any major manufacturing hub (Baldwin & Lopez-Gonzalez, 2013). Although no panacea for the Brazilian economy, however, there are some potential benefits from participation in GVCs. Sturgeon et al. (2013b, p. 4), in their study of such potentialities, have noted that some policy makers in Brazil have set unrealistic goals for manufacturing: 'The goals related to the electronics industry, in particular, embrace a manufacturing-centric vision of developing the entire electronics value chain in Brazil, from component design production (semiconductors and displays), to the manufacturing of sub-systems and final goods (computers and mobile phone handsets).' A more realistic proposition, they argue, might be to target particular ways in which Brazilian manufacturing might upgrade to (and participate in) different stages in the value chain. Indeed, despite Brazil's distance from large markets, such as the US and Europe, specialisation in more service-oriented and knowledge-based activities within the value chain, including engineering services and software design, has been suggested as a way forward. In targeting particular industries for development, it is therefore important to ascertain how outputs of manufacturing and services are employed: either as final goods or, importantly, as intermediate inputs in global production networks. In modern GVCs there is a rich pattern of inter-country and cross-industry trade, where intermediate inputs are exported via third party countries before incorporation into final production.

It may therefore be argued that Brazil has some degree of integration into GVCs, and it is necessary to understand the impact of this phenomenon on employment. This issue will be addressed in the empirical analysis that follows, using the input-output method developed here as an organising framework, exploring how this method might be usefully employed for this type of policy analysis. Summarizing this discussion of Brazil's role in global trade, three main research questions may thus be stated, with a particular focus on employment generation. First, with which countries does Brazil have strong export linkages? Second, what is the relative importance of final and intermediate goods in these export linkages? And finally, what are the industries of destination and origin of the employment embodied in exports? Before addressing these research questions, in Sections 5 and 6, we set up the method developed here and show how it can be operationalised.

3 | A QUANTITY SYSTEM FOR THE WORLD ECONOMY

This section provides a derivation of an extended input-output model that will serve as the basis for empirical estimation. Consider an economic system in which there are R countries with their own production systems each producing the same S commodities. Each $S \times S$ interindustry technical coefficients matrix ($\mathbf{A}^{ij}$) captures the intermediate input requirements of the S industries in country j, produced in the S industries of country i. Gross outputs in country i are represented by an $S \times 1$ column vector ($\mathbf{x}^i$). The total volume of labour employed in each country i is represented by the scalar L^i, and an autonomous $S \times 1$ vector ($\mathbf{f}^i$) of final demand (across all countries) is defined for the output of each country i.[3] Endogenous consumption is defined using an $S \times 1$ vector of per capita consumption coefficients ($\mathbf{c}^{ij}$) representing the

[3] A limitation of this approach is that we do not analyse flows of final demand outputs between countries, though these are accounted for in the final demand aggregates (see Appendix A).

consumption of commodities (produced in country i) per unit of labour employed in country j.[4] All household consumption is endogenous and the vector of final demand ($\mathbf{f}^i$) comprises all final demand except from consumption.

A quantity system can be constructed for the world economy in which these industry-related components for each country are collected in block matrix form:

$$\begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \vdots \\ \mathbf{x}^R \end{bmatrix} = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} & \cdots & \mathbf{A}^{1R} \\ \mathbf{A}^{21} & \mathbf{A}^{22} & \cdots & \mathbf{A}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}^{R1} & \mathbf{A}^{R2} & \cdots & \mathbf{A}^{RR} \end{bmatrix} \begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \vdots \\ \mathbf{x}^R \end{bmatrix} + \begin{bmatrix} \mathbf{c}^{11} & \mathbf{c}^{12} & \cdots & \mathbf{c}^{1R} \\ \mathbf{c}^{21} & \mathbf{c}^{22} & \cdots & \mathbf{c}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{c}^{R1} & \mathbf{c}^{R2} & \cdots & \mathbf{c}^{RR} \end{bmatrix} \begin{bmatrix} L^1 \\ L^2 \\ \vdots \\ L^R \end{bmatrix} + \begin{bmatrix} \mathbf{f}^1 \\ \mathbf{f}^2 \\ \vdots \\ \mathbf{f}^R \end{bmatrix} \tag{1}$$

This system can be summarised as

$$\mathbf{x} = \mathbf{Ax} + \mathbf{Cu} + \mathbf{f} \tag{2}$$

where $\mathbf{x}$ is a column vector of sectoral gross outputs across all countries, $\mathbf{A}$ is a country-by-country technical coefficients matrix, $\mathbf{C}$ is a country-by-country matrix of consumption coefficients, $\mathbf{u}$ is a column vector in which each scalar element denotes total employment in each country, and $\mathbf{f}$ a column vector incorporating the final demands (across all countries) for each country's sectoral outputs. Using the Leontief inverse, (2) can be re-expressed as

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Cu} + (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{3}$$

The system can be transformed into labour units by defining $\mathbf{l}^i$ as a $1 \times S$ vector of direct labour coefficients for country i. Collecting these labour coefficients into block matrix form:

$$\hat{\mathbf{l}} = \begin{bmatrix} \mathbf{l}^1 & 0 & \cdots & 0 \\ 0 & \mathbf{l}^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \mathbf{l}^R \end{bmatrix} \tag{4}$$

Pre-multiplying (3) by $\hat{\mathbf{l}}$ it follows that

$$\hat{\mathbf{l}}\mathbf{x} = \hat{\mathbf{l}}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Cu} + \hat{\mathbf{l}}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{5}$$

Let $\mathbf{u} = \hat{\mathbf{l}}\mathbf{x}$, and $\mathbf{N} = \hat{\mathbf{l}}(\mathbf{I} - \mathbf{A})^{-1}$ be a block matrix of vertically integrated labour coefficients. Equation (5) thus takes the form

$$\mathbf{u} = \mathbf{NCu} + \mathbf{Nf} \tag{6}$$

[4]Lower-case bold letters denote vectors and upper-case bold letters matrices. The symbol ^ refers to a diagonalised vector.

By manipulation, an employment multiplier relationship can then be established:

$$\mathbf{u} = (\mathbf{I} - \mathbf{NC})^{-1}\mathbf{Nf} \tag{7}$$

Using the approach of Miyazawa (1976), the expression $(\mathbf{I} - \mathbf{NC})^{-1}\mathbf{N}$ may be interpreted to be an 'enlarged inverse employment multiplier matrix'; and, using the terminology of Bradley and Gander (1969), this may also be referred to as a Type II employment multiplier relationship. Written out explicitly, this Type II relationship takes the form

$$\begin{bmatrix} L^1 \\ L^2 \\ \vdots \\ L^R \end{bmatrix} = \begin{bmatrix} \mathbf{m}^{11} & \mathbf{m}^{12} & \cdots & \mathbf{m}^{1R} \\ \mathbf{m}^{21} & \mathbf{m}^{22} & \cdots & \mathbf{m}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{m}^{R1} & \mathbf{m}^{R2} & \cdots & \mathbf{m}^{RR} \end{bmatrix} \begin{bmatrix} \mathbf{f}^1 \\ \mathbf{f}^2 \\ \vdots \\ \mathbf{f}^R \end{bmatrix} \tag{8}$$

Each $\mathbf{m}^{ij}$ is a $1 \times S$ row vector of Type II sectoral employment multipliers capturing the direct, indirect, and induced consumption impact of final demands for country i's output on employment in country i.

