AN INTER-REGIONAL NETWORK PERSPECTIVE TO EVALUATE THE BRAZILIAN ECONOMY

Abstract

Since the publication of Wassily Leontief's seminal work, input-output (IO) models went through by several improvements and extensions. In an attempt to proposing new ways of assessing sectoral interdependencies, integration with other models has been extensively explored in the specialized literature. In this regard, this paper aims to deepen the discussion about the productive interdependence among the Brazilian states through integration between an IO model and complex network theory and identify emergent patterns or properties within the Brazilian states. To do so, an inter-regional IO matrix, base year 2011, is used for the 27 Brazilian states and 68 sectors. The main results indicate that the sectors with the highest degree and weighted degree belong to states of the Southeast region, that is, São Paulo and Rio de Janeiro, mainly, and Minas Gerais. Economically speaking, this means that these sectors have a significant amount of intersectoral trade relations in Brazil. It is worth mentioning that the out-degree of these sectors was greater than the in-degree, which reveals, for this group of sectors, a greater relative importance on the supply side of the economy. Oil refining and coke plant of Bahia is the only Northeast’s sector that stands out considering all of the centrality measures. This can be justified by the presence of the Petrochemical Complex of Camaçari, which places Bahia as an important supplier of petroleum refining products in both regional and national terms.

Keywords: Brazilian economy; regional development; network theory; input-output.

1 Introduction

In an attempt to proposing new ways of assessing sectoral interdependencies, integration with other models has been extensively explored in the specialized literature. In this regard, this paper aims to deepen the discussion about the productive interdependence among the Brazilian states through integration between an input-output (IO) model and complex network theory and identify emergent patterns or properties within the Brazilian states.

Social network analysis provides powerful tools for formally describing and testing theories of complex interaction systems (Smith and White, 1992). There is an increase in the use of complex network approach in different fields like sociology, biology and economics. In economics, for example, we observe a number of applications of network analysis in the field of international trade, i.e., involving several countries at the same time (Tsekeris, 2017; Río-Chanona et al., 2017; Xing et al., 2017; Xiao et al., 2017; Cerina et al., 2015) and also for a single country assessment (He et al., 2017; Tsekeris, 2017; Acemoglu et al., 2016; Carvalho and Gabaix, 2013; Atalay, 2011; Xu et al., 2011). All of these previous studies have used IO database associated to network properties. We will apply this framework to better understand the interdependence among Brazilian states. To do so, we use an inter-regional IO matrix estimated by Haddad et al. (2017), base year 2011, covering up all of the 27 Brazilian states and 68 sectors.

The spatial dynamics of the productive distribution in Brazil and, therefore, regional economic growth is very heterogeneous. This heterogeneity can be measured by aspects such as the qualification of the workforce; physical and financial capital stock; availability of transport infrastructure, energy and logistics; productive integration, among others.

All these factors affect regional economic growth. In this article, we deal with a specific aspect that is productive integration, or sectoral and spatial interdependence. It is important to emphasize that the question of interregional interdependence, that is, interregional purchasing and selling flows is a relevant topic for issues related to the regional planning process. The literature shows that there are gains from trade and / or interdependence between nations and between regions belonging to the same country.

Within this aspect, Hirschman (1958) sought to understand how growth could be transmitted from one region to another. He proposes the hypothesis of unbalanced growth and is concerned with the analysis of the interrelationships between the various sectors, as well as with the promotion of the backward and forward linkages. According to this author, contrary to the orthodox view, growth must be unbalanced, as this creates tensions and creates opportunity for capital investment in other sectors. Therefore, growth starts in the key sectors and moves to the next in an unbalanced way.

The remainder of this paper is organized as follows. The next section presents the IO model and the concept of networks. The third section shows our data, and the fourth contains our main results and discussion. The last section includes our final remarks and policy implications.

2 Model and Data

2.1 The IO model

The IO model describes the relationships between economic sectors and final demand in a given economy. The solution of the standard model, proposed by Leontief (1941), can be specified as:

$$X = BY \qquad (1)$$

Where X is the production value; B = $(I - A)^{-1}$ is the Leontief inverse matrix; and Y is the final demand.

