Brazilian Functional Regions and Their Dynamics in 1980-2010

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1. Introduction

The boundaries of a city or region are traditionally expressed in terms of well-defined geographical limits, which are expressions of political phenomena. These boundaries divide levels of government and define the scope of resource allocation and public policy, and hence condition a host of other aspects of socioeconomic reality. However, this does not imply that such limits are an adequate representation of the scope of social or economic phenomena in space.

Different types of phenomena will naturally have different - and often unclear - boundaries, and these may or may not overlap, so that the choice to define and portray boundaries relative to a particular aspect of reality will almost certainly lead to an inadequacy regarding other dimensions. The scope of a given cultural phenomenon will be different from the space of commodity flows or the scope of a given environmental externality, for example – and none of these will be in full compliance with the boundaries of political units.

These different dimensions demand specific analyses in order to better understand them, which involves the effort for delimiting them in space, taking into account their peculiarities. Thus, for different types of phenomena different regions may be fitted, portraying them geographically and helping to present them in a clearer picture.

An example of an attempt to understand the urban phenomenon in terms of the reach of its economic dimension can be found in the idea of a city-region, a concept that is not new but that has recently gained ground in the regional economic literature (Davoudi [2008], Parr [2005], Rodríguez-Pose [2008])

The expansion of an urban centre is related to an increase in its connections with neighbouring cities and regions, through greater flows of commerce, people and information - processes that gain special relevance in the contemporary context. If, on the one hand, it was believed that the emergence of new information and production technologies would bring the "end of geography" (O'Brien [1992]) , the "death of distance" (Cairncross [2001]) and even the "death of cities" (Drucker [1989], Gilder [1995] *apud* Moss [1998]]); on the other hand, answers to these arguments have emerged, emphasizing the increasing importance of the geographical concentration of human activities, which reinvent themselves together with the space that comprehends them.

It is in this context that the concept of city-region resurges, proposing an attempt to relate the urban core to the regions that surround it. Such a proposal can be useful to bring the focus to an extended geographic space, what in turn allows more proper investigations of the phenomena that occur in such a dimension.

The city-region then can be understood as the theoretical framework behind an attempt to define, in practical terms, what are called functional regions from an economic point of view. These are generally defined as regions where the supply and demand for labour takes place (Casado-Díaz [2000]). In other words, it is a question of identifying a given region in terms of the conditions of its labour market, an idea that has been advanced by different studies (e.g.

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Smart [1974], Casado-Díaz [2000], Watts [2004]). Similarly, the Organisation for Economic Co-operation and Development (OECD [2002]]) characterizes functional regions as territorial units that result from the organization of economic and social relations, and their boundaries do not represent geographical particularities or historical events. In practical terms, there is a tendency to use information on commutation (or "pendular migration", as it is called in Brazil) to work in order to operationalize the concept of functional region.

In Brazil, the geographical divisions that are closest to the notion of functional region are the Metropolitan Regions (MR) and the Population Arrangements (PA) of the Brazilian Institute of Geography and Statistics (IBGE). Historically, the Metropolitan Regions, defined according to variable political criteria, have been of great relevance for the definition of policies and allocation of public resources; the Population Arrangement results from a recent theoretical and empirical effort to establish a region using more homogeneous criterion - based on pendular migration and contiguity of urban spots -, but up to now they did not had a great impact on political praxis.

Recently, new possibilities for the definition of functional regions have arisen, combining the use of large databases and intensive computational resources. New developments include the use of methods and models based on network analysis, which allow, for example, finding a certain optimal configuration of groupings based on the flows between certain units. Thus, the idea is to group elements that have more common flows to each other than with another set of elements that in turn will be allocated in other groups. Among the main potentialities of such methods is the possibility of reducing arbitrariness resulting from the establishment of ad hoc criteria and a priori specifications.

Given these possibilities and a perceived absence of their applications to Brazil, we propose here the use of a method of network analysis that allows us to find optimal groupings for municipalities, according to data of working and studying flows among them. Given the information available in the Demographic Census of IBGE, it is possible to apply such method for the periods of 1980, 2000 and 2010.

Once these groupings have been identified for each year, it is possible to contrast them with the divisions already mentioned and to verify their change over time. Therefore, the proposed analysis is restricted to the 26 large urban concentrations, defined by IBGE [2015] as population arrangements and isolated municipalities above 750 thousand inhabitants. The prominent position of these can be visualized using data from the 2010 Census, which show that such concentrations housed 41.43% of the Brazilian population and accounted for 54.14% of the country's Gross Domestic Product, (IBGE [2015]), evidencing the eminently concentrative character of these centres.

The importance of looking at such regions lies in the fact that it is increasingly necessary to understand the way in which these centres are articulated with the regions around them. As cities become more connected and their roles change as a result of productive transitions, the space also changes, demanding constant research that seeks to understand the extent and dynamics of these phenomena. In this sense, the functional regions are an analytical alternative to bring light to these questions.

The remainder of the present work deals with the methodological proposal to obtain functional regions in terms of commuting movements, in the second section; the presentation and discussion of the results obtained, in the third section; and, finally, final considerations about the work and unfolding perspectives from the same, in the fourth section.

2. Methodology

2.1. Analysis of network clusters

In order to find the best groupings of municipalities as a function of their commuting flows, we propose here the application of a network analysis method that allows to cluster their elements according to the intensity of the relations between them. Such clusters will constitute the functional regions of the present work.

This approach is based on the study by Farmer and Fotheringham [2011], who implemented a network method to find clusters in spatial data. The authors use the method proposed by Girvan and Newman [2002] and subsequent developments to find and evaluate clusters in network data, so that the internal connections of the clusters are dense and the connections between the different clusters are sparse. In this sense, Newman and Girvan [2004] present the *Q* function of modularity quality, which aims to evaluate the quality of network clusters. In geographical terms, the modularity expresses the idea that a good division of regional groupings is one in which there is a smaller amount of flows between regions than expected. In other words, it means that the flows between such regions should be smaller than those verified by a null model (a random network).

Thus, the modularity function of Newman and Girvan [2004] is given by

$$Q = \frac{1}{2w}\sum_{ij}\left(W_{ij} - \frac{w_i w_j}{2w}\right)\delta_{c_i,c_j} \tag{01}$$

Where *W* is a flows matrix; W_{ij} is an element of that matrix representing the flows between the localities *i* and *j*; δ is a Kronecker function that assumes value 1 if the localities *i* and *j* are in the same functional region ($c_i = c_j$) and 0 otherwise; w_i and w_j represent the magnitude of the flows associated with regions *i* and *j*, so that $w_i w_j/2w$ represents the expected magnitude of flows between regions *i* and *j*; and $w = \frac{1}{2}\sum_{ij} W_{ij}$ is the total network flows.

