BRAZILIAN STATES IN GLOBAL VALUE CHAINS: SPATIAL PRODUCTION SYSTEMS INTERPRETED BY FEEDBACK LOOP ANALYSIS

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The underlying geographical structure of global value chains is the object of study in the paper. Our objective is elucidating this geographical structure, with special attention to the spatial interdependencies of Brazilian states, by means of the hierarchical feedback loop methodology. In essence, this methodology offers a detailed view of economic interactions, first by identifying the paths of influence across regions, and then by proposing a hierarchical extraction method to identify the paths in terms of their economic importance. The application in our paper differs from previous studies adopting this methodology as it takes into account value-added flows involved in the supply chains, rather than interregional gross trade. In the paper, firstly, background perspectives are presented on how the fragmentation of production processes has lead to the reorganization of economic activities around the globe and within countries. Then, the hierarchical feedback loop methodology is applied to a novel country-state input-output table, covering the 27 Brazilian states and 39 foreign countries (and the rest of the world as another country), for the year 2008. Following the macro level application, the paper concludes with an analysis of feedback loops at sectoral level, increasing our understanding of the nature of the inter-regional dependencies. In our empirical results, the dominance of the Southeast region's states, especially São Paulo, in the spatial structure of the Brazilian supply chain networks, is verified. A great degree of production sharing among the Brazilian states is also observed. The results indicate that fragmentation within great regions is a major phenomenon for the Southeast and (secondary to the links with São Paulo) the South regions. For states elsewhere in the country, supply chain connections with the more developed states in Brazil overshadows production sharing with neighbouring states. In this way, the geography of production within Brazil seems to remain quite similar over the years. At global level, a spatial structure is observed where the flows linking major economies across trade blocks are dominant; more than 75% of international supply chain value-added flows link countries in different trading blocks. The fact that supply chains are well defined within blocks is only secondary to this structure. Therefore, our results support the observation that production fragmentation is a truly global phenomenon, not being merely circumscribed to trading blocks.

Keywords: fragmentation; global value chains; interregional input-output analysis

1. Introduction

Over the last few decades, the fragmentation of production processes has redefined comparative advantages at global level, inducing great changes in the spatial location and organization of economic activity. At the same time, the reorganization of value chains generated a complex system of interdependent flows, linking regions all over the world. As the process of fragmentation continues, inter-regional dependency will assume even greater importance in explaining the growth and path of development of economies (HEWINGS; OOSTERHAVEN, 2015). Therefore, there is increasing relevance in studying the spatial organization of production systems, a topic that has not received sufficient attention in the literature.

For studying production fragmentation across space, the inter-regional input-output methodology constitutes a natural and important analytical framework. In this paper, our objective is elucidating the geographical structure of global value chains' (GVCs) flows by means of the hierarchical feedback loop analysis. In essence, this methodology offers a detailed view of economic interactions by first identifying the paths of influence across regions and then proposing a hierarchical extraction method to identify the paths in terms of their economic importance flows (POLENSKE; HEWINGS, 2004).

The hierarchical feedback loop methodology has already been applied for analyzing the spatial structure of gross trade flows within Europe (SONIS *et al*, 1993), Asia (SONIS *et al*, 1995), and the Midwest region in the USA (SEO *et al*, 2002). It has also been employed for identifying the economic interactions among industries within Chicago region (LIU; HEWINGS, 2014). Our paper focuses on supply chain dependencies of the 27 Brazilian states, but also taking into account their linkages with producers abroad. This is relevant as international and inter-state fragmentation are fundamentally interconnected and trends in local income have recently become much more dependent on the extent subnational regions manage to contribute to GVCs (LOS *et al*, 2015). In this way, our analysis distinguishes 67 regions in the world, comprising the global economy, as in the year 2008. Another differential is that instead of gross trade analysis, which problems of double-counting are serious in the presence of production fragmentation (KOOPMAN *et al*, 2014), we consider the value-added flows involved in global production processes.

The remainder of this paper is organized as follows. In the rest of this Introduction, background perspectives are provided on how the fragmentation of production processes leads to a reorganization of economic activities around the globe and within countries. In section 2, the hierarchical feedback loop methodology is explored. Section 3 presents our results, first exploring the relevance of spatial fragmentation for each region considered and then identifying the spatial structure of the main supply chains flows at global level. Greater sectoral detail is also provided. Section 4 concludes.

1.1. Fragmentation and spatial reorganization of production systems

According to Krugman (2011), the world economic history can be staged as a play in three acts: "the fall and rise of comparative advantage". In Act I, before World War I, trade was primarily between countries with very different resources exporting very different products, so this trade fitted the comparative advantage paradigm well. In Act II, comprising the recovery of international flows after World War II, trade between similar countries became dominant. To explain the increasing intra-industry trade, the existence of advantages of specialization due to increasing returns was stated. However, in Act III starting in the 1990s, comparative advantage staged a comeback: more and more world trade take places between countries at different levels of development, with different resources, factor prices and technologies.

The role of technological developments in connecting services activities for global fragmentation is emphasized by Jones and Kierzkowski (2005). The authors indicate that the new comparative advantages came into play in world production systems due to the lowering of costs for service link activities, such as communication and transportation. In their pioneer general framework for analyzing fragmentation (JONES; KIERZKOWSKI, 1990), the authors highlight how production processes are being split into subsequent production blocks that are undertaken separately in the space, and need to be connected by service links. Differing from the new economic geography (NEG) literature, under the authors' fragmentation paradigm it is not the firm that present (internal) increasing returns, but the service links. This leads to an important reversal of the view often expressed in NEG literature that increases in the level of economic activity leads to spatial agglomeration of such activity. Under the fragmentation framework, increases in the scale of production might encourage its fragmentation.

In the simplified version of the model, Jones and Kierzkowski (2005) assume that the services links exhibit increasing returns associated with fixed costs invariant to the scale of output. [1] For a given degree of fragmentation of the production process, the nature of service links leads to average costs that are decreasing with total output. Further increases in output encourages a finer degree of fragmentation in order to reduce production costs if the extra cost of the service links is more than balanced by lower marginal costs obtained by a closer match of factor intensities with net factor productivities. In the aggregate, average costs of production decrease with output for a given degree of fragmentation, and marginal costs decrease discontinuously at the point the degree of fragmentation is increased. Thus, lowering of costs for service links promotes greater spatial separation of production processes, for any output level. Increases in the scale of production might also encourage the dis-agglomeration of economic activity, with consequential increased trade of intermediates, at both international and inter-regional levels.

Therefore, a central point in the fragmentation paradigm is that each production block can be carried out in the best possible location. Differences in productivities and factor prices then become very relevant for the determination of the geographical pattern of production (JONES; KIERZKOWSKI, 2005). As indicated by Romero *et al* (2009), the multinational corporations are currently reconsidering where to locate their plants, based on the regional characteristics such as cost of production factors, size of internal markets and regulatory issues. Therefore, globalization is bringing about significant transformation of international and inter-regional division of labor, which is altering the geography of production around the world.

We might ask, however, what is the extent of the spatial re-organization of production systems.

Baldwin (2006) indicates that the fundamental forces that have fostered international fragmentation of production – reduction in costs of moving ideas, products, and people, i.e. the service links of Jones and Kierzkowski (2005) – might result in regionalized

[1] According to the authors, it makes more sense with communications, but transportation costs are also declining with quantities transported.

fragmentation. According to the author, because the reduction in the cost of moving ideas (due to large technological advancements in communications) has greatly surpassed the reduction in the cost of shipping products and even more that of passenger transport (given increasing opportunity cost of time of skilled staff), regionalizing off-shoring is a way of saving of the costs of trade. In this context, the literature discusses whether the international fragmentation of production processes is actually global, involving countries that are geographically distant, or mainly regional, taking place between neighboring countries or within regional trade blocks. As indicated by Los *et al* (2014), this has important implications for trade policy. In the case fragmentation is a truly global phenomenon, extensive multilateral trade agreements are required to enhance the production benefits from supply chain trade; if not, regional trade arrangements might be sufficient.

The empirical evidence on this matter is mixed. Johnson and Noguera (2012b), based on their series of global input-output tables for 1970-2009, find that value added to exports (VAX) ratios are lower and falling more rapidly over time among countries within geographical regions, which suggests regionalization of production processes to be more important than globalization.[2] In the same sense, Baldwin and Lopez-Gonzalez (2014, p. 14) claim that "supply chain trade is not global – it is regional. 'Global value chains' is a great buzzword but it is inaccurate in aggregate". Such claim is based on the observation that international gross trade flows within regions are much larger than those across regions, as depicted on the tables from the World Input-Output Database (WIOD) project. On the other hand, also based on WIOD, Los *et al* (2014) argue that trends toward regional fragmentation might have been dominant in the 1980s and early-1990s, but that true global fragmentation has been more important in the 2000s. The authors find that in almost all product chains, the share of value added outside the country-of-completion has increased since 1995, which indicates increasing international fragmentation. Moreover, they find that this share is mainly added outside the region to which the country-of-completions belongs, suggesting that value chains are truly global.

In our analysis of the spatial organization of GVCs, we will assess the fragmentation of production processes both within and across blocks of countries (here, NAFTA, EU27, and East Asia), as in the year 2008. By means of the feedback loop approach, the bilateral supply linkages will be evaluated hierarchically at global level.

1.2. Inter-regional trade under the fragmentation paradigm

In our application, we are especially interested in fragmentation within countries, i.e. production sharing between subnational regions. For Krugman (2015), within the USA the ability to slice up the value chain is not going to lead to a significant rise in inter-regional trade. In this way, the explosion of international trade is not matched by comparable growth in inter-regional trade. According to the author, the regions in the USA are homogenizing, so they have less reason to trade with each other than once did. So, "to the extent that Americans are doing pretty much the same thing everywhere, the rationale for specialization and inter-regional trade is reduced" (KRUGMAN, 2015, p. 33). However, if contrary to Friedman, the world is not flat (KRUGMAN, 2015), the world inside nations is not flat either, but rather space is spiky and uneven (HEWINGS; OOSTERHAVEN, 2015). This is especially valid for

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[2] See Johnson and Noguera (2012c) for detail on the dataset. The author combine data from several sources for constructing the global input-output tables, including the OECD Input-Output Database, the IDE-JETRO Asian Input-Output Tables, and the UN Trade Database. The dataset is organized for four composite industries, covering 42 countries.

a country like Brazil, which we focus in our empirical application and is heterogeneous in several aspects.

Jones and Kierzkowski (2005) note that international trade allows a greater degree of concentration of productive activity nationally, often in urban areas, as it cuts the dependence of local consumption upon a corresponding range of local production, so that distance to market loses some of its importance. Alternatively, while at the international level the possibilities to fragment production processes allow more countries to join the supply chains, leading to dispersal of productive activity, increases in levels of international trade may encourage national agglomeration.

Thus, under the fragmentation paradigm, when the benefits of agglomeration exceed those of spatial fragmentation (due to a closer match elsewhere between factor intensities and net factor productivities), the firms find it more profitable to locate close. However, if significant differences in productivities and factor prices are to be found at regional level, according to Parr *et al* (2002), agglomeration economies are supplemented and perhaps replaced by less-spatially constrained advantages.

The authors emphasize the significant role being played by changes in firm organization (with most plants now being part of multiregional enterprises) in conditioning location decisions. In the single-establishment firm, economies of scale, scope and complexity, if realizable, would only be available at a particular geographic location, and any one of these would form the basis for an agglomeration economy. However, the changing relationship between the establishment and the firm has resulted in economies of scope and complexity being realized at the level of the firm, while specific product economies of scale are exploited within individual establishments with the best possible location. With this, the ties that once bound establishments in close spatial proximity seem to be unravelling in favor of spatial association at multi-state level (PARR *et al*, 2002).

The schematic process is illustrated in Figure 1. With high costs for transportations (i.e. Jones and Kierzkowski’s service links), market areas were limited and thus the ability to explore scale economies were spatially circumscribed. As a result, each establishment often produced more than one product in a given location. Declining transportation costs and changes in firm organization brought about intra-establishment specialization, with drastic transformation of the spatial structure of production. Value chain now involves more interstate movements. With the boost in interstate trade flows, the main implication of these changes is an increase in inter-regional spillover and feedback effects (HEWINGS; OOSTERHAVEN, 2015).