The IO model can be constructed for several regions, that is, interregional models. Following the matrix notation of Miller and Blair (2009), we can specify a model for two regions as:

$$\mathrm{Z} = \begin{bmatrix} \mathrm{Z}^{\mathrm{AA}} & \cdots & \mathrm{Z}^{\mathrm{AB}} \\ \vdots & \ddots & \vdots \\ \mathrm{Z}^{\mathrm{BA}} & \cdots & \mathrm{Z}^{\mathrm{BB}} \end{bmatrix} \qquad (2)$$

The main diagonal of this matrix shows intraregional trade relations, while the rest of the elements reveal interregional trade relations. It is worth mentioning that the mathematical specification of the interregional model's solution is the same as the standard model (equation 1). Haddad et al. (2013) point out that the main advantage of this model is to consider the whole system (states and sectors) in an integrated way through trade relations.

For the network construction, as well as its metrics that will support the topological analysis (described in the next section), we use the Leontief inverse elements (b_{ij}), in order to capture the direct and indirect effects between the sectors. Nevertheless, in order to have the net effects of the main diagonal we subtracted from B the identity matrix (I). According to Perobelli et al. (2007: 117), the subtraction of the identity matrix has the role of extracting from the matrix B the initial requirements produced by the final demand of each sector.

2.2 Concept of networks and properties

The structure of a complex network is represented in the same way as a graph through a set R which, in the case of networks that do not have weights in their connections, is defined by R (υ, ε), where $v = \{v_1, v_2, v_3, \dots, v_n\}$ are the nodes (or vertices) and $\varepsilon = \{e_1, e_2, e_3, \dots, e_n\}$ are the edges or connections that connect pairs of nodes. The number of elements in υ and ε are N and M, respectively. In that the number of vertices is given by the cardinality of the set of vertices $n = |V|$ and the number of arcs is given by the cardinality of the set of arcs $m = |A|$. In our case, $n = |V| = 68$, because we have 68 economic sectors. According to Newman (2010), there are several properties that support the topological analysis of the network. In this paper we will use the properties or metrics described below:

- The degree of vertex i is denoted by k_i and consists of the number of edges incident on vertex i.
- The average degree of an undirected network is given by $\langle k \rangle = \frac{1}{n}\sum_{i=1}^{n} k_i$. For directed networks, we calculate the average of the input and output degrees.
- Let us consider that $\Gamma(i)$ is the neighborhood of vertex i. The weighted degree of vertex i is given by the sum of the weights of all in-or-out arcs connected to vertex i, $k_{wi} = \sum_{j \in \Gamma(i)} w_{ij}$.

- The weighted average degree is given by $\langle k_w \rangle = \frac{\sum_{i=1}^{n} k_{w_i}}{n}$.
- The out degree of vertex *i* is given by the sum of all out arcs connected to vertex *i*. Economically speaking, it can be represented as the sum of the total sales of a sector *j*.
- The in degree of vertex *i* is given by the sum of all in arcs connected to vertex *i*. In other words, it can be represented as the sum of the total purchases of a sector *j*.
- The PageRank measures the importance of a node (sector) by counting the number and quality of arcs (if the network is addressed) by pointing to it. PageRank is a measure of quantity and quality because it captures both the number of arcs a node can have and the importance of the node in the network; a node (sector) can be important if it receives an arc from an important node.
- The metric betweeness identify the individual position in the network and is given by:

$$C_{bk} = \frac{\sum d_{ikj}}{\sum d_{ij}}, \quad i \neq j \neq k$$

Where d_{ikj} is the number of links of the geodesic path of the individuals *i* and *j* which passing through the node *k*, and d_{ij} is the number of links of the geodesic path of the agents *i* and *j*. In our case, this measure will identify the sectors that have strategic position in terms of information control.

The construction of the network for this paper did not use any filter for the edges and arcs definition which connect the vertices, since the average's value of the coefficients was very low. In other words, when defining the filter from the mean, for example, a lot of important information was lost.

2.3 Data

The database used for the construction of the network refers to an interregional IO system estimated for the year 2011 by Haddad et al. (2017). This system is made up of the 27 Brazilian states and takes into account 128 commodities and 68 sectors, according to the latest revision of the System of National Accounts – SNA 2008 (UNITED NATIONS, 2008).