The goal is to obtain a regional configuration that maximizes *Q*. Computational requirements, however, can be very large, which may require a heuristic to approximate the maximization, such as the Leading Eigenvector method proposed by Newman [2004], where the modularity is reformulated in a matrix *B*, which makes it possible to apply a spectral partition (a basic network partitioning in two groups, A and B, based on properties of its Laplacean matrix). Thus, when using the modularity matrix to approximate *Q*, the elements of matrix *B* take the form

$$B_{ij} = W_{ij} - \frac{w_i w_j}{2w} \tag{05}$$

Therefore (01) can be reformulated as

$$Q = \frac{1}{4w} s^T B s \tag{06}$$

Where *s* is and index vector, with $s_i = +1$ if the associated vertex belongs to the group A and $s_i = -1$ if it belongs to group B, and the elements of *s* are chosen so that the total flows between the two groups is minimized. The network can be continuously subdivided into more partitions by applying the procedure recursively to each new group formed, keeping the idea that each region is a component of a larger network of flows.

An alternative method consists of the Louvain heuristic developed by Blondel et al. [2008]. The advantage of this method lies in its computational speed, which allows it to work with very large networks. In this case, it is used an algorithm of two phases that repeats iteratively. In the first step, starting from a network with *N* nodes, initially a community is assigned to each node, and then the neighbours of each node are addressed, evaluating what would be the modularity gain in excluding the community of this node, allocating it in the same community of a neighbour (the one that returns greater gain in modularity) if the gain is positive. This process is repeated for all nodes, each node being considered several times, until no additional gain can be obtained from an individual movement, ending the first step. Thus, the gain in modularity, ΔQ, obtained by moving the isolated node *i* to a community *C*, can be calculated by the expression

$$\Delta Q = \left[\frac{\sum_{in} + k_{i,in}}{2m} - \left(\frac{\sum_{tot} + k_i}{2m}\right)^2\right] - \left[\frac{\sum_{in}}{2m} - \left(\frac{\sum_{tot}}{2m}\right)^2 - \left(\frac{k_i}{2m}\right)^2\right] \quad (07)$$

Where $\sum_{in}$ is the sum of the weights of the internal connections of the community *C*, $\sum_{tot}$ is the sum of the weights of all the connections that bind to nodes of *C*, k_i is the sum of the weights of the nodes which connect to the node *i*, $k_{i,in}$ is the sum of the weights of the connections from *i* to the nodes in *C*, and *m* is the sum of the weights of all the connections in the network. In practical terms, the change in modularity is assessed by removing *i* from its community and moving it to a neighboring community.

In the second stage a new network is constructed, whose nodes are now the communities formed in the previous stage. In this case, the weight of each connection is given by the sum of the weights of the connections between the nodes of each pair of clusters that will be connected. After completing this second step, the first step is reapplied, and so on until it is no longer possible to achieve modularity gains.

There are still other possible algorithms, such as Fast Greedy, proposed by Clauset et al. [2004] and Walktrap developed by Pons and Latapy [2005]. As the steps of these algorithms are more extensive, they will not be detailed here as the previous ones, but their applications will be compared to these. Objectively, the method that returns the highest value for the *Q* can be considered more adequate for the proposed analysis, since it provides the best community partitioning.

Because these methods do not ensure that the resulting clusters will be strictly contiguous, it is possible to impose a distance constraint so that more distant connections are less likely, increasing the chances of contiguous communities. Thus, following the proposal of Farmer and Fotheringham [2011], W_{ij} in (2) can be replaced, for example, by an adjusted flux matrix *A*, using an inverse Gaussian distance

$$A_{ij} = W_{ij} \exp\left(\frac{-d_{ij}^2}{h^2}\right) \quad (08)$$

Where d_{ij} is the geodesic distance between regions *i* and *j*, and *h* is a parameter used to control the bandwidth of the Gaussian operator. Small values of *h* result in faster decays of distance and, consequently, in more compact spatial units. In practical terms, such a parameter can be set manually, or by an automatic procedure, or even through a spatial interaction model to find a distance decay parameter.

Finally, even using the distance constraint, it is possible that some resulting clusters contain non-contiguous municipalities. To correct this problem, a final calibration step can be applied, where these municipalities are manually reallocated to ensure that the clusters remain contiguous in space.

2.2. Sample and database

Information available in the Demographic Census, carried out by the IBGE, is used for the years 1980, 2000 and 2010. Such databases provide information on flows of individuals, as they inquire if these individuals study and/or work (with remuneration) in a municipality different from the ones they inhabit, asking also which municipalities are these. The present sample covers individuals aged 14 or over who work and/or study in different municipalities than the ones they reside. The criterion of 14 years was defined based on existing legislation, which defines that from such age one can work as an apprentice[1].

With such data, it is possible to construct matrices of origin and destination, whose cells contain the number of flows between each pair of municipalities, each individual representing a flow. These flows are then weighted by the population (in ten thousands inhabitants) of the municipality of origin, in order to treat them in terms of intensity of movements, rather than their absolute values.

After applying the method (which identifies groups that cover the entire national territory) only those groups containing the 26 large Population Arrangements identified by IBGE [2015] are selected. The purpose of choosing this sample is to allow a direct comparison with the results obtained by the aforementioned research, as well as to reduce the number of units investigated to an amount that makes the analysis feasible and at the same time representative of a significant portion of the national economy and population.

Finally, given the creation of new municipalities in the period of analysis, the spatial temporal changes of the clusters were done using the Minimum Comparable Areas (MCAs) of the Institute of Applied Economic Research (IPEA), developed by Reis et al. (2007). However, since these MCAs do not comprise the periods of 1980 and 2010, manual adjustments were made in order to make the comparison. The MCAs for 1980 were rebuilt from the MCAs of 1970, disaggregating the municipalities created during that decade. In the case of 2010, the compatibility was created with the MCAs of 2000 through the aggregation of dismembered municipalities in the period. The criterion used was to aggregate the municipality to the one that had ceded the largest area.

3. Results

3.1. The network of commuting flows between 1980 and 2010

From the selected sample, the matrices of origin and destination flows between the municipalities were constructed. From these matrices, the graphs were made for the years 1980, 2000 and 2010. Their specific statistics are shown in the Table 1.