As shown in (7), following Miyazawa (1976, p. 5), this enlarged multiplier matrix is decomposed into two parts: first, the expression $(\mathbf{I} - \mathbf{NC})^{-1}$ is a 'subjoined inverse employment multiplier matrix'; and second this conjoins with the 'original' Leontief employment multiplier matrix, $\mathbf{N}$. Induced consumption is captured by the first part of this Type II matrix, with the second part representing Type I Leontief linkages.

Following the theoretical approach originally developed by Bradley and Gander (1969), we explore the relationship between the Type I and Type II multiplier linkages. To do this, the elements of (7) can be shown explicitly. The Type I employment multiplier matrix is

$$\mathbf{N} = \begin{bmatrix} \mathbf{n}^{11} & \mathbf{n}^{12} & \cdots & \mathbf{n}^{1R} \\ \mathbf{n}^{21} & \mathbf{n}^{22} & \cdots & \mathbf{n}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{n}^{R1} & \mathbf{n}^{R2} & \cdots & \mathbf{n}^{RR} \end{bmatrix} \tag{9}$$

Each $1 \times S$ row vector, $\mathbf{n}^{ij}$, captures Type I employment multiplier linkages, showing the total (direct and indirect) employment generated (for each industry) in country i by final demand generated for that industry's output in country j. Moreover, the diagonal employment multiplier vectors, where $i = j$, are national multipliers, showing the within country impacts of final demand on employment. In contrast, the off-diagonal vectors, where $i \neq j$, contain intercountry employment multipliers: representing the direct labour embodied in exports and the indirect labour embodied in intermediate inputs required to produce exports.

To further explore the Type II linkages, we can examine the structure of the subjoined inverse matrix:

$$[\mathbf{I} - \mathbf{NC}]^{-1} = \left[\begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix} - \begin{bmatrix} \mathbf{n}^{11} & \mathbf{n}^{12} & \cdots & \mathbf{n}^{1R} \\ \mathbf{n}^{21} & \mathbf{n}^{22} & \cdots & \mathbf{n}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{n}^{R1} & \mathbf{n}^{R2} & \cdots & \mathbf{n}^{RR} \end{bmatrix} \begin{bmatrix} \mathbf{c}^{11} & \mathbf{c}^{12} & \cdots & \mathbf{c}^{1R} \\ \mathbf{c}^{21} & \mathbf{c}^{22} & \cdots & \mathbf{c}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{c}^{R1} & \mathbf{c}^{R2} & \cdots & \mathbf{c}^{RR} \end{bmatrix} \right]^{-1} \tag{10}$$

Inversion results in a matrix of scalar elements:

$$[\mathbf{I}-\mathbf{NC}]^{-1}=\begin{bmatrix}\theta^{11} & \theta^{12} & \cdots & \theta^{1R}\\ \theta^{21} & \theta^{22} & \cdots & \theta^{2R}\\ \vdots & \vdots & \ddots & \vdots\\ \theta^{R1} & \theta^{R2} & \cdots & \theta^{RR}\end{bmatrix} \tag{11}$$

It follows that the multi-country/multi-industry employment multiplier relationship in (8) can be expressed as:

$$\begin{bmatrix}L^1\\ L^2\\ \vdots\\ L^R\end{bmatrix}=\begin{bmatrix}\theta^{11} & \theta^{12} & \cdots & \theta^{1R}\\ \theta^{21} & \theta^{22} & \cdots & \theta^{2R}\\ \vdots & \vdots & \ddots & \vdots\\ \theta^{R1} & \theta^{R2} & \cdots & \theta^{RR}\end{bmatrix}\begin{bmatrix}\mathbf{n}^{11} & \mathbf{n}^{12} & \cdots & \mathbf{n}^{1R}\\ \mathbf{n}^{21} & \mathbf{n}^{22} & \cdots & \mathbf{n}^{2R}\\ \vdots & \vdots & \ddots & \vdots\\ \mathbf{n}^{R1} & \mathbf{n}^{R2} & \cdots & \mathbf{n}^{RR}\end{bmatrix}\begin{bmatrix}\mathbf{f}^1\\ \mathbf{f}^2\\ \vdots\\ \mathbf{f}^R\end{bmatrix} \tag{12}$$

This enlarged multiplier relationship, between employment and final demand, is a linear combination of the Type I employment multiplier linkages ($\mathbf{n}^{ij}$) and new multi-country (theta) scalar subjoined multipliers, θ^{ij}, which transform the Type I linkages into Type II linkages. The elegance of this decomposition is that it maintains the use of scalar theta terms, as originally conceived by Bradley and Gander (1969), but in a more complex multi-country setting. In keeping with Bradley and Gander (1969), this decomposition also allows an exploration of induced consumption effects without the need to model industry level linkages. The induced consumption effects operate here purely at the inter-country level, only requiring specification of the scalar theta relationships.

In addressing the research questions set up at the end of Section 2, this framework provides a way of organising the information provided in international input-output tables. Type II multiplier linkages can first be used to model countries with which Brazil has strong export linkages, with induced consumption effects also distinguished at the country level using the scalar thetas. The theta (θ^{ij}) elements of the subjoined inverse matrix show the induced consumption effects from employment generated by final demand (across the world) on employment in country i. As a second stage in the analysis, the framework is also suitable for exploring which industries display the strongest export linkages.

4 | INPUT-OUTPUT DATA

The WIOD is a multi-country input-output system encompassing 44 countries/regions including the Rest of the World (ROW) region, with inter-industry interactions provided for 56 industries (Timmer et al., 2015). Brazil's role in the international production network is modelled here using these tables.

Data is organised using the input-output accounting identity

$$\mathbf{x}=\mathbf{Zi}+\mathbf{d}+\mathbf{f} \tag{13}$$

where **i** is a unitary summation vector, **d** is a vector representing household consumer expenditure and **f** is a vector including the remaining components of final output (i.e., government expenditure, private investment and changes in inventories). The matrix **Z** represents international transactions of intermediate inputs such that

$$\mathbf{Z} = \begin{bmatrix} \mathbf{Z}^{11} & \mathbf{Z}^{12} & \cdots & \mathbf{Z}^{1R} \\ \mathbf{Z}^{21} & \mathbf{Z}^{22} & \cdots & \mathbf{Z}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{Z}^{R1} & \mathbf{Z}^{R2} & \cdots & \mathbf{Z}^{RR} \end{bmatrix} \quad (14)$$

Each $S \times S$ sub-matrix ($\mathbf{Z}^{ij}$) captures the gross flow of intermediate goods from S industries in country i to the S industries in country j. Using these flows, together with gross outputs by industry collected in diagonal matrix $\hat{\mathbf{x}}$, the technical coefficients matrix can be calculated as:

$$\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}-1 \quad (15)$$

Since **Z** is an $(R \times S) \times (R \times S)$ matrix then, with $R = 44$ countries and $S = 56$ industries in the WIOD, it is of order $2,464 \times 2,464$.