Roughly speaking our idea is use the topological analysis of network applied to an IO database. In other words, we provide a novel method to analyses the Brazilian productive structure in 2011 in order to support policy directions.

3 Results and discussions

For this article, as commented earlier, we use the following measures of centrality: i) average degree; (ii) weighted degree; iii) in-degree; iv) out-degree; v) PageRank; and vi) betweeness. The use of these different measures gives complementary and important information about the network topology. When applying network centrality measures in a Brazilian interregional IO matrix, it is sought to capture the interaction between sectors and to better understand the functioning of their productive structure. Therefore, we provide a novel method to evaluate the productive interdependence among the Brazilian states.

The average degree is one of the most important metrics and measures the average amount of connections between the network's vertices. In our case, this metric indicates the average number of trade relations of the sectors. In 2011, the average degree of the Brazilian interregional IO network was approximately 174, that is, each sector, on average, is related (demand or supply) to another 174 sectors. Figure 1 shows an overview of the inter-regional IO network for Brazil in 2011. Each color indicates a specific Brazilian state (see Appendix 1) and the numbers indicate the economic sectors (see Appendix 2).

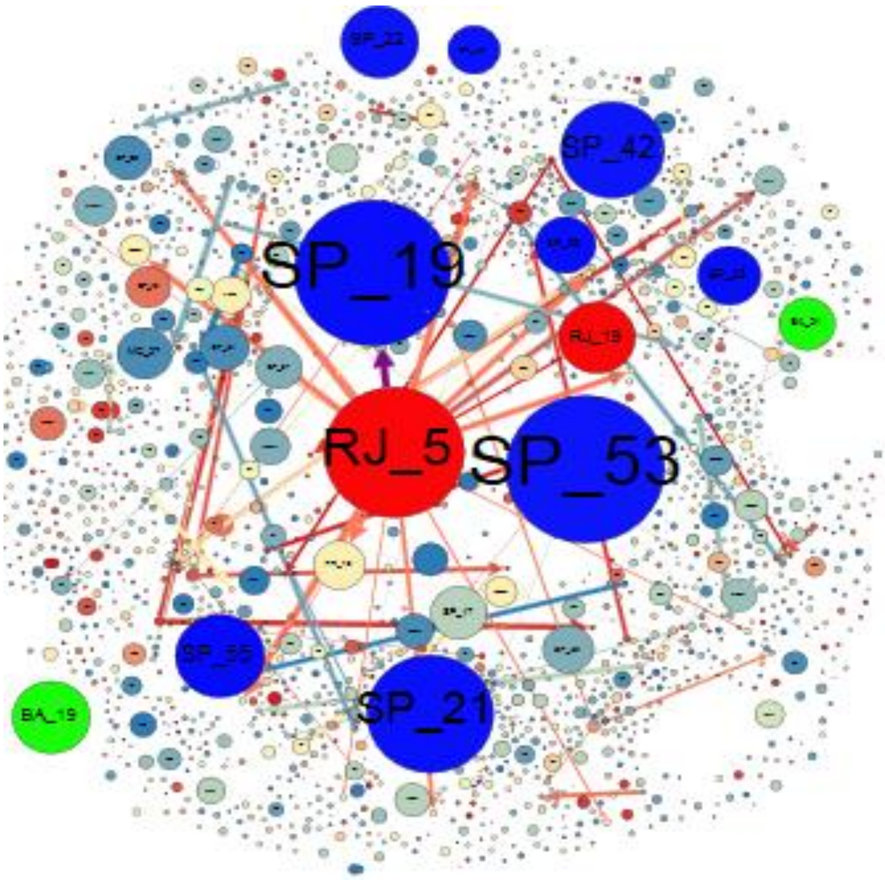

Figure 1: Brazilian inter-regional IO network
Source: Authors'own elaboration.