Table 1 – Graph statistics

Statistic	1980	2000	2010
Average path length	22.83	23.10	20.06
Average degree	230.68	377.13	749.54
Graph density	0.0581	0.0685	0.1347
Nodes	3974	5504	5565

Average path length consists on the mean number of steps required to connect each pair of nodes on the network; average degree is the mean number of connections that each node has with other nodes (here weighted by the population size of the origin municipality in ten thousand inhabitants); graph density expresses the number of connections in the network as a proportion of the total possible connections; the nodes (or vertices) are the number of elements in the system (in this case, each municipality is a node).

[1] Article 6, point XXXIV of the Federal Constitution; and Article 403 of the Consolidation of Labour Laws.

In general, the graphs become more connected over time, which is revealed mainly by the graph density, which expresses the ratio between the number of connections between the nodes and the total number of such possible connections. The value of this statistic has some increase between 1980 and 2000, but it is between 2000 and 2010 that an increase of greater magnitude is observed, so that the density of the graph practically doubles. In other words, this indicates that in 2010 the network of commuting flows between cities was almost twice as connected as in 2000, suggesting that in this period a growing number of cities began to attract (and/or expel) individuals in search of work and/or study.

Another indicator that reveals such increase in the connectivity of the graph is the average path length, which measures the average number of shortest path steps for each vertex reach the other vertices of the network. There is a slight increase between 1980 and 2000, which may be due, to some extent, to the large increase in the number of municipalities over that period. Between 2000 and 2010, when few municipalities were created, there was a considerable reduction in the average path size, which reinforces the finding that the network became more connected during that decade.

The average degree, in turn, reveals the average number of connections of each node in the network. In this case, it should be noted that the degree is weighted by the population of the municipality of origin. This statistic reveals a sharp and considerable increase over the decades, and between 1980 and 2000 the intensity of the commuting movements grew by 63.5%, while between 2000 and 2010 the increase was of 95.7%. Throughout the period, the total increase was of 224.9%, reaching an average of about 750 commuting flows per ten thousand inhabitants in the last year.

Another way to visualize these changes over time is to present a histogram of the degrees distribution between the different periods. To facilitate comparison, the traditional histogram can be replaced by kernel density distributions. These distributions are presented in Figure 1, where the horizontal axis presents the normalized degrees, which consist of the degrees divided by the number of nodes of the graph.

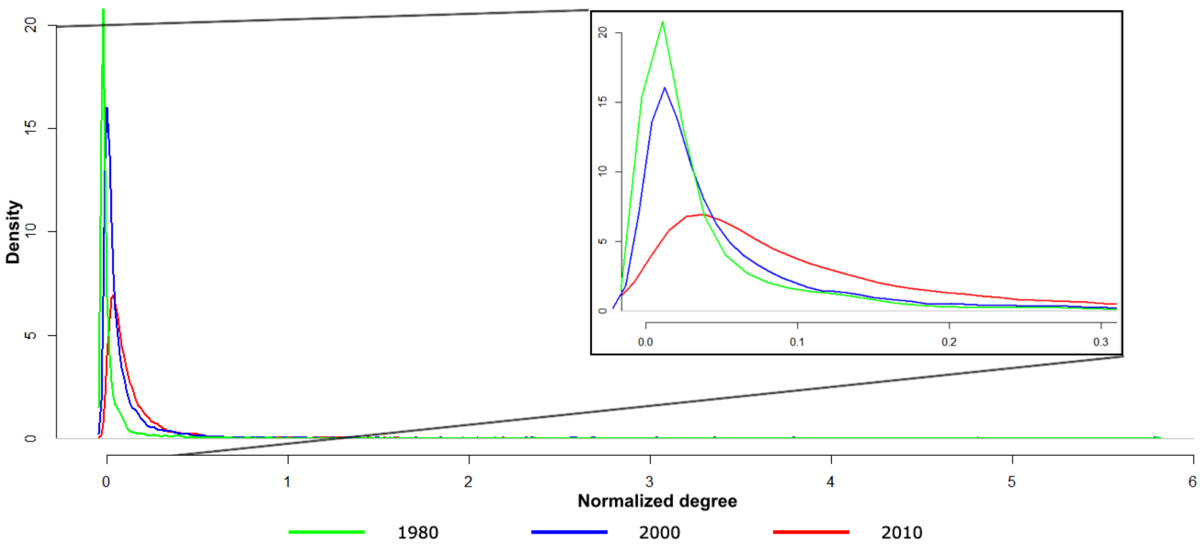

Figure 1 - Normalized degrees distribution for 1980, 2000 and 2010

It can be observed that the degrees distribution tends to shift to the right and become less concentrated over the periods, which reveals that not only the average connectivity has increased (as observed previously), but that its distribution as a whole presented increases.

One of the reasons for this increase in the connectivity is the expansion of the road network, especially of the paved highways. According to data from the National Department of Transport Infrastructure (DNIT [2016]) and information obtained by the Institute of Applied Economic Research (IPEA [2016a]), while between 1980 and 2010 the total extension of the Brazilian road network went from 1.36 to about 1.56 million kilometres, which means an increase of approximately 15%, the paved network went from just under 80 thousand to almost 196 thousand kilometres, an increase of 146%. This evolution can be visualized in Figure (2), where the average degree increment between 1980 and 2010 is also presented.