Consumption coefficients are derived using an $(R \times S) \times R$ matrix of household expenditure flows, obtained from the WIOD:

$$\mathbf{D} = \begin{bmatrix} \mathbf{d}^{11} & \mathbf{d}^{12} & \cdots & \mathbf{d}^{1R} \\ \mathbf{d}^{21} & \mathbf{d}^{22} & \cdots & \mathbf{d}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{d}^{R1} & \mathbf{d}^{R2} & \cdots & \mathbf{d}^{RR} \end{bmatrix} \quad (16)$$

Each $S \times 1$ column vector ($\mathbf{d}^{ij}$) represents the total expenditure of households in country j on the S commodities produced in country i. The matrix of consumption coefficients is obtained using an $R \times R$ diagonal matrix $\hat{\mathbf{u}}$ for which each element on the diagonal represents the volume of employment (N^i) in country i (also obtained from the WIOD[5]) such that

$$\mathbf{C} = \mathbf{D}\hat{\mathbf{u}}-1 \quad (17)$$

The $(R \times S) \times R$ consumption coefficient matrix ($\mathbf{C}$) derived from the WIOD is hence of order $2,464 \times 44$. Each column of this matrix is a vector ($\mathbf{c}^j$) , with each element indicating the per capita consumption in country j of good k proceeding from country i.[6]

These calculations will be used to focus on the export-based interactions between Brazil, which throughout this study will be identified as country 1, and the $j = 2,3,\ldots,R-1$ other countries, where $R - 1 = 43$. Data from the WIOD is used here for the most recent year available, 2014, together with some comparisons with 2000.

[5]The volume of employment is calculated using the EMP (persons engaged) variable from the WIOD.

[6]This is the Pasinettian input-output approach to calculating consumption coefficients (see, for example, Wirkierman, 2023); but it should be noted that using total household consumption expenditure (as the numerator) will overestimate the scale of these per capital consumption coefficients, a possible focus for refinement of the approach in future research.

5 | COUNTRY RESULTS

This section will analyse the employment linkages between Brazil and its trade partners, before turning in Section 6 to industry-level analysis. We start by addressing the first research question (posed in Section 2) asking with which countries Brazil has the strongest export linkages. As a starting point, using the elements of Equation (8), each Type II employment multiplier linkage between Brazil (country 1) and another country j can be analysed using the scalar $\mathbf{m}^{1j}\mathbf{i}$: which is an aggregation across industries of the elements of each Type II row vector of employment multipliers ($\mathbf{m}^{1j}$), where $\mathbf{i}$ is a column vector of ones. The strength of export linkages is examined between Brazil and each one of the 43 trade partners included in the WIOD database (Figure 1).

Figure 1 reports these export linkages; for example, between Brazil and a second country ($\mathbf{m}^{12}\mathbf{i}$) where the second country is country 2; and $\mathbf{m}^{1,44}\mathbf{i}$ is the export linkage between Brazil and country (region) 44. It transpires that some small European countries (such as Belgium, Cyprus, the Netherlands and Slovenia) are amongst those with the highest export linkages. Amongst the larger regions, there is a mixed picture, with ROW recording a strong linkage and the USA one of the weaker linkages. This latter observation lends some weight that to the argument that Brazil should shift its export focus away from its traditional partner (the USA).

Figure 2 provides a further insight into Brazil's trading relationships by graphing the relationship between these employment multipliers for 2000 and 2014. Most of the multipliers are above the 45-degree line, showing that the multipliers have fallen between 2000 and 2014; notably for the large countries, USA and India. Important exceptions, for which the employment multipliers have increased over this period, are provided by China (CHN) and ROW: further justification perhaps for Brazil's shift away from the USA as a trading partner. This employment multiplier approach provides an insight into both the scale and changes in export linkages over time.

Using our decomposition of the Type II system, from Section 3, we can further examine these results by also considering the strength of linkages between countries that are based purely on induced final consumption. The scalar θ^{1j}, from Equation (12), shows an induced consumption effect, on employment in country 1 of the (direct and indirect) labour employed (across the world) in the production of country j required to satisfy the worldwide final demand for its output. The higher the value taken by this (theta) subjoined multiplier, the stronger is the impact on employment in Brazil generated by induced final consumption exports to country j.

In Figure 3, for example, the subjoined multiplier relationship between Brazil (country 1) and a second country is $\theta^{1,2}$ where the second country is country 2; between Brazil and ROW (country 44) the linkage is $\theta^{1,44}$. The high induced consumption multiplier linkages for small European countries (especially Belgium, Cyprus, the Netherlands and Slovenia) are consistent with those shown in Figure 1. Figure 3 also shows that there are strong induced consumption linkages with the USA, but with some large countries (China, ROW and India) these are weak.

The induced consumption linkages are compared for 2000 and 2014 in Figure 4. This reaffirms the problem for Brazil of export linkages weakening over this period, with the majority of the positions located to the left of the 45-degree line. With the exception of the USA, for the largest countries/regions (as shown by the circle diameters in Figure 4, indicating total employment in each country), subjoined multiplier linkages tend to lie close to the origin,

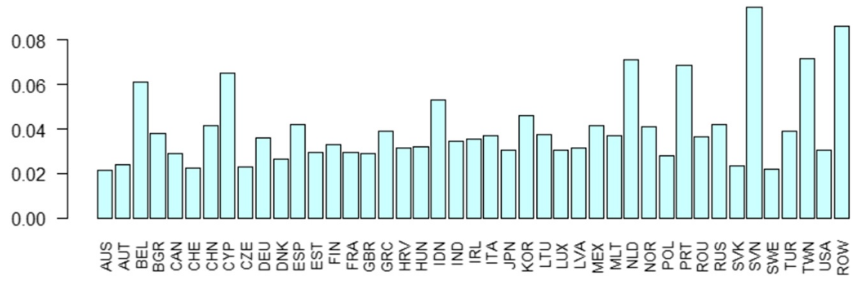

FIGURE 1 Brazilian employment activated by Type II export linkages ($\mathbf{m}^{1j}$) by trading partner, all industries, 2014. *Source*: Adaptation of WIOD data.

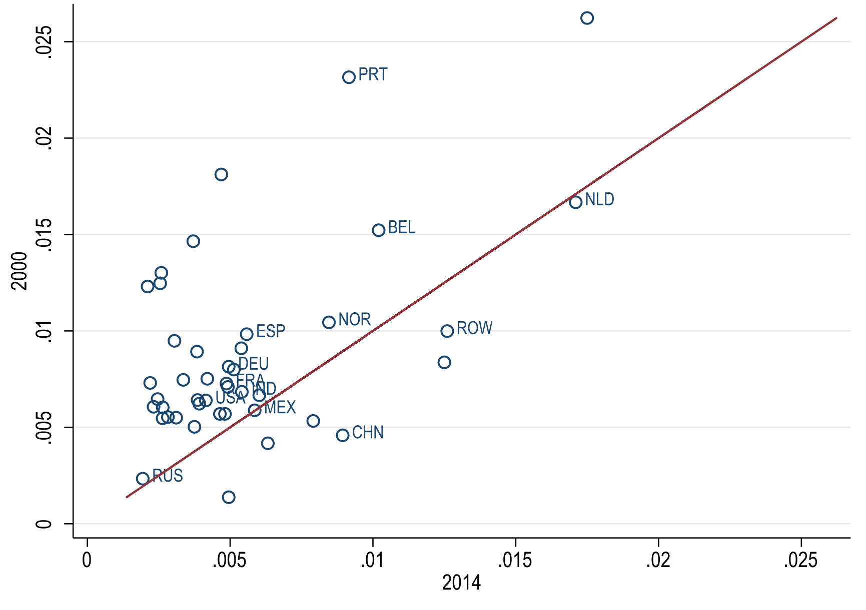

FIGURE 2 Comparison of Brazilian employment activated by Type II export linkages ($\mathbf{m}^{1j}$) by trading partner, 2000 and 2014. *Source*: Adaptation of WIOD data.