As we can see in Figure 1 the most important sectors are located in São Paulo (SP) and Rio de Janeiro (RJ) which will be commented further. The network diameter, which is the average distance between all the pairs of vertex, was 6 and the agglomeration coefficient was 0.434. In comparative terms, the network diameter calculated by Abreu (2014) for the Brazilian economy in 2007 was 2. However, it should be noted that this author has used a national IO matrix with 42 sectors, which justifies a smaller diameter. Roughly, a reduction of this indicator over two periods of time, for instance, would indicate increased network connectivity.

The average behavior of the network is not enough to understand the peculiarities of trade relations between sectors and regions. In this way, the network properties were calculated for each of the 68 sectors of the 27 Brazilian states. That is, this regional and sectoral structure provides 1,836 units of analysis. Figure 2 shows the number of connections per Brazilian state according to the weighted degree.

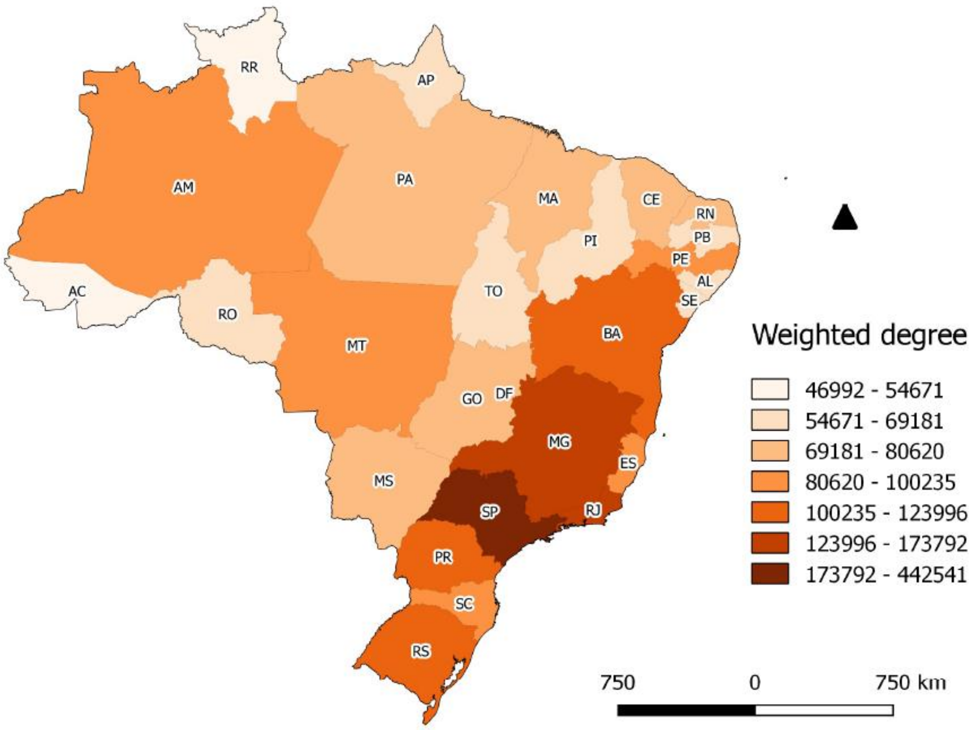

Figure 2: Weighted degree per Brazilian state, 2011
Source: Authors'own elaboration.

Table 1 show the ten sectors of each Brazilian state with higher and lower average degree in 2011. Economically speaking, this metric reveals the most important and least important sectors in terms of relations in the economy. In other words, we can use this metric to identify key sectors.

Eight of the ten sectors with the highest number of connections are in São Paulo state, one in Bahia and one in Rio de Janeiro, which means nine connections in the Southeast region. In general, all these sectors are related to industrial activities. On the contrary, nine of the ten sectors with the weakest linkages are in the poorest regions of the country, North (RR, RO, AP, TO) and Northeast (SE, RN and PB)[1]. Most of these activities are associated with services, with emphasis on public education.

Table 1: Average degree – selected sectors, 2011.

State	Sector	Degree
SP	Manufacture of pulp, paper and paper products	1,993
SP	Manufacture of pesticides, disinfectants, paints and various chemicals	1,983
SP	Manufacture of other organic and inorganic chemicals, resins and elastomers	1,972
BA	Oil refining and coke plants	1,965
SP	Oil refining and coke plants	1,963

[1] Appendix 1 shows the names of the Brazilian states and regions.