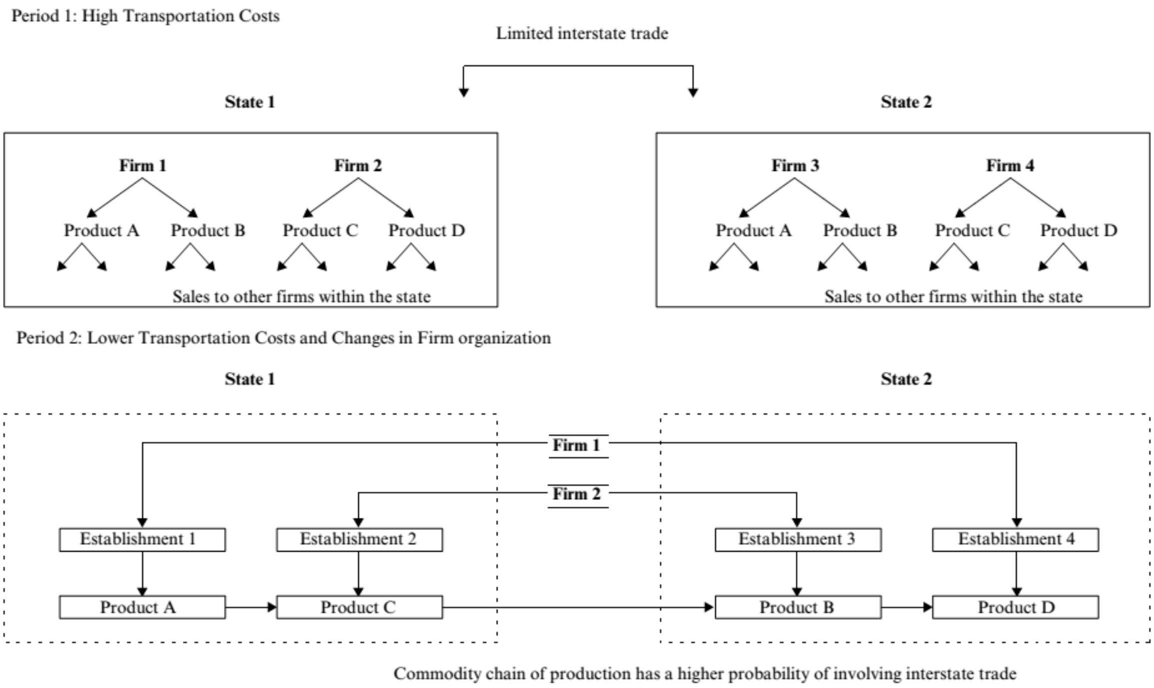

Figure 1 – Changing spatial organization of firms
Source: Hewings and Oosterhaven (2015).

Therefore, regions are becoming both more competitive and interdependent over time, so that understanding the spatial structure of production across subnational regions and countries is increasingly relevant. In our empirical application, we will analyze the spatial organization of value chains across the Brazilian states. In Brazil, the geographical heterogeneity results in diverse regional competitive advantages, many of them aroused by natural endowments. This also adds to the complexity of inter-regional dependency. Here we are not interested so much in the generating factors of regional interdependency, but in recognizing its spatial pattern as in 2008.

2. Methodology

In this paper, we focus on the spatial organization of production processes. Note that, in contrast to trade in value added (TiVA) studies, we are not interested in a country's contribution to final consumption, but in its contribution to the output value of a given consumption good. Several methodologies can be employed for analyzing inter-regional and intersectoral dependencies. In this paper, we address the identification and interpretation of global economic structure by means of the hierarchical feedback loop analysis of value added flows within GVCs. In essence, this approach offers a more detailed view of economic interactions by first identifying the paths of influence across regions and then proposing a hierarchical extraction method to identify the paths in terms of their economic importance flows (POLENSKE; HEWINGS, 2004). First, we analyze the macro-level (where all transactions are aggregated into one industry) structure of the feedback loops. Then, having in view the combination of interregional and intersectoral interdependencies, we proceed to a more detailed sectoral analysis.

For our empirical analysis, we apply the full country-state input-output table that was estimated for the year 2008. It follows the procedure that was proposed by Dietzenbacher *et al* (2013) for combining a world input-output table (WIOT) with an inter-regional input-output table (IRIOT), thus estimating a country-state input-output table for Brazil. In this approach, we do not to take one of the datasets (say the WIOT) as a starting point and adapt the other dataset (i.e. the IRIOT) accordingly, instead we construct input coefficients for which both datasets are used. We use the WIOT for 2008 that was constructed in the WIOD project (see Dietzenbacher *et al*, 2013b).[3] It is a full inter-country input-output table covering 40 countries and the rest of the world as a 41st "country".[4] One of the countries included is Brazil. The IRIOT for 2008 is for Brazil and covers the 27 Brazilian states (GUILHOTO *et al*, 2010).

2.1. Supply chains' value added flows

From the basic Leontief model, the total output of an economy can be expressed as the sum of intermediate consumption and final consumption (MILLER; BLAIR (2009)) as

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} \tag{1}$$

$$(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{B} \tag{2}$$

$$\mathbf{x} = \mathbf{By} \tag{3}$$

where $\mathbf{x}$ is the $n{\times}1$ total output vector (n is the number of industries in the system), $\mathbf{A}$ is the $n{\times}n$ direct input coefficients matrix, $\mathbf{y}$ is the $n{\times}1$ final demand vector, and $\mathbf{B}$ is the Leontief inverse matrix. Considering $\mathbf{G}$ as the $n{\times}n$ diagonal matrix of value added coefficients, we can describe the value added related input-output model as:

$$\mathbf{w} = \mathbf{Gx} \tag{4}$$

from (3):

$$\mathbf{w} = \mathbf{GBy} \tag{5}$$

where $\mathbf{w}$ is the $n{\times}1$ value added vector.

In our empirical analysis, we applied a state-country input-output model. In this way, the dimensions of the above matrices and vectors become: a) $\mathbf{x}$, $\mathbf{y}$, and $\mathbf{w}$, size $[(r.n) \times 1]$; b) $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{G}$, size $(r.n) \times (r.n)$.

Having in mind the definition of a GVC of final good according to Timmer *et al* (2015) (the set of value-adding activities needed in its production, and identified by the country-industry in which the last stage of production happens), we are interested in the spatial structure of value added flows from each region to each GVC in the world economy. In order to estimate these flows, we construct the $\mathbf{E}$ $(r.n) \times (r.n)$ diagonal matrix of final demand, which elements correspond to the sum of a given industry's final demand across destination regions (either domestic or foreign). Then, we compute

$$\mathbf{W} = \mathbf{GBE} \tag{6}$$

where $\mathbf{W}$ is the $(r.n) \times (r.n)$ matrix of supply chain's value added flows.

Figure 2 illustrates the framework for the supply chain's value added flows as represented in matrix $\mathbf{W}$:

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[3] The full database from the WIOD project (including a time series of WIOTs) is publicly and free of charge available at: http://www.wiod.org/database/index.htm.

[4] The countries in the WIOD's world input-output tables are: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, Poland, Portugal, Romania, Russia, Slovak Republic, Slovenia, Spain, Sweden, Taiwan, Turkey, United Kingdom, and USA (Dietzenbacher *et al*, 2013).

			Global value chain							Value added
			Region 1			...	Region r			
			Industry 1	...	Industry n	...	Industry 1	...	Industry n	
Value added from region - industries	Region 1	Industry 1	w_{11}^{11}	...	w_{1n}^{11}	...	w_{11}^{1r}	...	w_{1n}^{1r}	$\sum_t \sum_j w_{1t}^{1j}$
		...	...	...	...	...	...	...	...	...
		Industry n	w_{n1}^{11}	...	w_{nn}^{11}	...	w_{n1}^{1r}	...	w_{nn}^{1r}	$\sum_t \sum_j w_{nt}^{1j}$
	...	...	...	...	...	...	...	...	...	...
	Region r	Industry 1	w_{11}^{r1}	...	w_{1n}^{r1}	...	w_{11}^{rr}	...	w_{1n}^{rr}	$\sum_t \sum_j w_{1t}^{rj}$
		...	...	...	...	...	...	...	...	...
		Industry n	w_{n1}^{r1}	...	w_{nn}^{r1}	...	w_{n1}^{rr}	...	w_{nn}^{rr}	$\sum_t \sum_j w_{nt}^{rj}$
Total final output			$\sum_s \sum_i w_{s1}^{i1}$	...	$\sum_s \sum_i w_{sn}^{i1}$	...	$\sum_s \sum_i w_{s1}^{ir}$	...	$\sum_s \sum_i w_{sn}^{ir}$	World GDP

Figure 2 – Framework for supply chain's value added flows (matrix W)
Source: prepared by the author based on Timmer *et al* (2015).
Note: cell values represent the value added generated in the region-industry in the row within the GVC corresponding to the region-industry of completion in the column.

For the value chain of the final product *t* with completion in the region *j*, we define the foreign value added as all value added outside the region of completion *j*:

$$FVA_t^j = \sum_s \sum_{i \neq j} w_{st}^{ij} \quad (7)$$

Here, w_{st}^{ij} is the value added generated directly and indirectly in industry *s* of region *i* for the production of final products by industry *j* of region *t*, i.e. in the GVC of industry *j* of region *t*. There is one column for each GVC, characterized by the region-industry of completion, with cells showing the origin of value added. The sum across all industries participating in a GVC is equal to the gross output value of the final product, given by the bottom row. Since final output values equal global expenditure on the product, the summation of final output across columns equals world GDP, measured from the expenditure side. A given row in Figure 2 represents the value-added from a given region-industry to all GVCs. Thus, the summation across the row, depicted in the final column, equals the value added in an industry. Summed across all industries, this equals world GDP, measured from the production side (TIMMER *et al*, 2015).

2.2. Hierarchical feedback loop analysis

In our empirical application, we apply the hierarchical feedback loop approach developed by Sonis and Hewings (1988, 1991) to facilitate the identification of the spatial structure of the GVCs.[5]

We consider the *(r.n)* × *(r.n)* block matrix **W**, of supply chain's value added flows:

[5] This section draws on Sonis *et al* (1995).

$$\mathbf{W} = \begin{pmatrix} \mathbf{W}_{11} & \mathbf{W}_{12} & \cdots & \mathbf{W}_{1r} \\ \mathbf{W}_{21} & \mathbf{W}_{22} & \cdots & \mathbf{W}_{2r} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{W}_{r1} & \mathbf{W}_{r2} & \cdots & \mathbf{W}_{rr} \end{pmatrix} \tag{7}$$

where each block

$$\mathbf{W}_{ij} = \left\| w_{st}^{ij} \right\| \tag{8}$$

represents the value added from sectors in region *i* to the GVCs of region j. Define:

$$t_{ij} = \sum_{st} w_{st}^{ij} \tag{9}$$

as the sum of flows between all industries within each submatrix $\mathbf{W}_{ij}$. Hence, the $r \times r$ matrix of aggregate flows is defined as:

$$\mathbf{T} = \left\| t_{ij} \right\| \tag{10}$$

The major focus of our empirical application in this paper is the identification of feedback loops that reveal the economic influence of each region. A series of aggregate transactions is specified such that each region is allowed precisely one transaction flow entering it and one flow leaving it. Such a series of transactions is called “feedback loop”, since each and every region influences itself at the end of the loop. A feedback loop is complete if it includes all regions. A complete feedback loop is either closed or can be decomposed into a set of closed subloops. If the entering flow and the leaving flow for the same region are identical, the smallest closed subloop possible has been identified, i.e. the influence that a region directly exerts on itself, its domestic self-influence.

Economically, a series of transactions represents a chain of bilateral influences which are based on either backward or forward linkages. Thus, the economic meaning of a feedback loop is indicating how strongly (at each hierarchical level) each region is connected to all other regions included in the loop. By focusing on complete loops, one can evaluate the place and position of each region relative to all others.

For a set of *n* regions, the amount of all complete feedback loops is equal to *n!*. One method for dealing with this large amount of complete feedback loops is the derivation of some hierarchical structure. Essentially, the hierarchical feedback loop approach, proposed by Sonis and Hewings (1988), extracts complete feedback loops that successively account for the largest possible sum of transaction flows in each stage of the selection process. This procedure continues until all transaction flows have been included.

A complete feedback loop is presented by a submatrix $\mathbf{T}_x$ of flows extracted from the matrix $\mathbf{T} = \left\| t_{ij} \right\|$ of aggregate transaction flows. $\mathbf{T}_x$ must include in each row and in each column precisely one non-zero entry from the matrix $\mathbf{T}$ and zeros elsewhere. Replacing all the non-zero entries of $\mathbf{T}_x$ by units, a so-called permutation matrix $\mathbf{P}_x$ is obtained, corresponding to a permutation of the sequence of numbers 1, 2, …, r. This permutation (of regions) represents the structure of the flows in the corresponding feedback loop. Hence, the submatrix $\mathbf{T}_x$ is referred to as a quasi-permutation matrix. Moreover, the flow intensity of a complete feedback loop (V_x) is defined as the sum of all transaction flows of $\mathbf{T}_x$.