reaffirming the problem of weak induced consumption linkages for the Brazil economy. Out of 43 countries/regions, 32 record lower theta multipliers in 2014 than in 2000.[7]

In total, Brazil recorded an increase in the total labour employed in the production of exported products from 6.0 million of people to 7.4 million. However, this growth in absolute terms corresponds to a reduction in relative terms. In 2000, 7.5% of total employment was absorbed by activities devoted to the production of exported products, while this share decreased to 7.1% in 2014 (Table 1).

As part of this country-level analysis, our method also offers the possibility of investigating the structure of export linkages. In light of the rapid growth in GVCs since the early 1990s, it is important to distinguish between exports of final commodities and intermediate inputs (see, e.g.

[7]See Table B1, Appendix B.

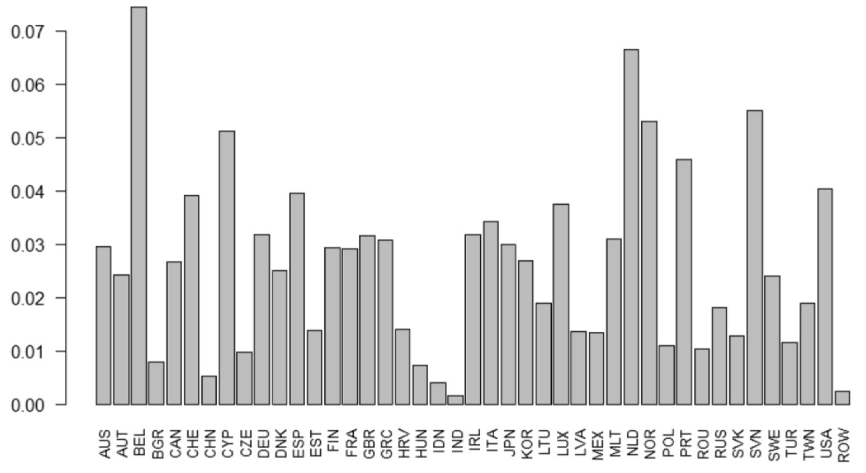

FIGURE 3 Brazilian employment activated by induced consumption export linkages (θ^{1j}) by trading partner, all industries, 2014. *Source*: Adaptation of WIOD data.

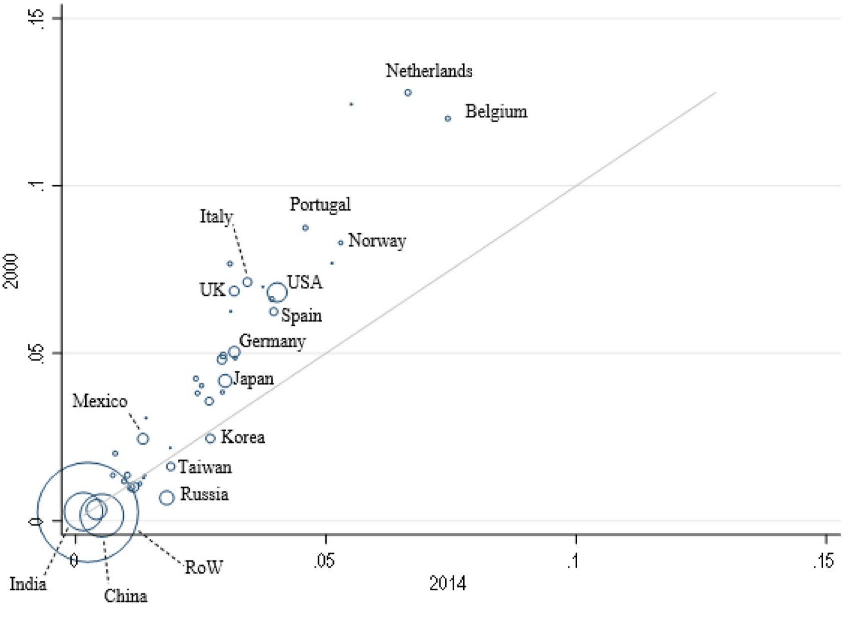

FIGURE 4 Comparison of Brazilian employment activated by induced consumption export linkages (θ^{1j}) by trading partner, 2000 and 2014. *Source*: Adaptation of WIOD data.

TABLE 1 Total employment activated by Brazilian exports (thousands).

	2000	2014
Number of workers activated by Brazilian exports	6040	7374
Share (%) of total Brazilian employment	7.5%	7.1%

Source: authors' calculations using WIOD data.

Johnson & Noguera, 2012; Koopman et al., 2014). We therefore turn to our second research question addressing the mix of intermediate inputs and final goods in Brazilian export linkages.

For this analysis, the multiplier relationship in Equation (12) can be expressed in more detail as:

$$\begin{bmatrix} N^1 \\ N^2 \\ \vdots \\ N^R \end{bmatrix} = \begin{bmatrix} \theta^{11} & \theta^{12} & \cdots & \theta^{1R} \\ \theta^{21} & \theta^{22} & \cdots & \theta^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \theta^{R1} & \theta^{R2} & \cdots & \theta^{RR} \end{bmatrix} \begin{bmatrix} \mathbf{n}^{11}\mathbf{f}^1 + \mathbf{n}^{12}\mathbf{f}^2 + \cdots + \mathbf{n}^{1R}\mathbf{f}^R \\ \mathbf{n}^{21}\mathbf{f}^1 + \mathbf{n}^{22}\mathbf{f}^2 + \cdots + \mathbf{n}^{2R}\mathbf{f}^R \\ \vdots \\ \mathbf{n}^{R1}\mathbf{f}^1 + \mathbf{n}^{R2}\mathbf{f}^2 + \cdots + \mathbf{n}^{RR}\mathbf{f}^R \end{bmatrix} \quad (18)$$

The right-hand side of Equation (18) consists of a column vector representing employment carried out in each country i that is activated by worldwide final demand, pre-multiplied by a subjoined inverse matrix of thetas. The structure of GVCs can be explored by considering the example case of trade linkages between Brazil (country 1) and a second country (country 2). Focussing on the multiplication of the first row of the subjoined inverse matrix by elements of the column vector relating to country 2, the following expression can be specified for the employment impact on country 1 of worldwide final demand for country 2's outputs:

$$\theta^{11}\mathbf{n}^{12}\mathbf{f}^2 + \theta^{12}\mathbf{n}^{22}\mathbf{f}^2 + \theta^{13}\mathbf{n}^{32}\mathbf{f}^2 + \cdots + \theta^{1R}\mathbf{n}^{R2}\mathbf{f}^2 \quad (19)$$