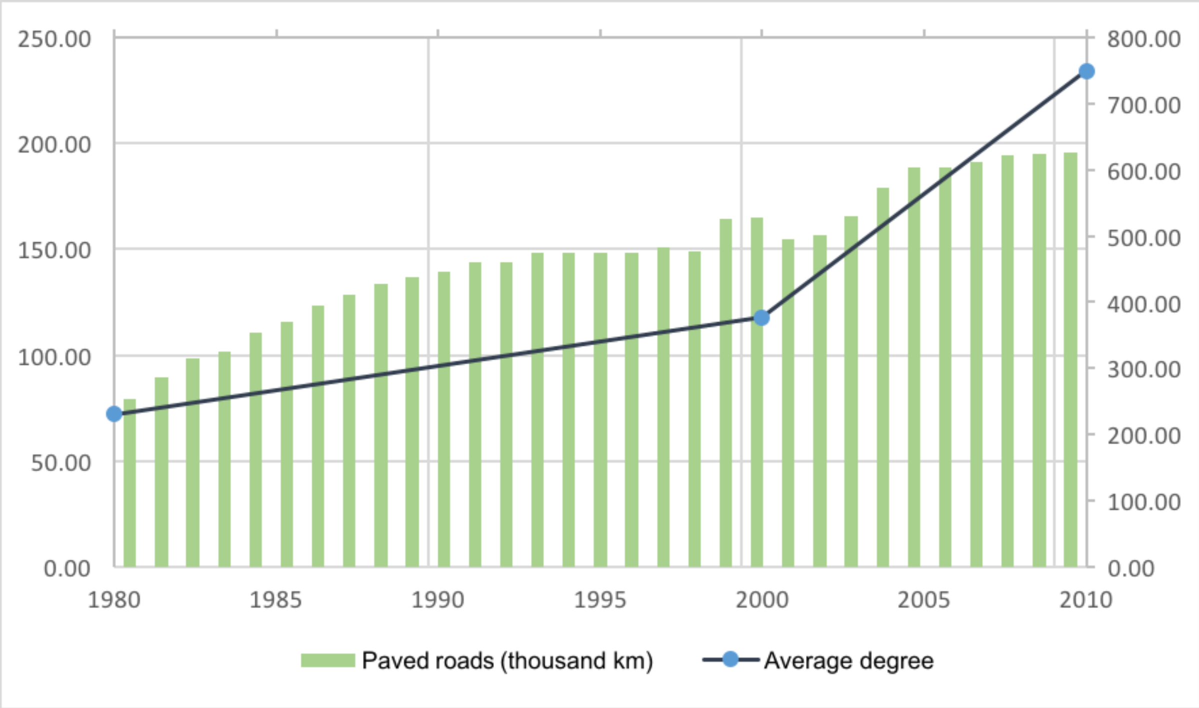

Figure 2 - Changes in the paved roads and in the average degree - 1980-2010
Average degree is measured on the right axis. Data for paved roads from DNIT [2016] and IPEA [2016a].

Between 1980 and 2000 the average degree (measured on the right axis) grows at a slower rate than the expansion of the paved network (i.e., the elasticity of the commuting movements in relation to the expansion of the paved roads was smaller than the unit), but in the decade between 2000 and 2010 there is an inflection, and the increase in the connectivity is faster than in the paved roads (the elasticity of the commuting in response to the expansion of the paved roads exceeded the unit), which suggests that other factors may have changed the response sensitivity of the commuting to the road expansion between the analysed periods.

Among some of these factors, we can list: a) the locations where the expansions occurred; B) the attraction power of the cities; C) general transportation costs; D) public policies. Regarding the first aspect, the connection capacity of a highway is directly related to the sites that are being interconnected by it and to the density of their urban network. In denser regions, with more populated municipalities close to each other, each additional kilometre of highway will have a greater connection potential than in less populated regions with greater distances between municipalities. So, for example, two highways of five hundred kilometres linking cities in the North (which have low population density) will be very different from five highways of two hundred kilometres connecting nodes from the Southeast (which are more densely populated) to nearby cities.

The attractive power of cities, in turn, is related to the agglomeration economies or diseconomies that are present in the urban environment. The concentration of people and economic activities brings positive externalities, which tend to attract more people and activities, reinforcing their effect. However, at the same time this concentration brings negative externalities, which diminish the attractiveness of a given location. The balance of these opposing forces will determine the attractive power of a given urban centre.

As for transportation costs, these can be associated with a number of other elements, such as fuel prices, road quality, availability of transport services and their level of competition, price of motor vehicles and the existence of tolls. It is important to emphasize that it is necessary to take into account the evolution of these costs in relation to living costs and their weight in the individual income, and not simply their level. That is, the cost of transportation will tend to have more negative impact on the displacement as much as it rises above the other prices and the higher its proportion in relation to the mean income.

Available data show that between 1980 and 1995, for example, transport costs from the municipalities to the nearest capital decreased by an average of 15.6%. Taking into account the period from 1968 to 1995, this reduction was 35.1% (there is no information for the 2000s)[2]. A reflection of such a reduction can be observed in the average distance of the displacements realized. While in 1980 the commuting movements had an average distance of 70.21 kilometres, in 2000 that distance increased by 16.4% to 81.71 kilometres (that increase is very similar to the observed reduction of transportation costs). However, it is between 2000 and 2010 that a more significant increase occurs, of the order of 44.7%, so that the average distance of the commuting movements in that year was 118.26 kilometres. This increase in distance indicates that the reduction in the relative transportation price persisted throughout the 2000s, either in its pecuniary aspect or in the temporal dimension, since faster means of transport and higher quality roads - shown by the expansion of the paved roads - allow to travel greater distances for each unit of time.

Finally, public policies can exert impacts through actions that affect the previous elements. An example can be found in investments in higher education, either by expanding access to public universities, or by granting scholarships or special funding for study in private institutions. According to data from the Higher Education Census provided by the National Institute of Educational Studies and Research (INEP [2016]), while in the 20 years between 1980 and 2000 enrolments in higher education expanded by 95.6% over the next ten years (2000-2010) they grew by 136.8%. Thus, from nearly 1.4 million enrolments in 1980, an amount of just under 6.4 million was reached in 2010, an expansion of about 363%. A considerable part of these enrolments were from students coming from cities close to those where the educational institutions are located, so that an expansion of higher education that is more intense than the increase in population[3] leads to an intensification of the flows.

3.2. Network clustering methods and the Functional Regions

After obtained the graph, it is possible to apply methods to group the nodes according to the intensity of their flows. The general idea is to form groups of municipalities whose flows between themselves (internal flows) are more intense than flows with municipalities of other groups (external flows). These clusters will be our Functional Regions (FR). One way to accomplish such clusterization is to maximize a modularity (Q) function, which expresses the strength of the clusters by comparing the proportion of flows between the nodes and the flows

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[2] Information obtained from data of the Nucleus of Studies and Systemic Space Models (NEMESIS), which applied a linear programming procedure to calculate the minimum transport cost between the municipalities and the nearest state capital. Available at: <http://ipeadata.gov.br>.

[3] For comparison purposes, according to data from the IBGE [2016], between 1980 and 2010 the Brazilian population grew by 57.45%. Between 1980 and 2000 this increase was of 40%, while between 2000 and 2010 it was 12.5%.

that would be expected from a random network. Different algorithms have been developed to maximize this function, and some of the most used were tested for the present case. Table 2 presents information on the application of the different network clustering methods.