Within the hierarchical feedback loop approach, the hierarchy of complete feedback loops is defined as the sequence of quasi-permutation submatrices $\mathbf{T}_x$ chosen according to the rank-size of their flow intensities V_x. Thus, on the top of the hierarchy, one finds the complete feedback loop with maximal flow intensity. The procedure is summarized in the following steps:

Step 1: For the matrix $\mathbf{T} = \|t_{ij}\|$ of aggregate transaction flows, find the quasi-permutation submatrix $\mathbf{T}_1$ (and the corresponding permutation matrix $\mathbf{P}_1$) associated with the complete feedback loop with maximal flow intensity (V_1). This loops stands on the top of the hierarchy.

Step 2: Replace in $\mathbf{T}$ the flows from $\mathbf{T}_1$ by arbitrary large negative numbers. For this new matrix $\mathbf{T}'$ find the quasi-permutation submatrix $\mathbf{T}_2$ (and the corresponding permutation matrix $\mathbf{P}_2$) associated with the complete feedback loop with maximal flow intensity (V_2). Since the flows from the top feedback loop have been replaced by arbitrary large negative numbers in $\mathbf{T}'$, they will not be included in this hierarchically subsequent loop.

Step 3 through *r*-1: repeat step 2 for the matrix $\mathbf{T}'$.

After *r*-1 steps, one obtains a sequence of *r* complete feedback loops, ordered according to the decreasing size of their flow intensities.

2.3. The Matrioshka approach

In order to analyze intersectoral next to inter-regional interdependencies, we apply an extension of the previous subsection's procedure at the sectoral level, as proposed by Sonis and Hewing (1991). As indicated by Sonis *et al* (1995), with this extension, the hierarchy of feedback lops reflects the intersectoral interdependencies intertwined spatially, enabling us to distinguish the spatial extent of inter-regional industrial processes.[6]

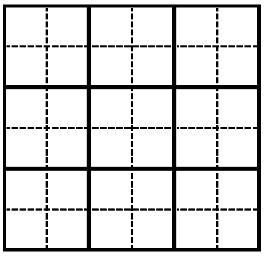
To this aim, the matrix **T** of aggregate transaction flows needs to be replaced by the detailed original matrix **W**. The hierarchical feedback loop procedure operates at successive levels of the system, but the approach at each stage is the same. This top-down decomposition is analogous to the construction of Matrioshka dolls in which successively smaller dolls of the same shape and style are nested within the larger dolls. Thus, the Matrioshka approach examines the domestic and inter-regional transactions at industry level in terms of the hierarchical structure of feedback effects.

In simple terms, given a quasi-permutation submatrix $\mathbf{T}_1$ corresponding to the complete feedback loop on top of the hierarchy at regional scale, we take the blocks of cells in matrix **W** that correspond to the regional flows from $\mathbf{T}_1$ and apply the hierarchical feedback loop procedure. With this, for this regional bloc in matrix **W**, we obtain a nested hierarchy of *n* complete feedback loops, according to the rank-size of their industry flow intensities. The procedure is then applied to the regional blocks defined by the quasi-permutation submatrix $\mathbf{T}_2$, and so on, within a structure of nested feedback loop hierarchies.

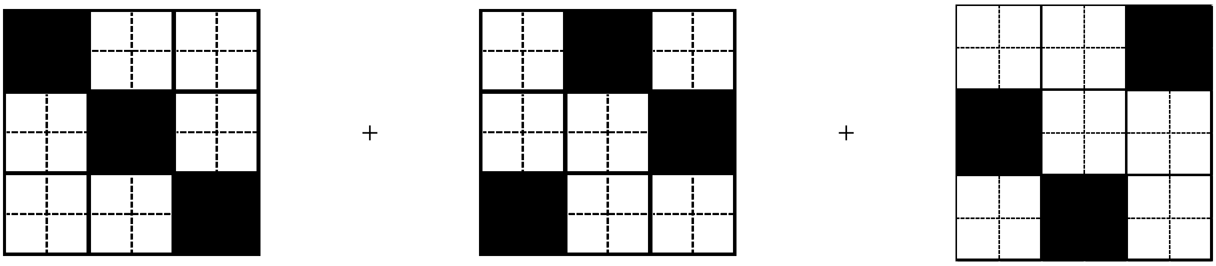
Considering, as an example, a three-region / two-industries matrix **W** of supply chain's value added flows of the following form:

[6] This section also draws on Sonis *et al* (1995).

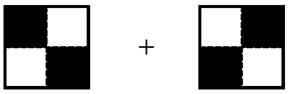
W =



At the regional spatial scale (i.e. where interested in merely focused on the aggregate flows rather than the intersectoral flows), suppose the following hierarchical feedback loop structure is identified:

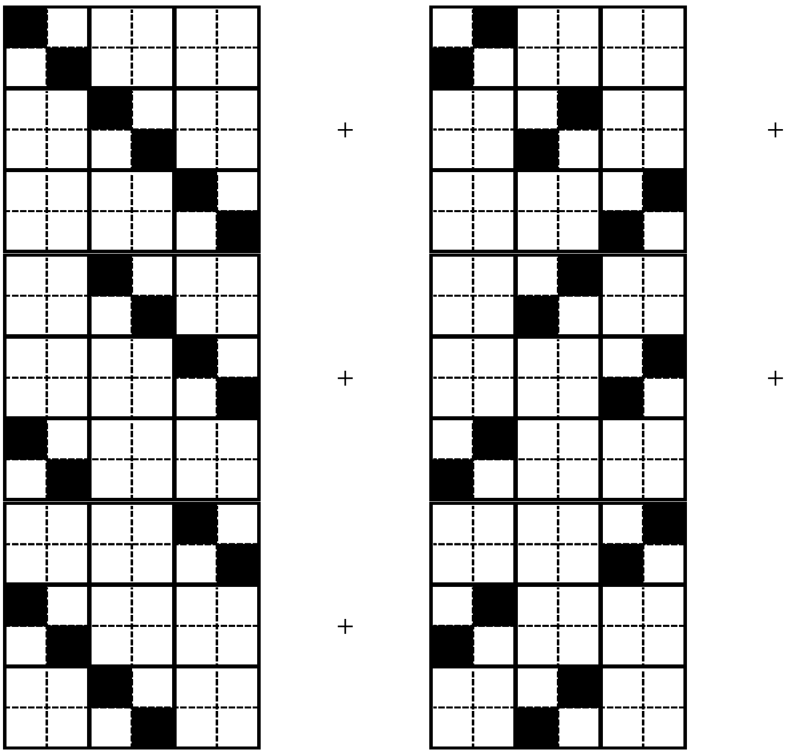


At the sectoral level, a simple decomposition necessarily holds distinguishing intra-sectoral and intersectoral flows. Suppose that, regardless of the regions involved, the flow intensity within industries is larger than between industries, so that the following hierarchical feedback loop structure holds at sectoral level:



Thus, the nested hierarchical decomposition satisfies the Matrioshka principle:

W =



A similar structure of nested feedback loop hierarchies can be extracted for the general case of an *r*-region / *n*-industries input-output system. For this paper, a Matlab program was compiled to find the hierarchical sequence of *r* complete feedback loops at regional scale (with a nested hierarchy of *n* complete loops of sectoral level in each of them).

3. Results

In order to understand the spatial configuration of global production processes, first we look at the individual national / state level, focusing on where each region sources the intermediate inputs required for its final production. This works as an indication of each region's dependency on the international supply networks. Next, we take the global perspective and apply the feedback loop methodology for our inter-country input-output table for hierarchically identifying the myriad of economic interaction in the GVCs.

3.1. Supply chain interdependency

Table 1 presents, for each country in our model, the foreign value added shares in total final output of their set of value chains. The countries of origin of supply chain's value added flows are grouped into five blocks: Brazil (i.e. Brazilian states), NAFTA, EU27, East Asia, and "Others and RoW" comprehending the rest of the global economy. In this way, we intend assess each country's dependency on the sourcing of intermediates from abroad, distinguishing their geographical origin.

Of all blocks, the degree of fragmentation within the NAFTA block is the lowest. On average, only 2.3% of its final production's total output corresponds to value added from other NAFTA members. This result is due the USA's self-sufficiency in intermediates and particularly its value chains' little reliance on other NAFTA countries. Also due to USA's self-sufficiency, of all blocks, NAFTA is the least integrated block with the rest of the world. The largest foreign value added share is sourced by the block "Others and RoW", which includes important energy and food producers in the world (e.g. the Organization of the Petroleum Exporting Countries). For both Mexican and Canadian value chains, fragmentation within the block is more important, i.e. their dependency on USA's intermediates is larger than the other way around.

Within the EU27, we find much tighter production sharing relationships. In this block, the average value chain has 8.1% of its total output corresponding to value added produced by other EU27 members. The reliance on intermediates sourced within the block is especially important for the Eastern European countries. Alongside Ireland and the Benelux countries, the largest shares of foreign value added sourced within the block correspond to the newer EU27 members' set of value chains, especially Hungary, Slovak Republic, Czech Republic, Slovenia, Bulgaria, and Estonia. Thus, as Los *et al* (2014), we observe that many value chains in the EU27 are predominantly fragmented within the block. For 17 of the EU27 countries, the share of foreign value added sourced within the block was larger than the share from elsewhere in the world. However, it is very important that most of the exceptions are major EU27 countries, which value chains are significantly globalized, relying more strongly on upstream activities outside EU27. Still concerning the Eastern European countries, Table 1 shows that the contribution of the block "Others and RoW" for the final production is especially relevant for these countries. This is because of their expressive production sharing with Russia (especially in Bulgaria and Lithuania), and in lesser extent with Turkey (especially in Bulgaria and Romania). In fact, the interdependency seems to work both ways with Turkey, as sourcing of intermediates from EU27 as a whole is relatively significant for this country's value chains. In the case of Russia, it is largely self-sufficient in intermediates, so the foreign content in its value chains is quite small. However, Russia's largest foreign value added share is in fact produced in EU27.

As for East Asia, the production sharing within the block is more expressive than NAFTA's, but quite timid compared to EU27's. Value chains in Japan are especially self-sufficient in intermediates, so that only 1.5% of its total output correspond to value added from elsewhere in East Asia. The relatively small East Asia share in the foreign value added of Chinese final production also seems to be at odds with the suggestion of a highly integrated production network with other countries in the block providing intermediates for further processing in China. As indicated by Los *et al* (2014), the small East Asia share does not contradicts this suggestion, but reflects that the highly integrated Asian production system pertains to a relatively small part of final output in China (e.g. production of electronics). At global level and considering the absolute values, the interdependency among East Asia countries is quite important, as we will observe in the next subsection. Value chains in both Korea and Taiwan rely more (than those in Japan and China) on upstream activities East Asia. They are also important for the value chains of Australia, Indonesia, and India, included in the block "Others and RoW". Of the other blocks specified in Table 1, East Asia is the main source of foreign value added for final production in these three countries.