SP	Manufacture of rubber and plastic products	1,949
SP	Manufacture of electrical machinery and equipment	1,944
RJ	Oil refining and coke plants	1,939
SP	Manufacture of metal products, except machinery and equipment	1,937
SP	Other professional, scientific and technical activities	1,927
RR	Public education	61
SE	Public education	60
RN	Public education	57
PB	Public education	54
RO	Public education	51
RR	Surveillance, security and research activities	39
AP	Public education	32
TO	Extraction of iron ore, including processing and agglomeration	15
RR	Manufacture of cars, trucks and buses, except parts	12
DF	Extraction of iron ore, including processing and agglomeration	7

Source: Authors'own elaboration.

Although the average degree takes into account the number of connections of each sector, it can be considered flawed because it also considers weak connections. Because of that, we also present the results of the weighted degree, which considers the links' weight of each sector in the entire productive structure. Thus, this centrality weights the average degree by a coefficient (see Table 2).

Table 2: Weighted degree – selected sectors, 2011.

State	Sector	Degree
SP	Financial intermediation, insurance and supplementary pension plans	36,117
SP	Oil refining and coke plants	35,657
RJ	Extraction of oil and gas, including support activities	31,922
SP	Manufacture of other organic and inorganic chemicals, resins and elastomers	28,811
SP	Wholesale and retail trade, except motor vehicles	23,529
SP	Legal, accounting, consulting and corporate headquarters activities	20,277
BA	Oil refining and coke plants	17,583
SP	Manufacture of pesticides, disinfectants, paints and various chemicals	17,573
RJ	Oil refining and coke plants	17,335
SP	Manufacture of rubber and plastic products	14,279
TO	Public education	109
RN	Public education	109
PB	Public education	94
RO	Public education	86
RR	Surveillance, security and research activities	62
AP	Public education	52
MA	Public education	22
RR	Manufacture of cars, trucks and buses, except parts	19
TO	Extraction of iron ore, including processing and agglomeration	18
DF	Extraction of iron ore, including processing and agglomeration	7

Source: Authors'own elaboration.

Even if the results in terms of states have been maintained in Table 3, we can see important changes for the sectors with the highest number of connections. The Financial intermediation, insurance and supplementary pension plans sector of São Paulo presents the highest weighted degree, which may be justified by the state being the financial center of the country (sector SP_53 in Figure 1). In addition, two other service segments, also from São Paulo, emerge as important sectors when considering their connections, they are: Wholesale and retail trade, except motor vehicles and Legal, accounting, consulting and corporate headquarters activities.

The ranking changes in sectoral terms when the weighted degree is used instead of the average degree. However, from the regional point of view, the states of the Southeast continue to present the greatest number of connections in the Brazilian inter-regional structure.

Another possibility of analysis is to relate the weighted degree sectors' ranking to the measures of in-degree and out-degree. In general, the out-degree is much higher than the in-degree of the sectors located in the richest regions of the country, Southeast and South, which indicates important relations of these sectors on the supply side of the economy. On the other hand, most of the sectors located in North, Northeast and Midwest regions, have the in-degree greater than the out-degree, indicating a relative importance of the demand side.

Among the 50 largest out-degree indicators, the only sectors in Northeast region that appear are Oil refining and coke plants and Manufacture of other organic and inorganic chemicals, resins and elastomers of Bahia's state. This can be justified by the presence of the Petrochemical Complex of Camaçari, which places Bahia as an important supplier of petroleum refining products in both regional and national terms, as already pointed out by Ribeiro and Rocha (2013) and Ribeiro et al. (2010).

We also use the metric PageRank. According to Cerina et al. (2015: 15) the use of this metric improves our analysis once "PageRank centrality considers that an industry is important if it is connected with other important industries". In this regard, Table 3 shows the highest and lowest PageRank for the Brazilian inter-regional IO network.

Table 3: PageRank – selected sectors, 2011.