Table 2 – Statistics for the network clustering methods, 1980-2010

	1980		2000		2010	
Method	Clusters	*Q*	Clusters	*Q*	Clusters	*Q*
Leading Eigenvector	279	0.89	249	0.90	171	0.90
Fast Greedy	208	0.80	170	0.76	108	0.74
Louvain	248	0.94	217	0.95	153	0.94
Walktrap	542	0.91	332	0.94	255	0.93

The methods that find the best partitions within the networks - that is, those that obtain the highest values for the modularity function (*Q*) - are the Louvain and Walktrap methods. However, even with similar modularity values, the number of clusters obtained by each of these methods is considerably different. In addition, a common pattern is observed between the three periods analysed: the number of clusters decreases as time progresses. One reason for this reduction is in the number of municipalities in the groups: over time, the proportion of isolated clusters, composed of only one or two municipalities, has been reduced, so that several of these municipalities have become part of larger groups, leading to an increase in the average number of municipalities in each cluster. By the Louvain method, while in 1980 each cluster had, on average, about 16 municipalities, in 2010 that number shifted to approximately 36. The histogram of Figure 3 presents another way of visualizing this distributional change over time.

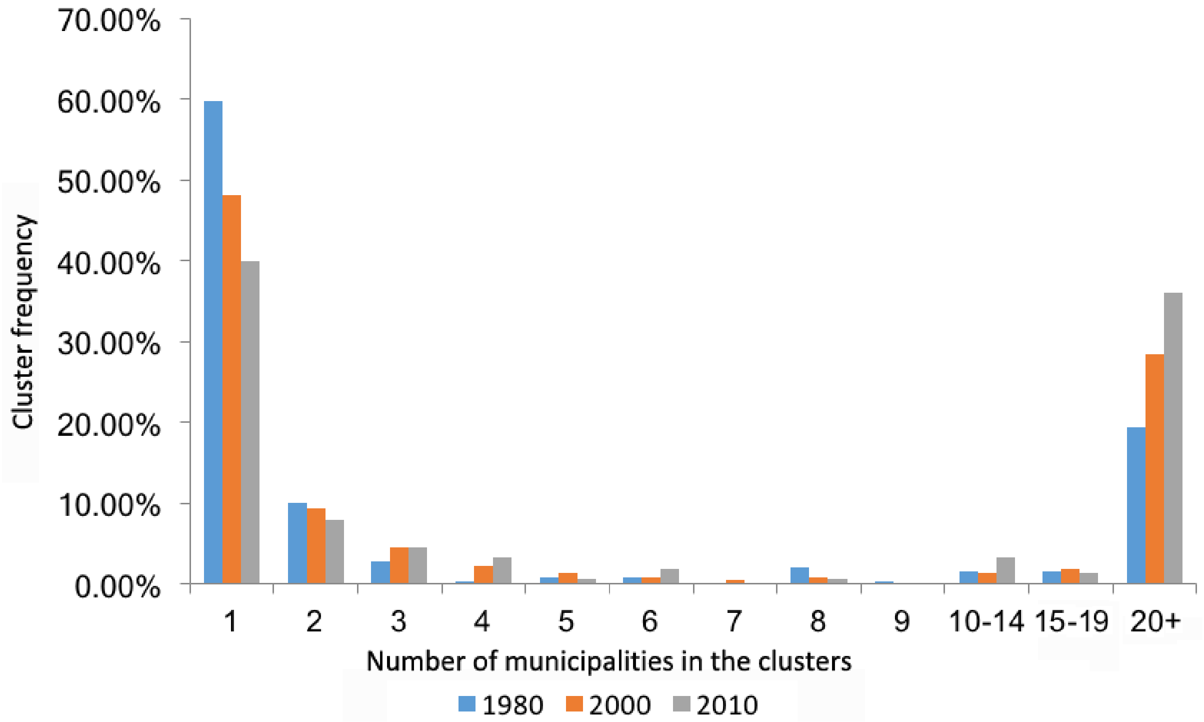

Figure 3 - Histogram of clusters size, 1980, 2000 and 2010

While in 1980 clusters with only one municipality accounted for more than half of the total, in 2010 this proportion declined to 40%. By contrast, groups with 20 or more municipalities increased in the period from almost 20% in 1980 to almost 36% in 2010.

Given the results obtained by the different algorithms, the Louvain method was chosen because it presented the highest values of modularity. Figures 4, 5 and 6 show the Functional Regions formed by such methods, taking into account only those that cover the 26 large PAs defined by the IBGE, whose boundaries (in black contours) are contrasted with the groupings now obtained (in colour).