Table 1 –Foreign value added shares in output of GVCs, by country of completion (%)

	Brazil	**NAFTA**	**EU27**	**East Asia**	**Other + RoW**	**Total**
Brazilian states	*15.3*	*1.4*	*2.4*	*1.2*	*3.2*	***23.5***
Nafta						
USA	0.1	1.6	1.7	1.6	3.1	**8.1**
Mexico	0.3	6.2	2.3	2.6	2.2	**13.6**
Canada	0.2	6.5	2.7	2.4	2.6	**14.3**
Nafta region	*0.2*	*2.3*	*1.8*	*1.7*	*3.0*	***8.9***
EU27						
Austria	0.2	1.2	12.8	1.7	4.6	**20.4**
Belgium	0.3	2.3	16.8	2.3	5.7	**27.3**
Bulgaria	0.3	1.5	13.5	2.6	12.8	**30.6**
Cyprus	0.2	1.6	9.9	4.0	3.7	**19.5**
Czech Republic	0.2	1.7	16.5	3.8	7.1	**29.2**
Germany	0.3	1.5	7.6	1.9	4.3	**15.6**
Denmark	0.3	2.3	11.9	1.9	4.4	**20.7**
Spain	0.2	1.5	6.9	1.8	4.3	**14.8**
Estonia	0.2	1.3	13.4	2.7	7.4	**25.0**
Finland	0.2	1.6	8.9	2.2	6.7	**19.5**
France	0.2	1.2	5.9	1.3	3.9	**12.4**
United Kingdom	0.1	2.1	5.6	1.5	3.9	**13.3**
Greece	0.1	1.4	7.1	1.3	6.2	**16.2**
Hungary	0.2	2.4	18.4	3.9	7.0	**31.9**
Ireland	0.2	7.8	16.6	2.6	5.2	**32.4**
Italy	0.2	1.1	6.2	1.4	5.5	**14.3**
Lithuania	0.1	0.8	10.3	1.3	12.0	**24.6**
Luxembourg	0.2	3.5	29.5	3.6	3.2	**40.0**
Latvia	0.1	1.0	11.9	1.1	6.5	**20.6**
Malta	0.2	1.6	16.4	3.5	7.6	**29.3**
Netherlands	0.4	2.7	10.2	2.6	7.1	**23.0**
Poland	0.1	1.2	10.8	2.2	5.5	**19.8**
Portugal	0.7	1.1	9.6	1.2	5.5	**18.1**
Romania	0.2	1.1	10.9	1.6	6.3	**20.0**
Slovak Republic	0.2	1.5	17.3	3.8	8.3	**31.0**
Slovenia	0.3	1.5	15.1	2.1	6.7	**25.6**
Sweden	0.6	1.9	10.8	2.2	4.5	**20.1**
EU27 region	*0.2*	*1.7*	*8.1*	*1.8*	*4.8*	***16.6***
East Asia						
China	0.4	3.0	4.6	4.3	8.8	**21.1**
Japan	0.1	1.2	1.0	1.5	5.4	**9.3**
Korea	0.3	3.1	3.4	6.6	10.3	**23.6**
Taiwan	0.3	3.3	3.7	6.3	8.9	**22.6**
East Asia region	*0.3*	*2.3*	*2.9*	*3.3*	*7.4*	***16.1***
Others + RoW						
Australia	0.1	1.6	2.2	2.6	3.5	**10.0**
Indonesia	0.2	1.7	2.8	4.8	6.6	**16.1**
India	0.1	1.5	2.4	2.6	6.7	**13.2**
Turkey	0.1	1.0	4.8	1.6	6.9	**14.5**
Russia	0.1	0.7	3.6	2.0	1.8	**8.1**
RoW	0.5	5.0	9.0	6.4	2.6	**23.6**
Others + RoW	*0.3*	*3.6*	*6.8*	*5.0*	*3.4*	***19.2***

Source: Research data.

From Table 1, we observe that Brazil as a whole is mostly self-sufficient in intermediates. Of the countries in our model, the foreign content in the set of Brazil's value chains is larger only than USA's and Russia's. However, there is a great degree of fragmentation among Brazilian states. For the average value chain, 15.3% of its final output's value are added in a state other than where it has its completion. This is larger than the share observed for EU27, indicating even tighter production sharing relationships. Focusing the supply chain network within Brazil, Table 2 presents the regional value added shares in each state's final production. In order to emphasize the spatial characteristics of the value chains, the Brazilian states are grouped into five regions.

In the Brazilian supply network, the dependency of all states' value chains in relation to Southeast's intermediates is outstanding. For every state, the largest value added share in their final production correspond to the Southeast region. São Paulo's upstream activities are especially important on average for final production anywhere in the country; their value added correspond to at least 4% (in Maranhão) and as much as 12% (in Amazonas) of final output in the other states. To a lesser extent, intermediates from the South region also have significant contribution to all regions' value chains.

Therefore, we observe that for Brazilian value chains the fragmentation within the regions is considerably less relevant for final production than production sharing with the more developed Southeast and South regions. Besides Southeast and South regions, interdependency within the region is more relevant for states in the Northeast; however, this is very much outshined by the supply networks across Brazilian regions.

Table 2 also presents the foreign value added shares in the states' value chains. Alongside Amazonas and Paraná, São Paulo is the state which value chains are more integrated with the rest of the world; almost 10% of their final output consisted of value added in foreign countries (note, however, that it is quite limited compared to other countries in our model). Intermediates from the block "Others and RoW" are the most important for São Paulo's final production, being followed by those sourced by EU27. Concerning the origin of foreign value added, Amazonas is distinguished as its final production absorbs intermediates from East Asia almost as much as from the block "Others and RoW". This is due the assembling of electronics in the Free Trade Zone of Manaus, which incorporates large amounts of parts from East Asia.

Table 2 – Regional value added shares in output of GVCs, by state of completion (%)

	North	North-east	Central-West	South-east	South	BRA total	NAFTA	EU27	East Asia	Other + RoW	Foreign total
North region											
Acre	0.6	1.3	0.9	8.0	2.0	**12.8**	0.6	1.0	0.4	1.4	**3.3**
Amapá	0.4	1.0	0.7	8.5	1.6	**12.2**	0.6	1.3	0.4	1.6	**3.9**
Amazonas	0.9	2.2	1.4	17.5	2.8	**24.8**	2.0	3.2	3.9	4.0	**13.1**
Pará	0.5	1.7	0.9	8.8	2.2	**14.1**	0.9	1.4	0.5	2.0	**4.8**
Rondonia	0.7	1.7	1.7	11.9	2.9	**18.9**	0.8	1.4	0.6	2.1	**4.9**
Roraima	0.6	1.1	0.6	6.8	1.7	**10.8**	0.5	1.1	0.3	1.3	**3.3**
Tocantins	0.6	1.9	1.8	11.0	2.6	**17.9**	0.9	1.5	0.6	2.1	**5.1**
North region	*0.7*	*1.8*	*1.3*	*12.5*	*2.5*	***18.7***	*1.2*	*2.1*	*1.8*	*2.7*	***7.8***
Northeast region											
Alagoas	0.7	3.2	1.1	9.0	2.5	**16.5**	0.8	1.1	0.5	1.7	**4.0**
Bahia	0.7	2.4	0.9	12.8	2.4	**19.1**	1.2	1.9	1.1	3.7	**7.9**
Ceará	0.6	2.7	0.8	7.8	2.0	**14.0**	0.9	1.8	0.9	2.5	**6.1**
Maranhão	0.7	1.6	0.5	6.8	1.5	**11.2**	1.0	1.8	0.6	3.0	**6.4**
Paraiba	0.6	3.2	0.9	7.9	1.9	**14.4**	0.8	1.3	0.7	2.0	**4.7**
Pernambuco	0.7	2.4	0.9	8.5	2.1	**14.5**	1.2	1.8	0.7	2.7	**6.5**
Piauí	0.7	3.2	0.8	10.5	2.2	**17.3**	0.7	1.2	0.5	1.7	**4.1**
Sergipe	0.6	2.8	0.9	8.9	2.2	**15.4**	0.8	1.2	0.5	1.8	**4.3**
Rio Grande do Norte	0.6	3.7	0.9	8.5	2.1	**15.7**	0.7	1.2	0.6	1.8	**4.3**
Northeast region	*0.7*	*2.6*	*0.9*	*9.6*	*2.1*	***15.9***	*1.0*	*1.7*	*0.8*	*2.8*	***6.3***
Central-West region											
Distrito Federal	0.8	1.6	0.8	9.8	1.7	**14.6**	0.7	1.7	0.4	1.6	**4.4**
Goiás	0.9	2.0	1.3	14.3	3.2	**21.7**	1.7	2.0	1.1	3.3	**8.1**
Mato Grosso	1.2	2.3	1.6	14.2	4.3	**23.6**	1.2	1.5	0.7	2.8	**6.2**
Mato Grosso do Sul	0.8	2.0	1.4	12.4	3.3	**19.9**	1.3	2.6	1.0	3.7	**8.5**
Central-West region	*0.9*	*1.9*	*1.1*	*12.0*	*2.7*	***18.6***	*1.1*	*1.8*	*0.7*	*2.5*	***6.2***
Southeast region											
Espírito Santo	0.6	1.6	0.9	9.9	2.1	**15.2**	1.0	1.5	0.9	2.1	**5.6**
Minas Gerais	0.7	1.6	1.3	10.7	2.7	**17.0**	1.5	2.3	1.1	2.9	**7.8**
Rio de Janeiro	0.5	1.0	0.7	6.9	1.9	**11.1**	1.3	2.4	0.8	2.9	**7.5**
São Paulo	1.1	1.9	1.1	4.9	3.0	**11.9**	1.7	2.9	1.5	3.6	**9.7**
Southeast region	*0.9*	*1.6*	*1.1*	*6.4*	*2.7*	***12.7***	*1.6*	*2.7*	*1.3*	*3.3*	***8.8***
South region											
Paraná	0.9	1.7	1.4	13.0	3.0	**20.0**	1.7	3.0	1.6	3.8	**10.1**
Santa Catarina	0.7	2.0	1.4	10.2	3.7	**17.9**	1.3	2.1	1.5	3.5	**8.4**
Rio Grande do Sul	0.9	2.1	1.0	12.7	3.0	**19.7**	1.3	2.1	1.0	4.0	**8.4**
South region	*0.9*	*1.9*	*1.2*	*12.2*	*3.2*	***19.4***	*1.4*	*2.4*	*1.4*	*3.8*	***9.0***

Source: Research data.

3.2. Aggregate feedback loops

In the previous subsection, we have analyzed, for each region in our model, the reliance of their final production on intermediates produced elsewhere in the world. Now, we take the global perspective and identify the paths in global supply chains in terms of the order of their economic importance, by means of the hierarchical feedback loop approach.

At the first level of analysis, all the supply chain's value added flows are aggregated into one industry to reveal the macro-level structure of feedback loops. Table 3 summarizes the hierarchy of complete feedback loops, which are ordered according to the decreasing size of their flow intensities. In our analysis, we will focus on the top ten feedback loops, which together represented 94.6% of the global supply chains' value added flows in 2008.

Inspection of the aggregate supply chain's value added flows shows that by far the largest are the domestic flows. Thus, Step 1 of the hierarchical procedure produces a diagonal quasi-permutation submatrix $\mathbf{T}_1$. Associated with this set of flows is a corresponding permutation matrix $\mathbf{P}_1 = \mathbf{I}$ and the permutation

p1 = (AC) (AP) (AM) (PA) (RO) (RR) (TO) (AL) (BA) (CE) (MA) (PB) (PE) (PI) (SE) (RN) (DF) (GO) (MT) (MS) (ES) (MG) (RJ) (SP) (PR) (SC) (RS) (CHN) (IND) (RUS) (USA) (MEX) (CAN) (AUT) (BEL) (BGR) (CYP) (CZE) (DEU) (DNK) (ESP) (EST) (FIN) (FRA) (GBR) (GRC) (HUN) (IRL) (ITA) (LTU) (LUX) (LVA) (MLT) (NLD) (POL) (PRT) (ROM) (SVK) (SVN) (SWE) (JPN) (KOR) (TWN) (AUS) (IDN) (TUR) (RoW)

which corresponds to the domestic flows within each state or country. The flow intensity of this complete feedback loop is equal to c = 50,856,717 million US$ and accounts for 84.9% of total supply chain's value added flows. The remaining percentage of the total flows, 15.1%, are the inter-regional flows.