State	Sector	Degree
PE	Food services	0.001200
DF	Associations and other personal services	0.001181
PR	Food services	0.001155
CE	Food services	0.001123
BA	Oil refining and coke plants	0.001033
MA	Associations and other personal services	0.001025
RJ	Manufacture of metal products, except machinery and equipment	0.001018
SC	Manufacture of cars, trucks and buses, except parts	0.001011
RS	Manufacture of metal products, except machinery and equipment	0.000978
PE	Manufacture of beverages	0.000923
DF	Real estate activities	0.000361
RJ	Real estate activities	0.000361
SC	Real estate activities	0.000361
MS	Real estate activities	0.000361
MT	Real estate activities	0.000361
PR	Legal, accounting, consulting and corporate headquarters activities	0.000361
PR	Real estate activities	0.000361
PR	Public education	0.000361
RS	Real estate activities	0.000361
DF	Extraction of iron ore, including processing and agglomeration	0.000361

Source: Authors'own elaboration.

Unlike Tables 1 and 2, Table 3 reveals different states which have the highest PageRank. In other words, the use of this metric changes the rank completely. States such as Pernambuco (PE), Ceará (CE), Maranhão (MA) and Bahia (BA), even located in a peripheral region (Northeast), present sectors with high PageRank, which means that they are connected with important sectors, not necessary in their region. On the other hand, it is worth mentioning that Real estate activities appear in several Brazilian states with the lowest PageRank. Moreover, none of the poorest regions' states (North and Northeast) appears in the top ten lowest indicators.

The last metric we use is called betweeness which identifies economic sectors in strategic positions in terms of information control. Brazilian sectors with highest and lowest betweeness are listed in Table 4.

Table 4: Betweeness – selected sectors, 2011.

State	Sector	Degree
SP	Other professional, scientific and technical activities	0.020948
BA	Oil refining and coke plants	0.013505
AM	Oil refining and coke plants	0.012219
AM	Manufacture of computer, electronic and optical products	0.010667
SP	Metallurgy of nonferrous metals and metal smelting	0.009750
SP	Manufacture of pulp, paper and paper products	0.009397
SE	Manufacture of other organic and inorganic chemicals, resins and elastomers	0.008415
AC	Wholesale and retail trade, except motor vehicles	0.008413
RN	Extraction of oil and gas, including support activities	0.008340
MA	Ground transportation	0.007649
PI	Legal, accounting, consulting and corporate headquarters activities	0.000000
AL	Manufacture of wearing apparel and accessories	0.000000
SE	Manufacture of pharmaceutical and pharmacokinetic products	0.000000
RN	Surveillance, security and research activities	0.000000
ES	Manufacture of pharmaceutical and pharmacokinetic products	0.000000
SE	Surveillance, security and research activities	0.000000
MG	Public health	0.000000
PR	Public health	0.000000
SC	Public health	0.000000
DF	Extraction of iron ore, including processing and agglomeration	0.000000

Source: Authors'own elaboration.

The most important observation about Table 3 is that sectors from North and Northeast regions appear in the top ten, such as: Oil refining and coke plants (BA and AM), Manufacture of computer, electronic and optical products (AM), Manufacture of other organic and inorganic chemicals, resins and elastomers (SE), Wholesale and retail trade, except motor vehicles (AC), Extraction of oil and gas, including support activities (RN) and Ground transportation (AM). The results for Amazonas state (AM) could be justified because of the oil refinery named Isaac Sabbá (Reman) and the "Zona Franca de Manaus" which has an important pole of electronics products. Furthermore, Rio Grande do Norte (RN) is one the greatest producer of oil in the country.

4 Final remarks

This paper aimed to deepen the discussion about the productive interdependence among the Brazilian states through integration between an IO model and complex network theory and identify emergent patterns or properties within the Brazilian states. To do so, an inter-regional IO matrix, base year 2011, was used for the 27 Brazilian states and 68 sectors.

The main results indicate that sectors of Southeast' states, mainly São Paulo, Rio de Janeiro and Minas Gerais, have presented the highest indicators in terms of average degree and weighted degree. However, it was possible to see a change in the ranking when we used different metrics, such as PageRank and Betweeness. Therefore, it is important highlight the use of these metrics in a complementary way.