First, we account for the impact on Brazilian employment of induced final consumption from employment (embodied in intermediate inputs) exported from Brazil to country 2, as represented by $\theta^{11}\mathbf{n}^{12}\mathbf{f}^2$. This is a conventional GVC linkage, capturing all the exported intermediate labour (from country 1) required to satisfy worldwide final demand for country 2's outputs. The second category $\theta^{12}\mathbf{n}^{22}\mathbf{f}^2$ represents a conventional (inter-country) induced consumption employment impact on Brazil of the intra-country flows (within country 2) of employment (embodied in intermediate inputs) required to produce outputs in country 2 in order to satisfy worldwide final demand for its outputs. The final category is the more sophisticated GVC linkage, where employment embodied in intermediate inputs is located in a third country. Here, with country 3 given as an example, $\theta^{13}\mathbf{n}^{32}\mathbf{f}^2$ captures the induced consumption effect on Brazilian employment of employment embodied in intermediate inputs exported from country 3 to satisfy worldwide final demand for the outputs of country 2. These third country GVC linkages (represented here as embodied labour) are usually referred to as 'imported to export' linkages (see Baldwin & Lopez-Gonzalez, 2013; Trigg, 2020, p. 16).

Figure 5 shows the distribution of these three types of exports of embodied labour (as summarised in Figure 6) for each country/region that Brazil is exporting to. The share of inter-consumption linkages (the second category in the decomposition) is 61% of the total. The remaining 39% is labour embodied in exports of intermediate inputs; out of which 33% are the simplest type of conventional GVC linkages, capturing employment (embodied in intermediate inputs) exported Brazil to the recipient country (the first category); with 6% representing third party linkages (the third category), where employment is exported via a third country other than Brazil and the recipient country.

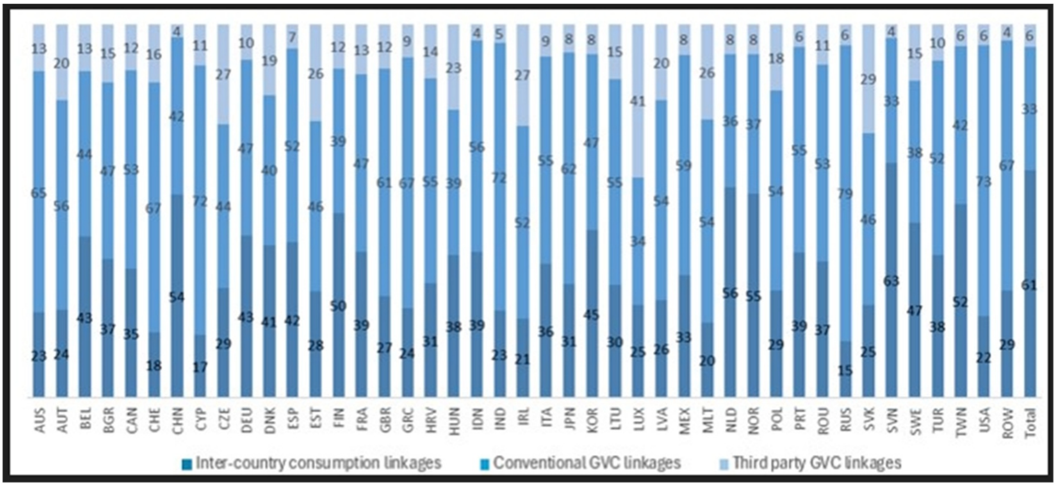

FIGURE 5 Percentage shares of induced consumption effects on Brazilian employment of three types of embodied employment generated by final demands for outputs, by country, 2014. *Source*: Adaptation of WIOD data.

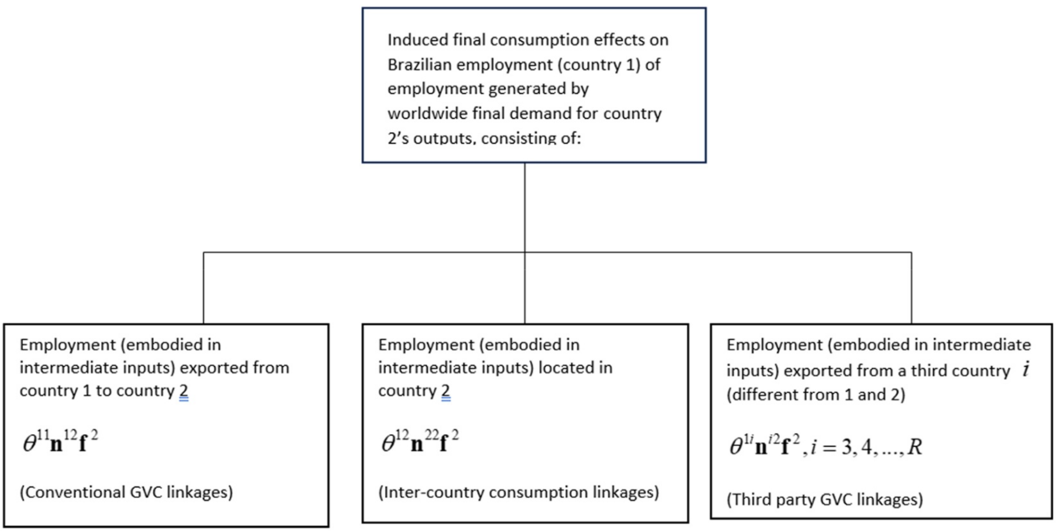

FIGURE 6 Decomposition of two-country trade linkages incorporating final demand, induced final consumption and employment (embodied in intermediate inputs).

6 | INDUSTRY RESULTS

Having considered the structure of trade across Brazil's trading partners, the analysis can now turn to the sectoral composition of this trade. Further developing the concept of vertical integration, a starting point for this sectoral investigation is to consider what Sraffa (1960, p. 89) and Pasinetti (1973) have referred to as subsystems.

For each Type I row vector of vertically integrated employment multipliers, as shown in (12), for exports from Brazil (country 1) to country j, a subsystem $(\mathbf{n}^{1j})_k$ can be established for the *kth* exported commodity. The notation $()_k$, following Pasinetti (1988, p. 126), means that all elements of $\mathbf{n}^{ij}$ are zero except for the *kth* industry element represented by n_k^{1j}. Each *kth* element shows the total (direct and indirect) labour employed in Brazil (across all industries) to produce the final demand in country *j* for commodity *k*: the subsystem of all vertically integrated labour required to produce this item of final demand.

This type of analysis is useful to establish what the demand patterns are at the global level. For example, a country whose exports are narrowly concentrated on production to meet final demand of very few goods may be more vulnerable to particular international demand shocks, compared to a country whose exports are spread across a more diversified number of subsystems.

We start by analysing in which subsystems the exported Brazilian labour is embodied. Table 2 reports summary statistics (T_k) for an aggregation across all subsystems for countries that receive exports from Brazil:

$$T_k^1 = \sum_{j=1}^{R} n_k^{1j} \tag{20}$$

Each T_k^1 captures the total labour employed in Brazil (country 1) required to service all subsystems (across the world) relating to commodity *k*.