Table 3 – Decomposition of supply chain's value added flows into feedback loops

Rank	Structure of the complete feedback loop	Flow intensity	% total flows	% inter-regional flows
1	(AC) (AP) (AM) (PA) (RO) (RR) (TO) (AL) (BA) (CE) (MA) (PB) (PE) (PI) (SE) (RN) (DF) (GO) (MT) (MS) (ES) (MG) (RJ) (SP) (PR) (SC) (RS) (CHN) (IND) (RUS) **(USA)** (MEX) (CAN) (AUT) (BEL) (BGR) (CYP) (CZE) (DEU) (DNK) (ESP) (EST) (FIN) (FRA) (GBR) (GRC) (HUN) (IRL) (ITA) (LTU) (LUX) (LVA) (MLT) (NLD) (POL) (PRT) (ROM) (SVK) (SVN) (SWE) (JPN) (KOR) (TWN) (AUS) (IDN) (TUR) (RoW)	50,856,717	84.9%	
2	(AC TO AP RR) (AM PA ES BA PE PB CE RN RO) (AL SE) (MA PI) (DF GO) (MT MS) (MG RJ SP) (PR RS SC) (CHN KOR IDN IND TWN AUS JPN) (RUS TUR) **(USA RoW)** (MEX CAN) (AUT HUN ROM BGR GRC CYP SVN MLT EST FIN POL CZE SVK) (BEL NLD) (DEU FRA ITA ESP PRT LUX IRL GBR) (DNK SWE) (LTU LVA)	1,180,642	2.0%	13.1%
3	(AC SE BA GO MT RO) (AP MLT RR) (AM DF TO MS ES) (PA MA) (AL PE CE PI) (PB RN) (MG SP RJ) (PR SC RS) **(CHN RoW)** (IND AUS) (RUS POL) (USA CAN) (MEX DNK IRL TWN IDN JPN KOR) (AUT SVN HUN SVK CZE) (BEL GBR NLD DEU ITA FRA ESP) (BGR CYP GRC) (EST LVA) (FIN SWE) (LTU LUX PRT) (ROM TUR)	1,088,000	1.8%	12.1%
4	(AC RR MLT AP) (AM RO SE ES PA RN CE PB PE BA DF) (TO MA MT SC RJ PR SP RS MG GO MS AL PI) (CHN USA) (IND CAN) **(RUS DEU RoW JPN TWN MEX IDN AUS KOR)** (AUT CZE POL SWE NLD GBR IRL PRT ESP ITA GRC TUR BGR ROM SVN SVK HUN) (BEL FRA) (CYP LVA LUX) (DNK FIN) (EST LTU)	832,397	1.4%	9.2%
5	(AC AP RN PI) (AM MT GO TO PB SE MA CE PE AL MS RO ES RJ RS SP PR MG BA SC DF PA) **(RR EST LUX FIN RUS NLD DNK PRT SVK POL IRL BEL SWE IND IDN KOR CHN JPN RoW ITA TUR GRC SVN BGR LVA CYP MLT LTU)** (USA MEX) (CAN AUS TWN) (AUT ROM) (CZE HUN) (DEU GBR ESP FRA)	662,774	1.1%	7.4%
6	(AC RO RR PI CE MA TO) (AP LVA) (AM PE RN SE MS) (PA DF ES MG RS GO) (AL PB) (BA SP) (MT PR RJ SC) (CHN IND MEX ESP NLD ITA DEU) **(RUS FRA GBR RoW KOR CAN BEL LUX BGR TUR PRT GRC SWE POL DNK AUS IDN TWN CZE)** (USA JPN) (AUT SVK ROM HUN IRL FIN EST MLT CYP LTU SVN)	493,197	0.8%	5.5%
7	(AC PB PI AP LTU) (AM SP DF RO AL TO PA MS SC MG PR MT CE) (RR LUX EST CYP) (BA RS RJ) (MA PE SE RN) (GO ES) **(CHN DEU USA GBR FRA NLD ESP IRL CAN JPN RUS RoW IND FIN HUN SVN CZE ROM GRC PRT SWE BEL DNK MEX AUS)** (AUT ITA POL) (BGR SVK) (LVA MLT) (KOR TWN) (IDN TUR)	439,804	0.7%	4.9%
8	**(AC MLT LUX BEL IND NLD FRA RoW DEU ESP TUR SVK SVN LVA RR CYP EST AP TO AL RO RN ES RS BA PR GO MG AM RJ DF PI SE CE PA MT PE MA MS PB)** (SP SC) (CHN CAN GBR USA	411,490	0.7%	4.6%

	KOR JPN IDN GRC ROM CZE FIN AUS MEX PRT IRL SWE RUS ITA AUT POL HUN BGR LTU DNK TWN)			
9	(AC CYP AP SE PB TO PI RO MLT) (AM MA AL RN PA CE MS PR BA RJ GO RS MT ES SP) **(RR LVA DNK CZE SWE AUS CAN KOR IND TUR HUN FIN NLD POL ROM SVK RUS CHN ESP GBR ITA RoW FRA USA DEU AUT BEL IRL LUX GRC IDN PRT EST)** (PE DF MG SC) (MEX TWN JPN) (BGR SVN LTU)	358,752	0.6%	4.0%
10	(AC RN AL MT RJ AM MS PA RS CE ES PR PE PI RR LTU MLT TO SE RO PB AP EST) (BA MG DF MA SC) (GO SP) (CHN MEX IND USA FRA TUR CZE SVN ROM CYP BGR LUX LVA FIN PRT AUS IRL ITA RUS JPN CAN) (AUT DEU NLD SWE) **(BEL ESP GRC KOR RoW GBR)** (DNK IDN) (HUN POL SVK TWN)	331,029	0.6%	3.7%
11 to 67		3,212,047	5.4%	35.6%

Note: for each complete feedback loop, the dominant subloop is in bold text.
Source: Research data.

Next, we consider the direction and magnitude of the complete inter-regional feedback loops. Step 2 of the hierarchical procedure results in the quasi-permutation submatrix $\mathbf{T}_2$. The flow intensity of this complete feedback loop is equal to V_2 = 1,180,642 million US$ and accounts for 13.1% of total inter-regional supply chain's value added flows. Associated with these flows is a permutation matrix $\mathbf{P}_2$ which corresponds to the permutation

$\mathbf{p}_2$ **=** (AC TO AP RR) (AM PA ES BA PE PB CE RN RO) (AL SE) (MA PI) (DF GO) (MT MS) (MG RJ SP) (PR RS SC) (CHN KOR IDN IND TWN AUS JPN) (RUS TUR) (USA RoW) (MEX CAN) (AUT HUN ROM BGR GRC CYP SVN MLT EST FIN POL CZE SVK) (BEL NLD) (DEU FRA ITA ESP PRT LUX IRL GBR) (DNK SWE) (LTU LVA)

It is broken down into 17 independent closed subloops. The dominant subloop, i.e. the subloop with largest flow intensity, (USA RoW) corresponds to the pair-wise exchange between the USA and RoW. It accounts for 62.4% of the flow intensity that is represented in the complete loop. The second most important (in intensity terms) subloop (CHN KOR IDN IND TWN AUS JPN) corresponds to the Oceania and Asia's countries in our model. The supply chain's value added flows go from China, to Korea, to Indonesia, to India, to Taiwan, to Australia, to Japan, and back to China. The flow intensity of this subloop is 15.7% of V_2. The third most important subloop (DEU FRA ITA ESP PRT LUX IRL GBR) includes the central economies in EU27, comprising the flows starting in Germany and going via France, Italy, Spain, Portugal, Luxembourg, Ireland and Great Britain going back to Germany. Its flow intensity represents 12.0% of V_2. The other subloops also have a clear geographical definition: Eurasian countries in (RUS TUR); the North American countries other than the USA in (MEX CAN); the South and East of EU27 in (AUT HUN ROM BGR GRC CYP SVN MLT EST FIN POL CZE SVK); the Benelux countries other than Luxembourg in (BEL NLD); the Nordic countries other than Finland in (DNK SWE); and the Baltic countries other than Estonia in (LTU LVA).

The remaining of the supply chain's value added flows in this feedback loop corresponds to eight closed subloops within Brazil. The dominant subloop within Brazil (MG RJ SP) corresponds to the most developed states in the Southeast region, including the flows going from Minas Gerais, to Rio de Janeiro, to São Paulo and back to Minas Gerais. Its flow intensity is 2.1% of V_2. Excepting the subloop (AM PA ES BA PE PB CE RN RO), which comprises states from the North, Northeast, and Southeast regions, each of the six other subloops includes states from exclusively one Brazilian region.

Figure 3 presents the second complete feedback loop graphically.[7] The spatial nature of the top rank inter-regional feedback loop is readily apparent. The supply chain network described by this loop is geographically concentrated within blocks of countries. However, we must remember that dominant subloop, which accounts for 62.4% of the flow intensity in the loop, corresponds to production sharing relationships across blocks (between the USA and the composite region RoW). In order to evaluate correctly the importance of fragmentation within blocks in opposition of global fragmentation, we must analyze the subsequent complete feedback loops, as we do in the following.

As for Brazil, the top rank inter-regional feedback loop singles out supply chain networks within great regions. However, the apparent importance of fragmentation within each Brazilian region should be considered having in mind the adopted hierarchical procedure. In each step, it searches for the complete feedback loop with maximal flow intensity, with the constraint that each region is allowed precisely one transaction flow entering it and one flow leaving it. Thus, the presence of the Southeast states' subloop precludes others states to display flows with this great region in the same loop. Given this, the procedure then points out the South region's subloop as part of the complete feedback loop with maximal flow intensity. With the preclusion of flows entering in (and leaving from) both Southeast and South regions, then for the other states the maximal flow intensity is found in within-great regions flows.

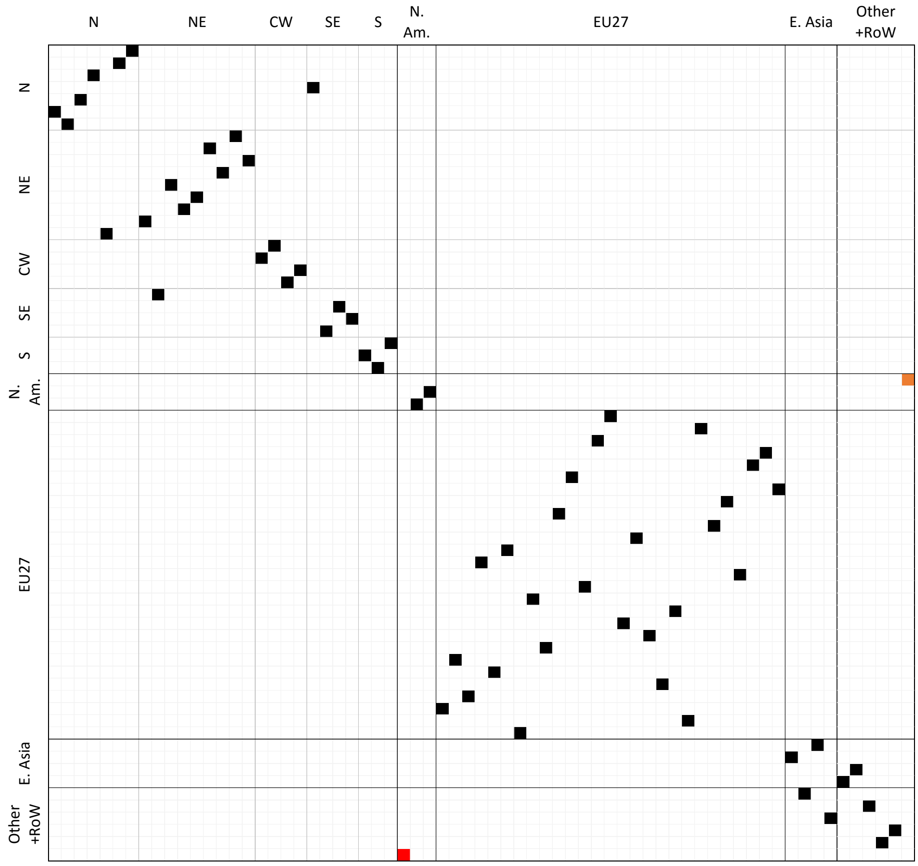


Figure 3 – Second aggregate feedback loop

Source: Research data.

Note: the red cell indicates the largest flow in the loop; orange cells, the dominant subloop.

[7] For better visualization, we have omitted the regions' names in the figures. States are aggregated into the five great Brazilian regions and are sorted as in Table 2. Countries are aggregated into the blocs NAFTA, EU27, East Asia, and "Others and RoW", and are sorted as in Table 1.

Step 3 of the hierarchical procedure gives the next complete feedback loop. All the flows identified in the first two steps are now eliminated from further consideration. The resulting quasi-permutation submatrix $\mathbf{T}_3$ has flow intensity V_3 = 1,088,000 million US$ (12.1% of total inter-regional supply chain's value added flows). From the permutation matrix $\mathbf{P}_3$, we identify the following permutation:

p₃ = (AC SE BA GO MT RO) (AP MLT RR) (AM DF TO MS ES) (PA MA) (AL PE CE PI) (PB RN) (MG SP RJ) (PR SC RS) (CHN RoW) (IND AUS) (RUS POL) (USA CAN) (MEX DNK IRL TWN IDN JPN KOR) (AUT SVN HUN SVK CZE) (BEL GBR NLD DEU ITA FRA ESP) (BGR CYP GRC) (EST LVA) (FIN SWE) (LTU LUX PRT) (ROM TUR)

Figure 4 present the third complete feedback loop graphically. This complete feedback loop is divided into twenty closed subloops. The dominant subloop is now (CHN RoW), which corresponds to the pair-wise exchange between China and RoW. It accounts for 55.1% of the flow intensity V_3. Also important in intensity terms, there is the subloop (USA CAN) of cross-border exchanges between the USA and Canada, corresponding to 21.4% of V_3. Accounting for 13.3% of V_3, we identify the subloop (BEL GBR NLD DEU ITA FRA ESP), which comprises central economies in EU27, including the flows from Belgium to Great Britain, to the Netherlands, to Germany, to Italy, to France, to Spain and back to Belgium. As in the previous step, the EU27 countries are connected among themselves in this loop. The exceptions are: Romania in the (ROM TUR) of pair-wise exchange with Turkey; Poland, which is connected to Russia in (RUS POL); Denmark and Ireland, which are in the more complex subloop (MEX DNK IRL TWN IDN JPN KOR), which also includes countries from America and Asia, and Malta in the subloop (AP MLT RR) with states from the North region of Brazil.