As a step further, we also could do sensitivity analysis choosing different filters to construct the Brazilian IO network. For instance, average, average plus one or two standard deviation's criteria and so on and so far. The main idea would be assess if the results would keep the same pattern or if they would be sensitive according to the adopted filter.

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Appendix 1: Brazilian states and regions

Code	**State**		**Region**
11	RO	Rondônia	North
12	AC	Acre	
13	AM	Amazonas	
14	RR	Roraima	
15	PA	Pará	
16	AP	Amapá	
17	TO	Tocantins	
21	MA	Maranhão	Northeast
22	PI	Piauí	
23	CE	Ceará	
24	RN	Rio Grande do Norte	
25	PB	Paraíba	
26	PE	Pernambuco	
27	AL	Alagoas	
28	SE	Sergipe	
29	BA	Bahia	
31	MG	Minas Gerais	Southeast
32	ES	Espírito Santo	
33	RJ	Rio de Janeiro	
35	SP	São Paulo	
41	PR	Paraná	South
42	SC	Santa Catarina	
43	RS	Rio Grande do Sul	
50	MS	Mato Grosso do Sul	Midwest
51	MT	Mato Grosso	
52	GO	Goiás	
53	DF	Distrito Federal	

Source: Authors'own elaboration.

Appendix 2: Economic sectors (continue)

1	Agriculture, including support for agriculture and post-harvest
2	Livestock, including support for livestock
3	Forestry production fisheries and aquaculture
4	Extraction of coal and non-metallic minerals
5	Extraction of oil and gas, including support activities
6	Extraction of iron ore, including processing and agglomeration
7	Extraction of non-ferrous metal ores, including
8	Slaughter and meat products, including dairy products and fishery products
9	Manufacture and refining of sugar
10	Other Food Products
11	Manufacture of beverages
12	Manufacture of tobacco products
13	Manufacture of textiles
14	Manufacture of wearing apparel and accessories
15	Manufacture of footwear and leather goods
16	Manufacture of wood products
17	Manufacture of pulp, paper and paper products
18	Printing and reproduction of recordings
19	Oil refining and coke plants
20	Manufacture of biofuels
21	Manufacture of other organic and inorganic chemicals, resins and elastomers
22	Manufacture of pesticides, disinfectants, paints and various chemicals
23	Manufacture of cleaning products, cosmetics / perfumes and toilet preparations
24	Manufacture of pharmaceutical and pharmacokinetic products
25	Manufacture of rubber and plastic products
26	Manufacture of non-metallic mineral products
27	Production of pig iron / ferrous alloys, steel and seamless steel tubes
28	Metallurgy of nonferrous metals and metal smelting
29	Manufacture of metal products, except machinery and equipment
30	Manufacture of computer, electronic and optical products
31	Manufacture of electrical machinery and equipment
32	Manufacture of machinery and mechanical equipment
33	Manufacture of cars, trucks and buses, except parts
34	Manufacture of parts and accessories for motor vehicles

Appendix 2: Economic sectors (conclusion)

35	Manufacture of other transport equipment, except motor vehicles
36	Manufacture of furniture and products of various industries
37	Maintenance, repair and installation of machinery and equipment
38	Electricity, natural gas and other utilities
39	Water, sewage and waste management
40	Construction
41	Trade and repair of motor vehicles and motorcycles
42	Wholesale and retail trade, except motor vehicles
43	Ground transportation
44	Water transportation
45	Air Transport
46	Storage, auxiliary transport and mail activities
47	Accommodation
48	food
49	Print-integrated editing and editing
50	Television, radio, cinema and sound / image recording / editing activities
51	Telecommunications
52	Development of systems and other information services
53	Financial intermediation, insurance and supplementary pension plans
54	Real estate activities
55	Legal, accounting, consulting and corporate headquarters activities
56	Architectural, engineering, testing / technical analysis and R & D services
57	Other professional, scientific and technical activities
58	Non-Real Estate Rentals and Intellectual Property Asset Management
59	Other administrative activities and complementary services
60	Surveillance, security and research activities
61	Public administration, defense and social security
62	Public education
63	Private education
64	Public health
65	Private health
66	Artistic, creative and entertainment activities
67	Associations and other personal services
68	Domestic services