Summary statistics can be considered for an aggregation of Equation (20) across all *R* countries that receive exports from Brazil, as presented in Table 2 for groups of sectors (such as manufacturing) and for more disaggregated sectors such as Textiles. We can report that 52.9% of the (direct and indirect) exported Brazilian labour ends up being embodied in the final demand for Manufacturing goods (the manufacturing subsystem), showing that it has a substantive impact on employment in the economy as a whole, across all sectors. Lower volumes of employment are report for Services (33.8%) and Primary goods (13.3%). A notably high 12% of

TABLE 2 Subsystems that use up exported Brazilian labour, 2014 (% of the total of exported employment).

Industry of final consumption	% of Total
a. Primary	**13.3**
...of which	
Crops and animal production	7.5
b. Manufacturing	**52.9**
...of which	
Food	12
Textiles	5.3
c. Services	**33.8**
...of which	
Accommodation and food services	5.0
Total (a + b + c)	**100.0**

Note: The bold values show the percentage of total for each main category.

Source: Adaptation of WIOD data.

the total labour is embodied in the final demand of Manufacture of Food products, followed by Crops and animal production (7.5%), Textiles (5.3%), and Accommodation and food services (5.0%). All of these are agro-based products, that is heavily based on agricultural production. This means that out of the initial 56 industries recorded in the WIOD database, 30% of the total exported employment is embodied in the final production of only four agro-based subsystems.

Subsystems provide an insight into the total amount of labour in Brazil that is used to satisfy final demand in other countries for Brazilian exports. They do not indicate in which industries the labour force is employed in Brazil for the production of exports, one of the research questions posed in Section 2. To examine this, we decompose the Type I employment multipliers according to its industry of origin in Brazil (see Appendix C). The shares of each industry of origin in employment generated by exports are reported in Table 3.

Table 3 indicates even more strongly the importance of agro-based industries. One industry, Crops and animal production, makes up 44.5% of Brazilian export-oriented employment. For services, the most important generators of employment are wholesale trade, retail trade and land transport. Manufacturing industries account for the lowest proportion of employment generation. In this case, the most important activities are represented by textiles and the food industry, which according to OECD classification of manufacturing sectors are defined as low tech manufacturing (see Sarra et al., 2019, Table 21; OECD, 2003). This analysis reveals how Brazilian exports largely generate employment in traditional activities, mainly related to the agro and food industry. Overall, we find that exports play a crucial role in fostering the specialization patterns centred around low-tech activities. These results are consistent with existing literature that underscores the deepening of traditional growth patterns rooted in primary specialization (Castilho et al., 2019; Chiarini & Silva, 2019).

TABLE 3 Industry of origin of Brazilian employment involved in the direct or indirect production of exports, 2014 (% of total exported employment).

Industry of origin	**% of Total**
Primary	**47.7%**
... *of which*	
Crop and animal production	44.5%
Manufacture	**16.4%**
... *of which*	
Food	3.0%
Textiles	3.1%
Services	**35.9%**
... *of which*	
Wholesale trade	4.7%
Retail trade	6.9%
Land transport and transport via pipelines	3.1%
Total (a + b + c)	**100%**

Note: The bold values show the percentage of total for each main category.

Source: Adaptation of WIOD data.

For a production-centred approach, as discussed in Section 2, that promotes advanced manufacturing industries, the employment multipliers do not point to key advanced manufacturing industries to be targeted. Indeed, the high multipliers would suggest, alongside some role for developing service-sectors, the promotion, under the densification approach discussed in Section 2, of primary (agro-based) sectors.

Though insightful, these industry level comparisons are something of an aggregation across types of exports. Our multisectoral approach also affords the possibility of distinguishing between exports of final and intermediate commodities, as considered in Section 5. The question may now be posed, as in Section 2, what are the key vertically integrated sectors via which Brazil inserts itself into global trade, and especially into GVCs.

The three-part decomposition introduced in Figure 6, concerning the example of trade between Brazil (country 1) and the second country (country 2), can thus be further disaggregated according to the 53 industries in the WIOD. The three types of export linkages set out in Figure 6 can be expressed in sectoral form. First, for the induced consumption effect on Brazilian employment of labour embodied in exports of intermediate goods:

$$\theta^{11}\mathbf{n}^{12}\mathbf{f}^{2} = \theta^{11}n_1^{12}f_1^2 + \theta^{11}n_2^{12}f_2^2 + \cdots + \theta^{11}n_S^{12}f_S^2 \tag{21}$$

Brazil's exports of final commodities to country 2 are disaggregated in Equation (21) into $S = 56$ sectoral elements. An analysis of these sectoral linkages will be carried out below.

The second category captures the impact on Brazilian employment of the induced export of final consumption goods, such that

$$\theta^{12}\mathbf{n}^{22}\mathbf{f}^{2} = \theta^{12}n_1^{22}f_1^2 + \theta^{12}n_2^{22}f_2^2 + \cdots + \theta^{12}n_S^{22}f_S^2 \tag{22}$$

Finally, the more sophisticated GVC third-party exports of intermediates can be disaggregated. Consider, for example, the induced consumption effects on employment in Brazil (country 1) from labour embodied in exports of intermediate inputs from say Austria (a third country 3) for use in the production process of country 2:

$$\theta^{13}\mathbf{n}^{32}\mathbf{f}^{2} = \theta^{13}n_1^{32}f_1^2 + \theta^{13}n_2^{32}f_2^2 + \cdots + \theta^{13}n_S^{32}f_S^2 \tag{23}$$

To make the reporting of these third-party linkages manageable, they are summed across all (third party) countries such that, for trade between Brazil and country 2, we aggregate third-party export linkages:

$$\begin{aligned}\theta^{1\bullet}\mathbf{n}^{\bullet 2}\mathbf{f}^{2} = {} & \theta^{13}\left(n_1^{32}f_1^2 + n_2^{32}f_2^2 + \cdots + n_S^{32}f_S^2\right) + \theta^{14}\left(n_1^{42}f_1^2 + n_2^{42}f_2^2 + \cdots + n_S^{42}f_S^2\right)\\ & + \cdots + \theta^{1R}\left(n_1^{R2}f_1^2 + n_2^{R2}f_2^2 + \cdots + n_S^{R2}f_S^2\right)\end{aligned} \tag{24}$$

Here the second term, for example, represents third-party export linkages via country 4. Equation (24) can then be re-arranged to yield

$$\begin{aligned}\theta^{1\bullet}\mathbf{n}^{\bullet 2}\mathbf{f}^{2} = {} & \left(\theta^{13}n_1^{32}f_1^2 + \theta^{14}n_1^{42}f_1^2 + \cdots + \theta^{1R}n_1^{R2}f_1^2\right) + \left(\theta^{13}n_2^{32}f_2^2 + \theta^{14}n_2^{42}f_2^2 + \cdots + \theta^{1R}n_2^{R2}f_2^2\right)\\ & + \cdots + \left(\theta^{13}n_S^{32}f_S^2 + \theta^{14}n_S^{42}f_S^2 + \cdots + \theta^{1R}n_S^{R2}f_S^2\right)\end{aligned} \tag{25}$$

The third-party linkages are now grouped by industry in each set of brackets. The first set of brackets, for example, shows the aggregate third party linkages (across all countries) associated with final demand for output of industry 1.