The result of Malta being connected to states from the North region of Brazil at a major feedback loop should not be interpreted as an indication of strong economic linkage; instead, we need to have in mind the adopted hierarchical procedure. In each step, the solution determines a series of transactions with maximal flow intensity such that each region is allowed precisely one transaction flow entering it and one leaving it. For small economies such as Malta and these states, a likely result is that their main partners are already connected to third regions at major feedback loops, so they end up being connected to other small economies.

As for the Brazilian states, also in this third feedback loop they join closed subloops comprising exclusively domestic flows (with the exception of Malta). The states in the Southeast region again compose the dominant subloop within Brazil (MG SP RJ), now corresponding to flows starting from Minas Gerais and going via São Paulo and Rio de Janeiro back to Minas Gerais. The flow intensity of this subloop corresponds to 1.9% of V_3. We still observe a closed subloop comprising the states in the South region, but for the other regions in the country the transaction flows become more spatially spread out.

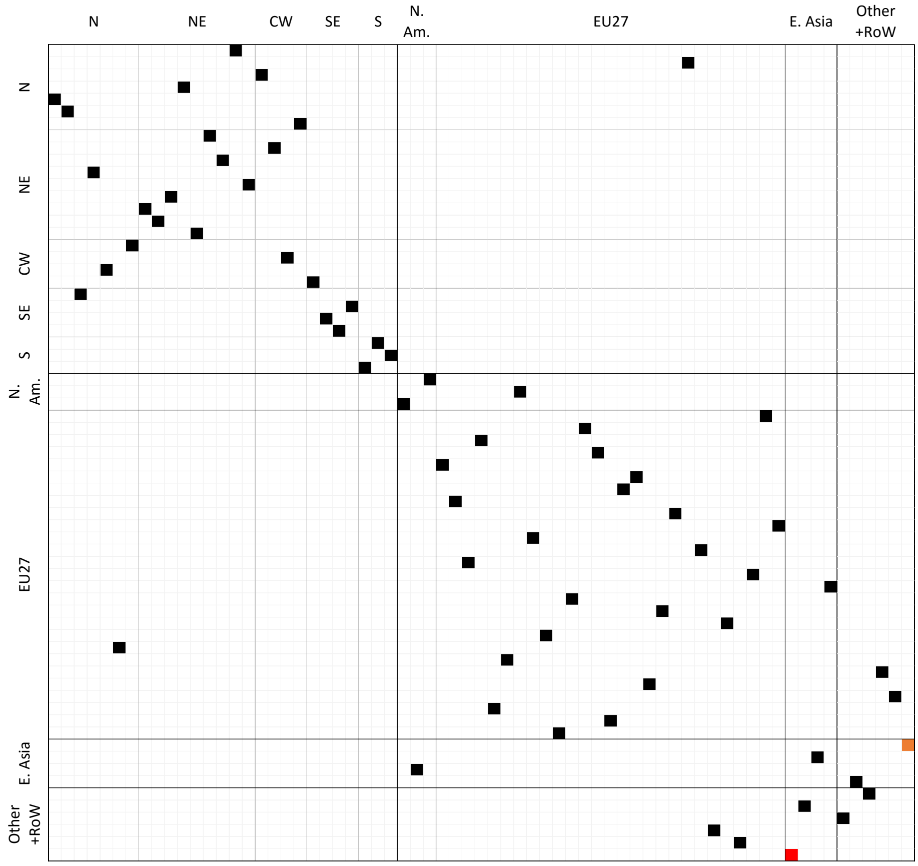


Figure 4 – Third aggregate feedback loop

Source: Research data.

Note: the red cell indicates the largest flow in the loop; orange cells, the dominant subloop.

Proceeding with the hierarchical procedure, in the step 4 we obtain the quasi-permutation submatrix $\mathbf{T}_4$ with flow intensity V_4 = 832,397 million US$ (9.2% of total inter-regional supply chain's value added flows). Associated with these flows is a permutation matrix $\mathbf{P}_4$ representing the following permutation:

$\mathbf{p}_4$ = (AC RR MLT AP) (AM RO SE ES PA RN CE PB PE BA DF) (TO MA MT SC RJ PR SP RS MG GO MS AL PI) (CHN USA) (IND CAN) (RUS DEU RoW JPN TWN MEX IDN AUS KOR) (AUT CZE POL SWE NLD GBR IRL PRT ESP ITA GRC TUR BGR ROM SVN SVK HUN) (BEL FRA) (CYP LVA LUX) (DNK FIN) (EST LTU)

Figure 5 present the fourth complete feedback loop graphically. It is composed by eleven independent closed subloops. Differently from the previous loops, here the dominant subloop does not correspond to exchanges between two regions, but to a sequence of transactions centered on RoW and involving countries from Asia, Europe, Oceania, and America. In this subloop (RUS DEU RoW JPN TWN MEX IDN AUS KOR), the supply chain's value added flows go from Russia, to Germany, to RoW, to Japan, to Taiwan, to Mexico, to Indonesia, to Australia, to Korea, and back to Russia. The flow intensity of this subloop is 52.7% of V_4. The second most important (in intensity terms) subloop is (CHN USA) corresponding to the pair-wise exchange between China and the USA. It accounts for 31.4% of the flow intensity that is represented in the complete loop. Also important, we find a subloop of transactions connecting older and newer members of EU 27 (plus Turkey). This subloop (AUT CZE POL SWE NLD GBR IRL PRT ESP ITA GRC TUR BGR ROM SVN SVK HUN) accounts for 9.0% of V_4.

The Brazilian states continue to be connected among themselves in this loop (excepting Roraima and Amapá, connected to Malta in (AC RR MLT AP)). The dominant subloop within the country (TO MA MT SC RJ PR SP RS MG GO MS AL PI) comprises states from all Brazilian regions and is centered on São Paulo, which is connected to states from the South region. The flow intensity of this subloop is 2.6% of V_4.

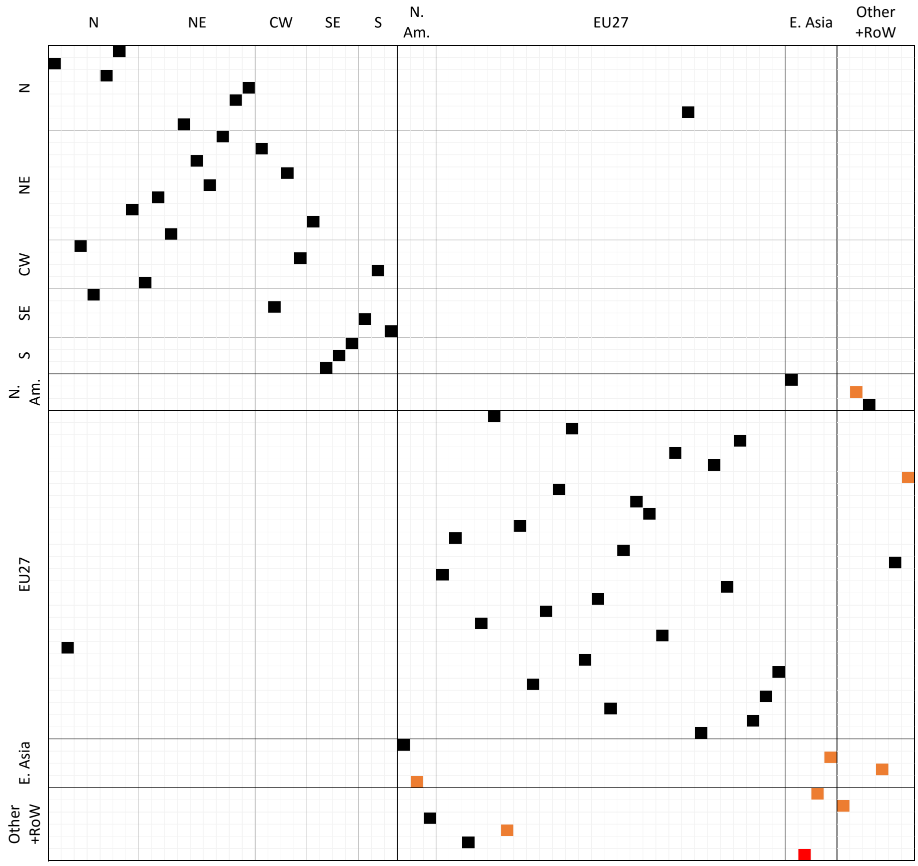


Figure 5 – Forth aggregate feedback loop

Source: Research data.

Note: the red cell indicates the largest flow in the loop; orange cells, the dominant subloop.

In each of the fifth to the tenth complete feedback loops, the largest flow involves the composite region RoW (incoming flows from Japan and from Great Britain in the fifth and sixth loop, respectively; outgoing flows directed to India, Germany, France, and Great Britain from the seventh to the tenth loop, respectively).

The fifth complete feedback loop still presents a supply chain network that is geographically concentrated within blocks of countries: it includes the flow intensive subloops (USA MEX) and (DEU GBR ESP FRA), besides the chain of value added flows going from Korea, China, and Japan in the dominant subloop. From the sixth loop, we do not observe such a clear spatial pattern for supply chain networks. Although these loops still present many links between countries within EU27, the major economies in the block also connect to outside-block countries (e.g. Germany is linked to China in the sixth and seventh loops; Great Britain connects with the USA in the seventh and eighth loops; France links with the USA appear in the ninth and tenth loops).

As for the Brazilian states, with exception of minor flows involving small EU27 countries, they continue being linked exclusively among themselves in these loops. In fact, it is only in the 13th feedback loop that an expressive supply chain flow takes place between a Brazilian state and a foreign country (with flows of value added from Espírito Santo to Indonesia's vaue chains). Within Brazil, we observe that the subloops increasingly spread out geographically, depicting supply networks across great regions. In each of the loops, the dominant subloop is centered on São Paulo.

Having this in view, Table 4 presents the pairwise São Paulo's supply chain interactions, sorted in decreasing order of the bilateral flow's intensity. The fact that the hierarchy of feedback loops reflects the rank-size of São Paulo's links with other Brazilian states is an evidence of the polarizing role of São Paulo for production fragmentation within Brazil. On the other hand, we observe this does not hold for São Paulo's foreign supply chain interactions. The pairwise interaction with the composite region RoW, which bilateral flow intensity is smaller only than the intra-regional's for São Paulo, is depicted only in the 21th and 28th feedback loops (value added flows going from São Paulo to RoW's value chains, and the other way around, respectively). This shows that even though the production sharing with foreign countries is important for the state itself, at global level its supply chain flows are relatively small.

In summary, the top ten feedback loops reveal a spatial structure for the global supply chains networks where the flows linking major economies across trade blocks are dominant. It is only secondary to this structure that supply chains are well defined within trade blocks. Together with the results for supply chain interdependency for individual countries, obtained in subsection 3.1, we observe that production fragmentation is truly global, and not merely circumscribed to trade blocks.

Therefore, our finding stands with the results of Los *et al* (2014) and seem to be at odds with Baldwin and Lopez-Gonzalez (2014), as well as with Johnson and Noguera (2012). We find no evidence for the statement of Baldwin and Lopez-Gonzalez (p. 37, 2014) that "international supply chains are mostly regional. Most supply-chain trade happens within have been called Factory Asia, Factory Europe and Factory America". In fact, of the supply chain's international value added flows, less than one forth takes place within those blocks (4%, 16%, and 4% of the world total, respectively within East Asia, EU27, and NAFTA).