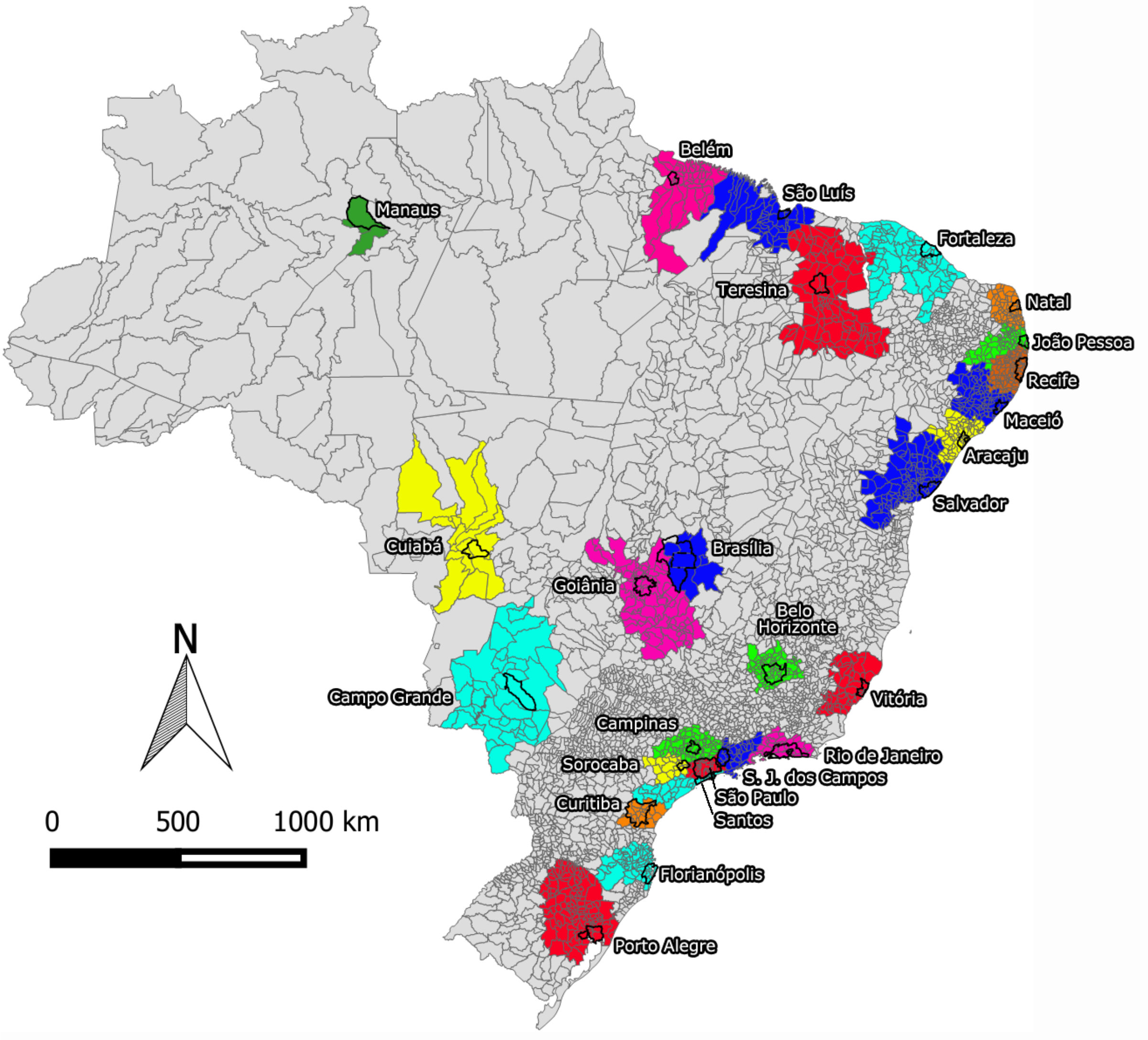

Figure 4 - Distribution of Functional Regions for large urban concentrations, contrasted with the Population Arrangements - 1980

Population Arrangements are shown in a black contour. The names for each Functional Region are the same for the Population Arrangements, and are taken from their main municipality

Firstly, it should be noted that the FRs formed have more municipalities than the PAs defined by the IBGE, which is due in large part to the fact that their methodology considers only the most intense flows, which induces the results to be more spatially restricted; whereas in the present approach all flows are considered, regardless of their size in relation to the population in the municipality of origin.

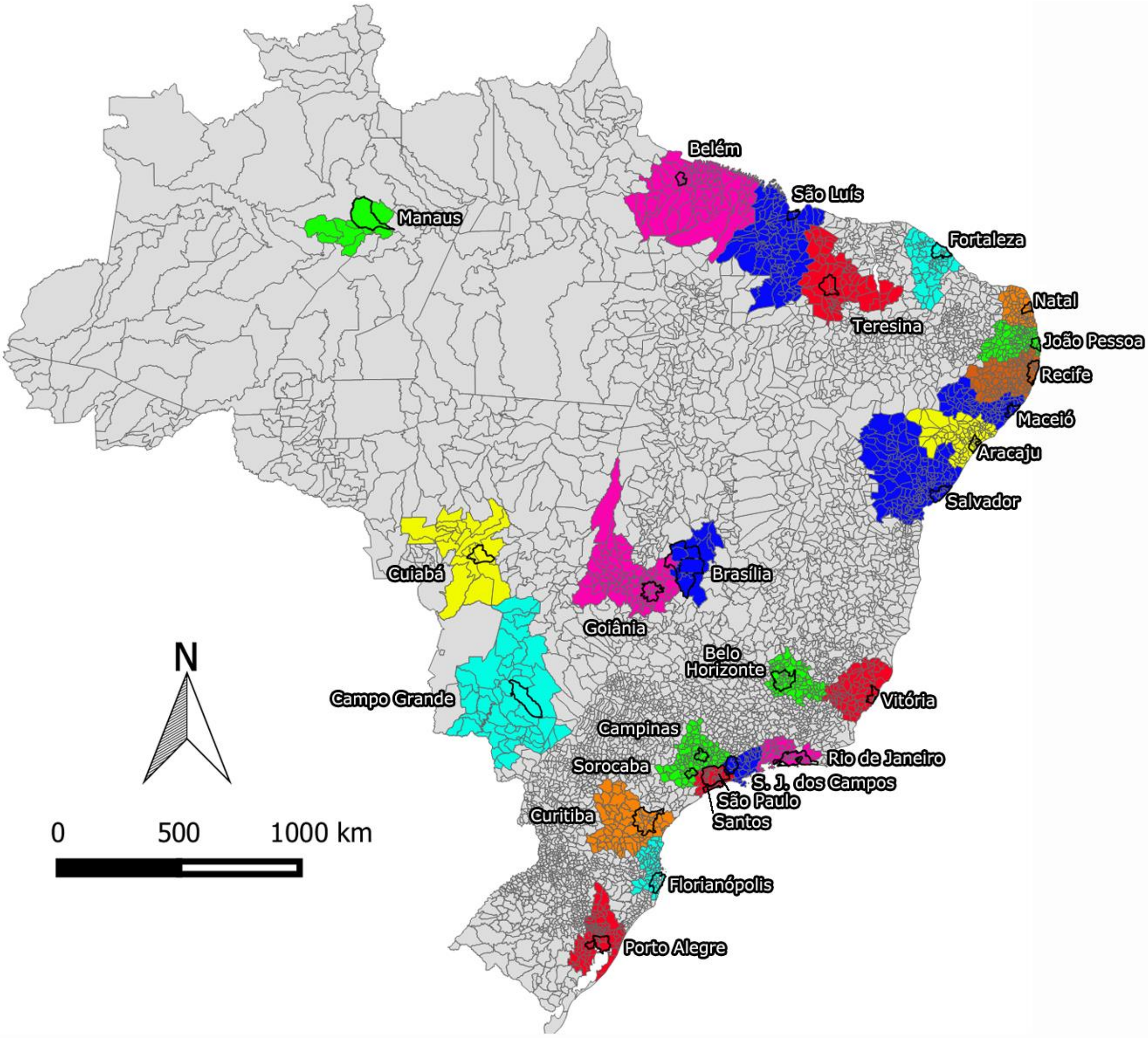

Figure 5 - Distribution of Functional Regions for large urban concentrations, contrasted with the Population Arrangements - 2000

Population Arrangements are shown in a black contour. The names for each Functional Region are the same for the Population Arrangements, and are taken from their main municipality

It can be observed that some FRs cover more than one PA in its limits. In 2000 this is the case of Sorocaba and Campinas, and also of São Paulo and Santos. In 2010, in addition to these, there is also the FR of João Pessoa and Natal. Thus, the 26 largest PA were contained in 26 FRs in 1980, 24 in 2000 and 23 in 2010.