These three types of employment linkages—as shown for the above example of bilateral trade in Equations (21), (22) and (25)—have been ranked according to size for each industry's share of total exports (from highest linkage to lowest) of each labour embodied export linkage (across all countries Brazil trades with). The rankings are reported in Table 4 for the top 10 industries in each of the three categories.

Table 4 again shows the dominance of agro-based industries in exports from Brazil, as exemplified by the prominence of Crop and animal production, ranked first for all three types of exports, reporting the strongest employment multiplier linkage. There is, however, some interesting variation offered by examining the three main types of exports. Exports of final consumption (the second category) feature the above agro-based industries (food and textile manufacturing), ranked fifth and sixth, but there is also a role for service sectors, such as Legal and accounting activities (ranked 8). For direct exports of intermediates (the first category), there is also a role for food and textile manufacturing (ranked 9 and 10), with other service sectors such as Education and Other service activities featuring (ranked 6 and 7).

TABLE 4 Highest ranked industries for three types of Brazil's export linkages, and share of total exports, 2014.

	Direct intermediate exports	%	Final consumption exports	%	Intermediate exports via third party countries	%
1	Crop and animal production, hunting	20.7	Crop and animal production, hunting	52.5	Crop and animal production, hunting	16.2
2	Retail trade, except of motor vehicles, motorcycles	10.0	Retail trade, except of motor vehicles, motorcycles	6.4	Wholesale trade, except of motor vehicles, motorcycles	8.7
3	Accommodation and food service activities	7.0	Administrative and support service activities	4.7	Administrative and support service activities	6.4
4	Human health and social work activities	6.8	Wholesale trade, except of motor vehicles, motorcycles	4.3	Retail trade, except of motor vehicles, motorcycles	4.3
5	Wholesale trade, except of motor vehicles, motorcycles	6.7	Man. of food products, beverages	3.4	Land transport and transport via pipeline	4.1
6	Other service activities	6.6	Man. of textiles, wearing apparel and leather	3.3	Man. of textiles, wearing apparel and leather	3.6
7	Education	3.5	Land transport and transport via pipeline	2.7	Mining and quarrying	3.6
8	Administrative and support service activities	3.3	Legal and accounting activities, management and consultancy activities	2.2	Legal and accounting activities, management and consultancy activities	3.1
9	Man. of textiles, wearing apparel and leather	2.9	Accommodation and food service activities	1.4	Accommodation and food service activities	2.6
10	Man. of food products, beverages	2.9	Repair and installation of machinery and equipment	1.3	Man. of computer, electronic and optical products	2.6

More variation in featured high ranking sectors is displayed for intermediates exported by a third-party country (the third column of Table 4). Mining, which is notably absent from the other industry results, appears here in these third-party linkages. These linkages are again agro-dominated, but to a slightly lesser degree than the other two categories. There is no role here for the important manufacturing of food industry, and the share for Crop and animal production is slightly lower in size than for direct intermediates. There also appears one 'high tech' industry, all be it ranked 10: the manufacturer of computer, electronic and optimal products. This third-party linkage provides an insight into the type of high-tech integration into GVCs that some policy makers (see Section 2) have tended to emphasise.

However, it should be emphasised that these third-party linkages make up a small part of total exports: only 1.6%, for example, for the manufacture of computer, electronic and optical products. The scope of these third-party linkages as an engine for generating employment is dwarfed by the sheer scale of agro-based activities of Brazil's economy. A great deal of optimism about the future possible scale of these third-party linkages, and a step change in policy geared towards pronounced structural change, would be required for industrial strategy and investment to focus on these linkages.

7 | CONCLUSIONS

This paper shows how the Type II input-output model, originally developed by Bradley and Gander (1969) and Miyazawa (1976), can be generalised to a multi-country setting. Inspired by the approach of Pasinetti (1993, 1981), this multi-country/multi-sector model combines a focus on employment generation and industrial composition with a Keynesian endogenous treatment of household consumption—all in a full open Leontief input-output system. A two-part decomposition of this multi-country system is provided. First, the Type I input-output multipliers, of the usual Leontief type, capture the direct and indirect impacts of final demand on employment. Second, new multi-country scalar (theta) subjoined multipliers are established, resembling the induced consumption effects first established in a one-country setting by Bradley and Gander (1969).

This Type II system is made empirically operational using data from the WIOD tables, with particular focus on Brazil as a case study. Tailored to issues relating to industrial development in Brazil—as a way of exploring how this input-output method may be applied—three main research questions have been addressed. The first, ascertaining with which countries Brazil has the strongest export linkages, has identified something of a dilemma for trade-related industrial policy. The countries with which Brazil enjoys strong per capita export linkages (in Europe, for example) are not those with which Brazil trades at scale (such as China). However, the USA has relatively low export linkages, which helps to justify a move away from this traditional trading partner. Moreover, in a comparison of Type II linkages between 2000 and 2014, the export linkage for the USA has weakened, and that of China has slightly improved.

Different insights are provided once the type of export linkages is considered. The subjoined (theta) linkages, relating to induced consumption, are relatively strong for the USA and weak for China, although for China these linkages did improve between 2000 and 2014. However, this should be set against some importance identified for intermediate inputs, with a small part represented by trade in intermediates via third part countries.

Exploring the structure of trade in more detail at the industry level (addressing the third research question), the input-output method had been extended to include the modelling of subsystems capturing the total direct and indirect employment required in Brazil to produce each unit of final exports. This subsystem approach highlights the importance of final demand for agro-industry exports once the complete value chain is considered. Tracing back the origins of employment to each industry further re-enforces the primary (resource based) nature of export related activities in Brazil.

This presents a further dilemma for industrial strategy. On the one hand, since export linkages are so strong for primary-based industries, Brazil could be encouraged to further develop these industries, both in terms of scale and densification of supply chains. On the other hand, since there is some evidence that major trading partners (such as China) restrict these exports to unprocessed products, there are constraints on the possible densification of these linkages. The way forward may be for Brazil to diversify away from primary industries to other more sophisticated (GVC) linkages, such as in high tech or service industries. For third-country (importing to export) linkages for Brazil, a possible key sector might be computing, electronic and optical products. But these linkages are quite weak (in density and scale) compared to the dominant primary-based linkages, and would require major intervention, and a step change in policy, in order to generate significant structural change.

This first attempt to show how the Type II multiplier framework may be operationalised in a multi-country setting, has thus shown how it can provide insights into the inter-country and industry-based structure of exports: in this case for the particular issues associated with Brazil. The proposed method allows a focus on different aspects of trade, including different geographical locations, types of products (intermediate and final), and industry level decompositions. This adaptation of input-output methods to the structure of trade has been limited to Brazil at a particular point in time, using the WIOD database as a starting point to work out the feasibility of the model. The model could in principle be applied more widely using, for example, OECD data, and by considering the insertion of other countries into global production networks, using available input-output tables.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon request.

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APPENDIX A: TRADE IN FINAL DEMAND

The final demand vector in Equation (1) can be expressed as

$$\mathbf{f} = \mathbf{F}\mathbf{i} \tag{A1}$$

where $\mathbf{i}$ is a unitary summation vector of dimension $R \times 1$, and

$$\mathbf{F} = \begin{bmatrix} \mathbf{f}^{11} & \mathbf{f}^{12} & \cdots & \mathbf{f}^{1R} \\ \mathbf{f}^{21} & \mathbf{f}^{22} & \cdots & \mathbf{f}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{f}^{R1} & \mathbf{f}^{R2} & \cdots & \mathbf{f}^{RR} \end{bmatrix} \tag{A2}$$

Each $\mathbf{f}^{ij}$ represents a $(S \times 1)$ vector of autonomous final demand for gross output produced by country i and absorbed by country j (see, e.g., Wang et al., 2017).