What may explain the divergence in the studies' conclusions? As indicated by Los *et al* (2014), even though the findings of Baldwin and Lopez-Gonzalez (2014) are also based on WIOD, there is the crucial difference that they focus on an analysis of trade in intermediates rather than in value added, as we and Los *et al* (2014) do. There is a large literature on how gross trade analysis suffers from double-counting problems (e.g. Koopman *et al*, 2014), as the gross value of products in downstream stages of production also include the value added from upstream activities. For the analysis of the spatial structure of value chains it is crucial that if trading within a trade block is more in downstream intermediates than outside the block, within-block trade will be overestimated (in comparison with outside-block trade). We indicate this also affects the findings of Johnson and Noguera (2012) for the VAX ratio. With an overestimated denominator, logically the VAX ratio among partners within blocks will be undervalued; interpreting this indicator may then lead to an overstatement of production sharing within trade blocks.

As for the spatial structure of supply chains networks within Brazil, the main feature is the dominance of the Southeast region's states, especially São Paulo. That is, not only these states have major weight as suppliers of intermediates to other regions' value chains, as seen in subsection 3.1, but also in absolute terms they have central roles for the Brazilian value chains. Fragmentation within great regions is a major phenomenon for the Southeast and (secondary to the links with São Paulo) the South regions. For states elsewhere in the country, supply chain connections with the more developed states in Brazil overshadows production sharing with neighboring states. Focusing in supply chain interdependency and applying the hierarchical feedback loop methodology, our findings concerning the spatial structure of Brazilian states' interdependency are in line with other studies for the inter-regional linkages in the country, such as Perobelli *et al* (2006).[8]

Table 4 – Pairwise São Paulo's supply chain interactions

Rank	Partial permutations	Aggregate flow	Place in hierarchy	Rank	Partial permutations	Aggregate flow	Place in hierarchy
1	(SP)	393,148	1	35	(SP SE)	1,162	26 / 19
2	(SP RoW)	29,100	28 / 21	36	(SP RO)	1,136	20 / 24
3	(SP RJ)	20,484	3 / 2	37	(SP PB)	972	21 / 38
4	(SP MG)	19,846	2 / 3	38	(SP AL)	943	25 / 29
5	(SP PR)	14,246	5 / 4	39	(SP IND)	906	43 / 40
6	(SP RS)	14,164	4 / 5	40	(SP FIN)	880	53 / 28
7	(SP USA)	11,689	22 / 23	41	(SP PI)	830	24 / 44
8	(SP BA)	8,950	6	42	(SP AUS)	767	47 / 42
9	(SP DEU)	8,367	30 / 31	43	(SP TWN)	762	51 / 25
10	(SP CHN)	8,015	27 / 26	44	(SP TO)	736	35 / 41
11	(SP SC)	7,667	8	45	(SP AUT)	709	45 / 46
12	(SP AM)	6,954	9 / 7	46	(SP PRT)	686	44 / 47
13	(SP GO)	5,789	10	47	(SP IDN)	585	52 / 45
14	(SP DF)	5,275	7 / 20	48	(SP DNK)	569	46 / 51
15	(SP ES)	4,338	16 / 9	49	(SP POL)	500	50 / 49
16	(SP MT)	3,968	11	50	(SP TUR)	405	49 / 55
17	(SP FRA)	3,365	31 / 30	51	(SP IRL)	296	54 / 53
18	(SP ITA)	3,311	33	52	(SP AC)	295	42 / 48
19	(SP PE)	3,242	12 / 13	53	(SP AP)	275	40 / 50
20	(SP JPN)	3,005	32 / 22	54	(SP CZE)	272	56 / 54
21	(SP CAN)	2,766	37 / 15	55	(SP GRC)	252	59 / 55
22	(SP GBR)	2,761	34 / 32	56	(SP HUN)	192	57 / 58
23	(SP MS)	2,738	13 / 12	57	(SP ROM)	184	58 / 60
24	(SP PA)	2,478	15 / 16	58	(SP RR)	172	48 / 52
25	(SP CE)	2,446	14 / 17	59	(SP SVK)	102	63
26	(SP SWE)	2,206	18 / 39	60	(SP SVN)	90	61 / 67
27	(SP NLD)	2,180	29 / 34	61	(SP LUX)	75	66 / 65
28	(SP MA)	1,817	19 / 14	62	(SP BGR)	69	67 / 64
29	(SP RUS)	1,631	41 / 35	63	(SP LTU)	32	64 / 66
30	(SP ESP)	1,569	36 / 37	64	(SP CYP)	31	62 / 57
31	(SP MEX)	1,560	17 / 43	65	(SP EST)	27	65 / 61
32	(SP BEL)	1,392	38 / 36	66	(SP LVA)	21	60 / 62
33	(SP RN)	1,384	23 / 18	67	(SP MLT)	14	59 / 56
34	(SP KOR)	1,336	39 / 27				

Source: Research data.

3.3. Sectoral feedback loop hierarchy

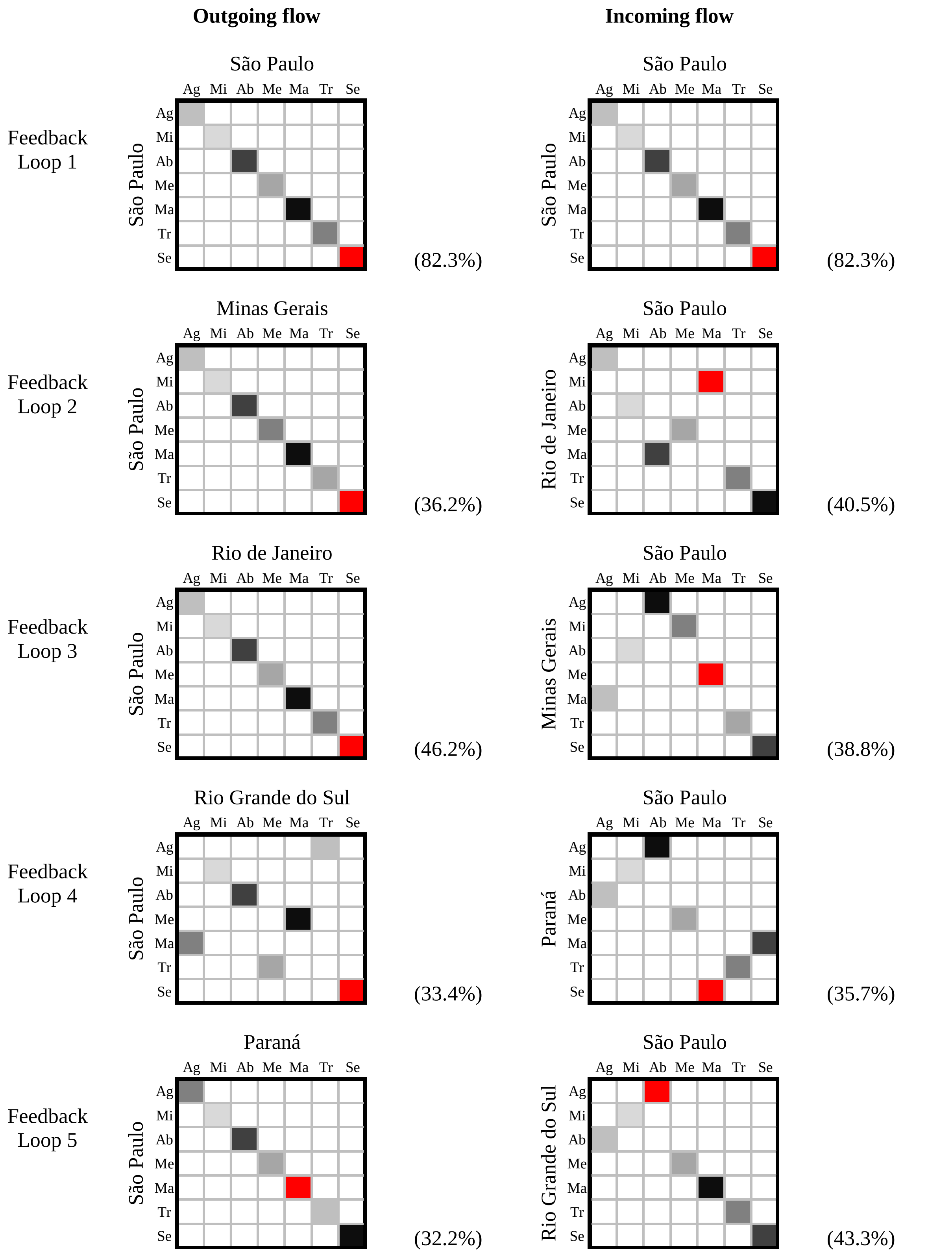
[8] Perobelli *et al* (2006) evaluate the interregional linkages based on an input-output table for Brazilian regions, for the year 1996, applying the extraction method by Dietzenbacher *et al*, 2003.

Alongside inter-regional linkages, we analyze the GVC's intersectoral interdependencies by applying the hierarchical feedback loop procedure at the sectoral level, as in subsection 2.3. Here we focus on the results concerning the main links of São Paulo (dominant in the Brazilian supply chain network). Because of computational limitation, the 28 industries in our model have been aggregated into seven composite industries, as indicated in the Appendix.

Figure 5 presents the main intra / intersectoral transactions loop nested within São Paulo's supply chain links in the major aggregate feedback loops. We observe that most of São Paulo's value added incorporated in the final production of other states or countries is generated in its Manufacturing or Services upstream activities. On the other hand, the participation of other Brazilian states in São Paulo's value chains is highly diversified at the sectoral level. The major value added flows for São Paulo's final production may be generated in upstream Mining activities (Rio de Janeiro and also the composite foreign region RoW), in Metallurgy industry (other states in the Southeast region, Minas Gerais and Espírito Santo), in Agriculture (states in the South region and Goiás), or in Manufacturing activities (Bahia and Amazonas, as well as the USA, China, and Germany).

Even though it is not our focus investigating the generating factors of regional interdependency, these results are elucidating about the nature of inter-regional trade for Brazil's main manufacturing core, São Paulo. We observe that this state's final production mainly promotes agricultural activities in the South region and Goiás, which can be interpreted in terms of the core-periphery model. With the other main state partners, supply chain trade seems primarily based on comparative advantages originated also from deliberate policies (the Camaçari Petrochemical Complex in Bahia, and the Free Trade Zone of Manaus in Amazonas), but mostly from natural endowments (mineral resources in Minas Gerais and Espírito Santo, oil explored in Rio de Janeiro).

These results also bring light to the limited integration of other states in Brazil's value chains, especially those which comparative advantages are due resources with restricted mobility. This is the case of Pará, in the North region, which important production of mineral and metallurgical intermediates is integrated mostly in foreign value chains. Pará's link as a supplier of inputs to São Paulo's value chains is depicted only in the 16th complete feedback loop (ordered by rank-size of global flows' intensity). Attention must be paid to the cost of transportation, which as a service link is a fundamental force in the fragmentation paradigm (as seen in subsection 1.1). As indicated by Vassallo (2015), in the presence of heterogeneous spatial distribution of productive activities and comparative advantages, the transportation cost acts as an impedance factor, limiting inter-regional trade and reducing its potential welfare benefits. In fact, by means of a computable general equilibrium application for the Brazilian states, the author observed that reducing costs of rail transportation from Pará to the Southeast region has a relevant positive effect on this state's value added. Pará's inter-regional trade (in opposition to the prevailing exports) is greatly encouraged by lower transportation costs, notably its sourcing of iron ores to metallurgic plants in Minas Gerais, and automotive industries in São Paulo.