Of the 60 FRs composed of only one municipality in 2010, 41 of them (or 68%) were in the North, especially in the state of Amazonas, where there were 25 municipalities in such situation, equivalent to 40% of the total municipalities in the state (62). The Midwest had 16 isolated municipalities, of which 15 were in the state of Mato Grosso and one in Mato Grosso do Sul. Most of these 60 municipalities are small, with a population average of around 18.7 thousand inhabitants. 62% of them are smaller than the average, and 32% have less than 10 thousand inhabitants. The location pattern of these FRs coincides with the occurrence of subsistence areas and agricultural or extractive enclaves, as described by Lemos et al. [2003].

Such enclaves constitute isolated urban centres, unable to integrate their environments and develop an export base to maintain intense trade flows.

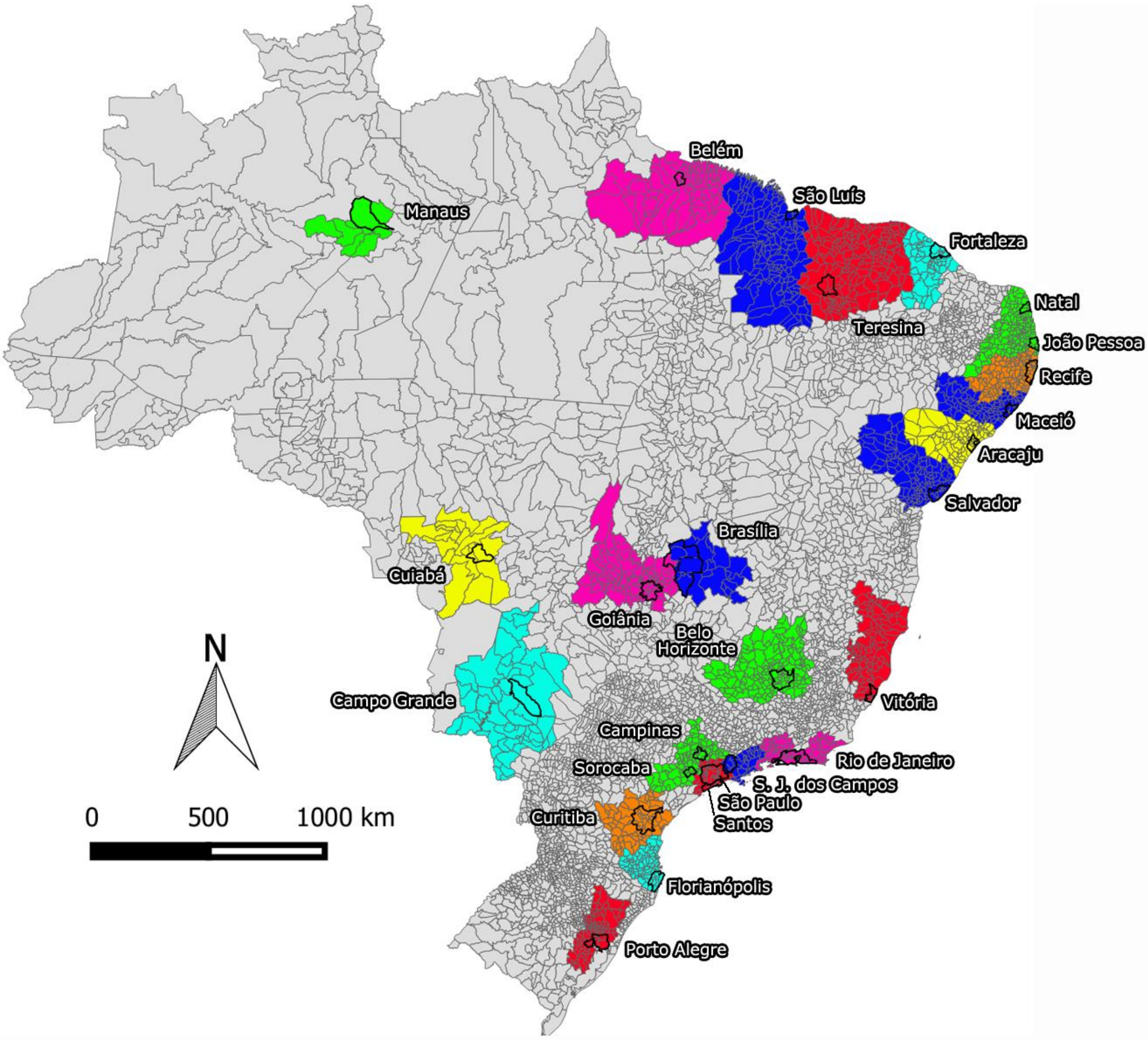

Figure 6 - Distribution of Functional Regions for large urban concentrations, contrasted with the Population Arrangements - 2010

Population Arrangements are shown in a black contour. The names for each Functional Region are the same for the Population Arrangements, and are taken from their main municipality

It is also possible to observe the constitution of "corridors" of FRs of the great urban concentrations, in the Northeast and South-Southeast. In such corridors, the surroundings (or areas of influence) of the centres have borders with each other, creating municipal contiguities where neighbouring labour markets articulate more to one or other centre, suggesting some degree of rivalry between their forces of attraction. It is also evident the distinction between the areas closest to the coast - where the largest and oldest metropoles are situated - and the innermost regions of the country, where the metropoles are smaller in size and number, so that they are not able to form the same corridors and integrate the hinterland of the country, which remains marked by empty spaces not connected to large urban concentrations.

Figure 7 aims to contrast the Functional Regions formed (in colour) with the Metropolitan Regions (with black contours) equivalent to the central cities of each grouping for the year 2010 (except for Campo Grande, Sorocaba and São José dos Campos, which do not had MRs in 2010[4]). It is possible to notice that the FRs also have a greater geographical amplitude than these MRs have, covering a greater amount of municipalities in their limits.