Under Equation (A1), these intra and inter country final demand flows are incorporated in the aggregate final demand vector:

$$\mathbf{f} = \begin{bmatrix} \mathbf{f}^{1} \\ \mathbf{f}^{2} \\ \vdots \\ \mathbf{f}^{R} \end{bmatrix} = \begin{bmatrix} \mathbf{f}^{11} + \mathbf{f}^{12} + \cdots + \mathbf{f}^{1R} \\ \mathbf{f}^{21} + \mathbf{f}^{22} + \cdots + \mathbf{f}^{2R} \\ \vdots \\ \mathbf{f}^{R1} + \mathbf{f}^{R2} + \cdots + \mathbf{f}^{RR} \end{bmatrix} \tag{A3}$$

APPENDIX B: SUBJOINED MULTIPLIER LINKAGES

Table B1

TABLE B1 Induced consumption subjoined multiplier linkages (θ^{1j}), 2000 and 2014.

	2000	2014	2014–2000		2000	2014	2014–2000
AUS	0.0493	0.0295	−0.0199	ITA	0.0713	0.0343	−0.037
AUT	0.0381	0.0243	−0.0138	JPN	0.0418	0.0299	−0.012
BEL	0.1201	0.0744	−0.0458	KOR	0.0246	0.0269	0.002
BGR	0.0201	0.0079	−0.0122	LTU	0.0218	0.0189	−0.003
CAN	0.0357	0.0267	−0.0090	LUX	0.0698	0.0374	−0.032
CHE	0.0662	0.0392	−0.0270	LVA	0.0128	0.0135	0.001
CHN	0.0016	0.0052	0.0036	MEX	0.0245	0.0134	−0.011
CYP	0.0769	0.0512	−0.0257	MLT	0.0625	0.0310	−0.032
CZE	0.0118	0.0097	−0.0021	NLD	0.1279	0.0664	−0.061
DEU	0.0504	0.0317	−0.0187	NOR	0.0830	0.0530	−0.030
DNK	0.0403	0.0251	−0.0152	POL	0.0100	0.0110	0.001
ESP	0.0625	0.0396	−0.0229	PRT	0.0875	0.0459	−0.042
EST	0.0136	0.0138	0.0002	ROU	0.0136	0.0103	−0.003
FIN	0.0384	0.0293	−0.0091	RUS	0.0068	0.0182	0.011
FRA	0.0481	0.0292	−0.0189	SVK	0.0111	0.0129	0.002
GBR	0.0686	0.0317	−0.0369	SVN	0.1244	0.0551	−0.069

(Continues)

TABLE B1 (Continued)

	2000	2014	2014–2000		2000	2014	2014–2000
GRC	0.0768	0.0308	−0.0459	SWE	0.0425	0.0240	−0.018
HRV	0.0307	0.0140	−0.0166	TUR	0.0101	0.0116	0.001
HUN	0.0136	0.0074	−0.0061	TWN	0.0162	0.0190	0.003
IDN	0.0033	0.0042	0.0008	USA	0.0682	0.0403	−0.028
IND	0.0027	0.0015	−0.0012	ROW	0.0025	0.0024	0.000
IRL	0.0486	0.0319	−0.0167	WAVG	0.0102	0.0090	0.0013

Note: WAVG is the weighted average of all per capita export linkages, for all trade partners.
Source: Adaptation of WIOD data.

APPENDIX C: INDUSTRIES OF ORIGIN

A procedure is shown here how to decompose an export-related quantity into industries of origin. Instead of the Type I employment matrix derived in Equation (9) we can further diagonalise the labour coefficients in Equation (4) such that

$$\overline{\mathbf{L}} = \begin{bmatrix} \hat{\mathbf{l}}^1 & \mathbf{0} & \cdots & \mathbf{0} \\ 0 & \hat{\mathbf{l}}^2 & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{\mathbf{l}}^R \end{bmatrix} \tag{C1}$$

A new square Type I employment multiplier matrix thus takes the form:

$$\overline{\mathbf{N}} = \overline{\mathbf{L}}(\mathbf{I} - \mathbf{A})^{-1} \tag{C2}$$

which may be written explicitly as

$$\begin{bmatrix} \mathbf{N}^{11} & \mathbf{N}^{12} & \cdots & \mathbf{N}^{1R} \\ \mathbf{N}^{21} & \mathbf{N}^{22} & \cdots & \mathbf{N}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{N}^{R1} & \mathbf{N}^{R2} & \cdots & \mathbf{N}^{RR} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{l}}^1 & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{l}}^2 & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \hat{\mathbf{l}}^R \end{bmatrix} \begin{bmatrix} \mathbf{B}^{11} & \mathbf{B}^{12} & \cdots & \mathbf{B}^{1R} \\ \mathbf{B}^{21} & \mathbf{B}^{22} & \cdots & \mathbf{B}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{B}^{R1} & \mathbf{B}^{R2} & \cdots & \mathbf{B}^{RR} \end{bmatrix} \tag{C3}$$

where $\mathbf{B}^{ij}$ is a typical sub matrix of the multi-country/multi-industry Leontief inverse.

Displaying the industrial structure of the matrix $\mathbf{N}^{12}$, for example, over S industries, we have:

$$\mathbf{N}^{12} = \hat{\mathbf{l}}^{1}\mathbf{B}^{12} = \begin{bmatrix} l_1^1 & 0 & \cdots & 0 \\ 0 & l_2^1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & l_S^1 \end{bmatrix} \begin{bmatrix} b_{11}^{12} & b_{12}^{12} & \cdots & b_{1S}^{12} \\ b_{21}^{12} & b_{22}^{12} & \cdots & b_{2S}^{12} \\ \vdots & \vdots & \ddots & \vdots \\ b_{S1}^{12} & b_{S2}^{12} & \cdots & b_{SS}^{12} \end{bmatrix} = \begin{bmatrix} l_1^1 b_{11}^{12} & l_1^1 b_{12}^{12} & \cdots & l_1^1 b_{1S}^{12} \\ l_2^1 b_{21}^{12} & l_2^1 b_{22}^{12} & \cdots & l_2^1 b_{2S}^{12} \\ \vdots & \vdots & \ddots & \vdots \\ l_S^1 b_{S1}^{12} & l_S^1 b_{S2}^{12} & \cdots & l_S^1 b_{SS}^{12} \end{bmatrix} \tag{C4}$$

The origins of employment for each industry are then captured by the row sums of Equation (C4). Consider industry 2. The sum of the second row is made up of country 1's labour coefficient $\left(l_2^1\right)$ combined with the output multipliers with, for example, b_{21}^{12} showing the output required by industry 1 from industry 2. The row sum for industry 2 captures all of the employment generated in industry 2 from export activity.

To establish the industries of origin across all of Brazil's trading partners, the row sums of $\overline{\mathbf{N}}$ can be calculated across the first S rows of the matrix.