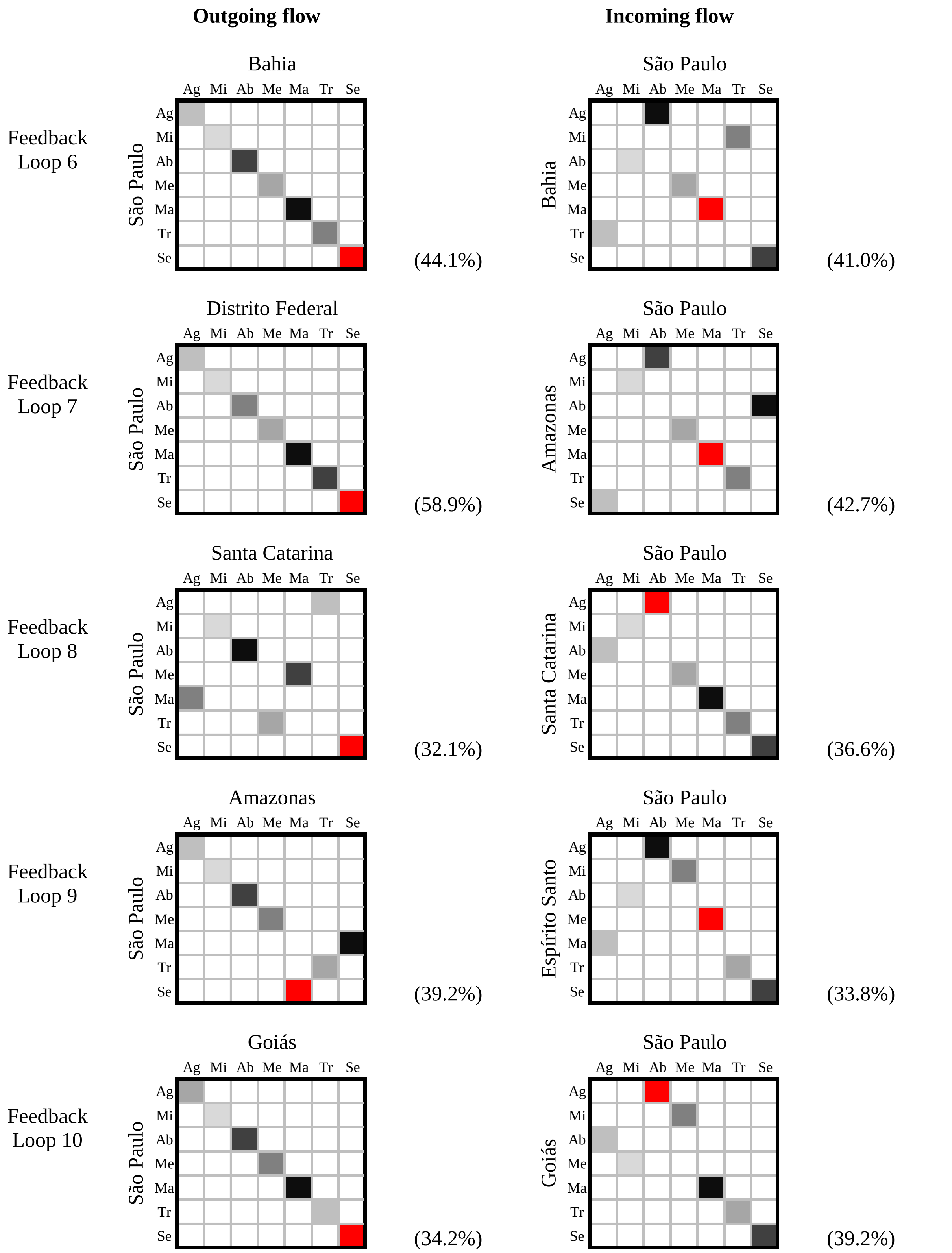


(continues...)

Figure 5 – First intra / intersectoral transactions loop within São Paulo's link in major aggregate feedback loops

Source: Research data.

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.



(continues...)

Figure 5 (continued) – First intra / intersectoral transactions loop within São Paulo's link in major aggregate feedback loops

Source: Research data.

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

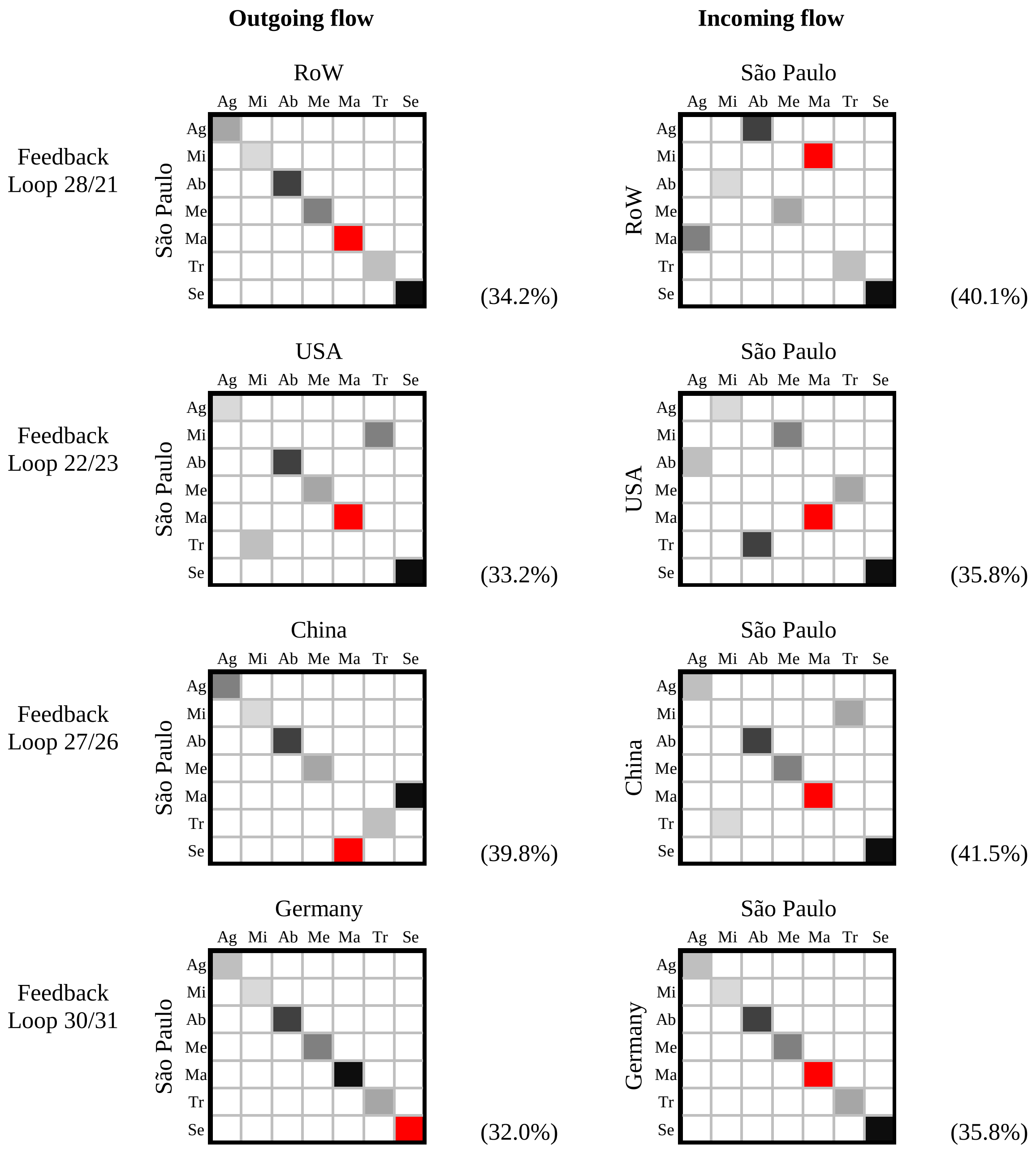


Figure 5 (continued) – First intra / intersectoral transactions loop within São Paulo's link in major aggregate feedback loops

Source: Research data.

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

4. Concluding remarks

The fragmentation of production processes has induced great changes in the spatial location and organization of economic activity. In this paper, our objective was analyzing the geographical structure of GVCs' flows as in 2008 by means of the hierarchical feedback loop methodology. In contrast to other studies that employed this methodology previously, we considered the regional interdependencies as depicted in a country-state input-output table comprising the global productive system. Our application also differs as we take into account value-added flows involved in the supply chains, rather than inter-regional gross trade.

At global level, our analysis primarily reveals a spatial structure for the global supply chains networks where the flows linking major economies across trade blocks are dominant. In fact, more than 75% of supply chain's international value-added flows link countries in different trade blocks. It is only secondary to this structure that supply chains are well defined within blocks. On average, within-block production fragmentation is more intense for countries in EU27 than in NAFTA or East Asia. In EU27, the average value chain has 8.1% its total output corresponding to value added produced by other country members. In NAFTA and East Asia, only 2.3% and 3.3% respectively of their final output correspond within-block foreign value added. Thus, our results indicate that production fragmentation is a truly global phenomenon, not being merely circumscribed to trade blocks.

For Brazil as a whole, we observed that the country's value chains are mostly self-sufficient in intermediates. Moreover, even for the states where production sharing with foreign countries is relevant, such as Amazonas, Paraná, and São Paulo, at global level its supply chain flows are relatively small. On the other hand, there is a great degree of fragmentation among Brazilian states. In the average value chain, 15.3% of final output corresponds to value-added from a state other than where it has its completion. This is larger than the share observed for EU27, indicating even tighter production sharing relationships in the Brazilian production networks.

When it comes to the spatial structure of supply chains networks within Brazil, the main feature is the dominance of the Southeast region's states, especially São Paulo. Not only these states have major weight as suppliers of intermediates to other regions' value chains, but also in absolute terms (as indicated by the feedback loop analysis) they have central roles for the Brazilian value chains. Fragmentation within great regions is a major phenomenon for the Southeast and (secondary to the links with São Paulo) the South regions. For states elsewhere in the country, supply chain connections with the more developed states in Brazil overshadows production sharing with neighboring states.

Finally, the application of the feedback loop approach at regional level evidenced the nature of the inter-regional dependencies. For São Paulo's value chains, we observed that the state's final production mainly promotes agricultural activities in the South region. With the other main state partners, supply chain trade seems primarily based on comparative advantages mostly from mineral natural endowments, alongside deliberate policies directed to manufacturing poles elsewhere in the country.

Our results concern the production systems as in the year 2008. At global level, we may wonder what were financial crisis' effects on the fragmentation of value chains. The aforementioned study of Los *et al* (2014), with basis on the WIOD tables for 2009 to 2011, indicates that the steady increases in international fragmentation continued until the onset of the crisis in 2008. The crisis induced a major dip on the participation of foreign value added in final product outputs in 2009, but this appeared to be a short-run effect for virtually all chains. Concerning the crisis' effects on the geography of value chains, the authors observe that it seems to have propelled the trend toward truly global fragmentation. Contrary to regional fragmentation, global fragmentation of value chains picked up immediately after the crisis and had reached the precrisis level again in 2011. In this movement, China appears to have played an important role in the global relocation of activities.

Regarding the spatial organization of value chains within Brazil, it seems unlikely that major changes took place since 2008. According to the Regional Accounts (IBGE, 2014), between 2008 and 2012 the Southeast and the South region lost participation in the national value added to the other regions, especially the Central-West. However, this relocation involved only 1% of the country's value added. In fact, the geography of production within Brazil remains quite similar over the years. For example, Perobelli *et al* (2006) evaluated the interregional linkages based on an input-output table for the year 1996, and obtained results close to ours indicating the dominance of São Paulo in the Brazilian productive structure, and the low level of interdependency of the states within the North, Northeast and Central-West regions. These results should be observed in the designing of regional development policies. For example, our results indicate that the installation of a manufacturing plant in a state from the Northeast region, on average, will not impact value adding activities of its neighboring states as much as will impact the developed Southeast region.

In the case policies intend to alter the configuration of regional interdependencies, its generating factors must be evaluated, which was not our focus in this paper. However, from what was observed for the global fragmentation process it seems that the lowering costs of service links activities, which brought out profound changes in the spatial structure of economic activities worldwide, may also lead to spatial reorganization within Brazil (with limitations, of course, as many activities cannot be relocated at regional level). In this regard, investments in transportation infrastructure, acting as shortener of distances across regions (HADDAD, 2004), deserve special attention in development policies.

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Appendix

Table A.1 – Composite industries for obtaining the sectoral feedback loop hierarchy

Composite industry		Original industry	
1	Agriculture	1	Agriculture, Hunting, Forestry and Fishing
2	Mining and Quarrying	2	Mining and Quarrying
3	Agribusiness	3	Food, Beverages and Tobacco
		4	Textiles and Textile Products
		5	Leather, Leather and Footwear
		6	Wood and Products of Wood and Cork
		7	Pulp, Paper, Paper , Printing and Publishing
4	Basic Metals and Fabricated Metal	12	Basic Metals and Fabricated Metal
5	Other manufacturing	8	Coke, Refined Petroleum and Nuclear Fuel
		9	Chemicals and Chemical Products
		10	Rubber and Plastics
		11	Other Non-Metallic Mineral
		13	Machinery, Nec
		14	Electrical and Optical Equipment
		15	Transport Equipment
		16	Manufacturing, Nec; Recycling
		17	Electricity, Gas and Water Supply
		18	Construction
6	Transport	21	Transport
7	Services	19	Wholesale and retail trade
		20	Hotels and Restaurants
		22	Post and Telecommunications; Other Business Act.
		23	Financial Intermediation
		24	Real Estate Activities
		25	Public Admin and Defence; Compulsory Social Sec.
		26	Education
		27	Health and Social Work
		28	Other Community, Social and Personal Services