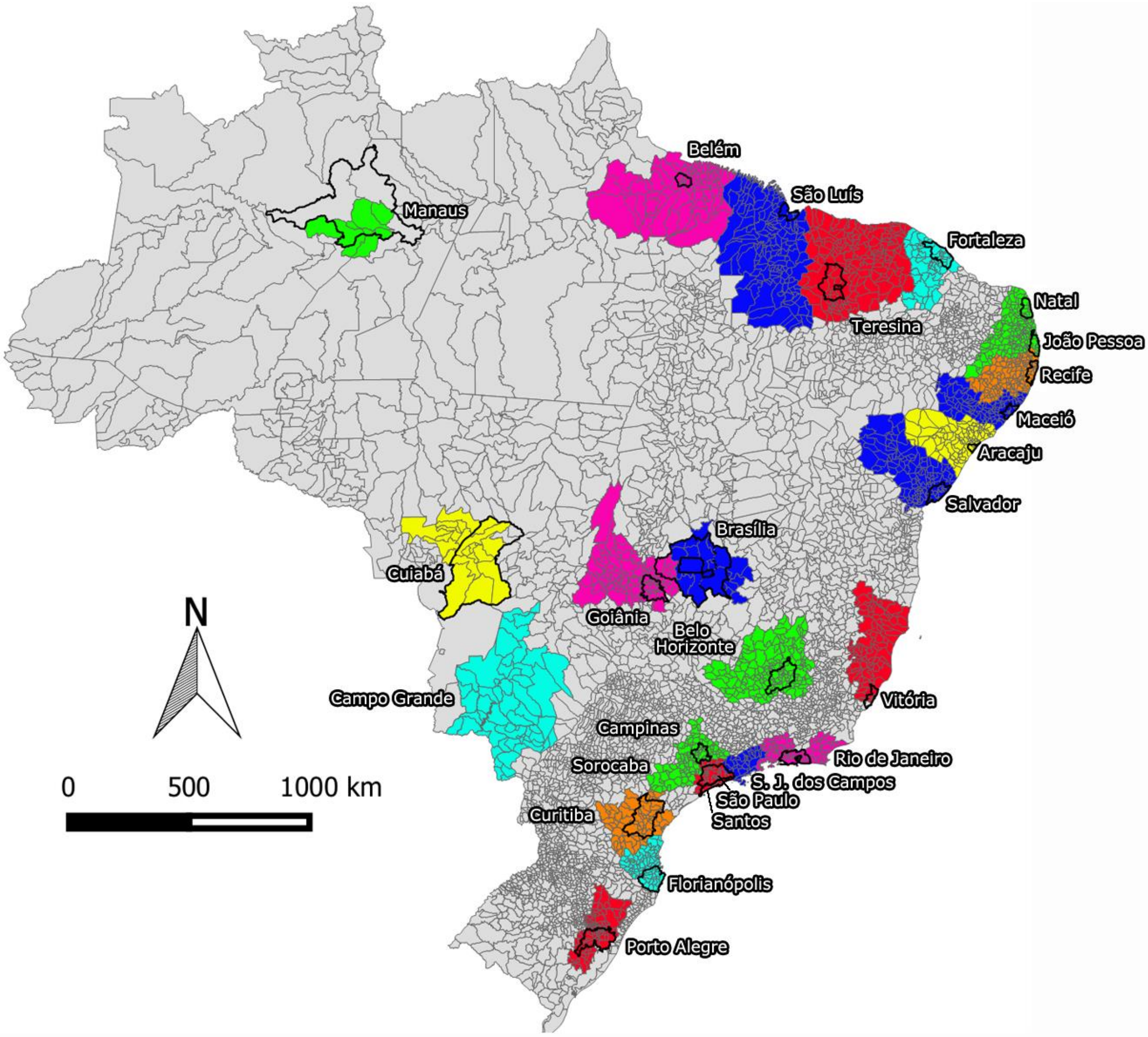

Figure 7 - Functional Regions for large urban concentrations, contrasted with equivalent metropolitan regions - 2010
Metropolitan Regions are shown in a black contour.

In the case of the MRs, there is no single criterion for their definitions, since it is up to the Federative Units to classify - according to their political criteria and objectives - what is characterized as such a region[5]. A consequence of this fact is that the boundaries of the MRs will necessarily be contained within the state boundaries. In any case, the definition of these regions aims to meet certain political and urban-regional planning demands, much more than reflect purely socioeconomic contexts, or to attend to specifical criteria related to the integration of labour markets, as is the case with the present approach.

[4] Sorocaba had established its MR in 2014 (State Complementary Law 1,241 / 2014), while São José dos Campos became part of the MR of the Paraíba Valley and North Coast, instituted in 2012 (State Complementary Law 1166/2012).

[5] Before the 1988 Constitution, the MRs were defined by Federal Law, in which case 9 Regions were established, still in the 1970s: Belém, Belo Horizonte, Curitiba, Fortaleza, Porto Alegre, Recife, Rio de Janeiro, Salvador and São Paulo. From 1988 onwards, the States of the Federation became responsible for creating or changing the MRs.

It should be emphasized that, although the 26 selected centres are the starting point and are in fact the core of their respective FRs, it is not implied that all the flows are directed to them, being polarized exclusively by the centre. Given the geographic dimensions of the FRs and the characteristics of the method, which prioritizes the internal cohesion of flows, each region is more likely to constitute a city system, following Christaller [1933] and Lösch [1954], where these cities are distributed and related according to a hierarchy.

As an example, one can analyse the FR that has Belo Horizonte (capital of the Minas Gerais state) as its core. In 2010 it covered municipalities such as Divinópolis, located more than 100 kilometres away. This city, with a population of more than 200 thousand inhabitants, has its own force of attraction on the nearby municipalities, like Nova Serrana, Carmo do Cajuru or São Sebastião do Oeste. In fact, these three municipalities present commuting flows to Divinópolis much more intense than towards Belo Horizonte, while Divinópolis, in turn, maintains considerable flows destined for the state capital. In simple terms, these relations fit into a hierarchy that has Belo Horizonte as a central place, followed by Divinópolis as the second centre, subordinating the other three municipalities. Otherwise, it could be said that Nova Serrana maintains a first-degree relationship with Divinópolis, and a second-degree relationship with Belo Horizonte.

The MRs, on the other hand, emphasize direct (or first degree) relations with the central place. Drawing again to the case of Belo Horizonte for comparative purposes, of the other 33 municipalities of its MR, 26 have the capital as the major destination of their commuting flows. The main destinations of the other seven municipalities are varied, so it is not possible to even rank a second centre within the region. In other words, the MR give much more emphasis to the immediate field of influence of their main centres, not covering possible broader structures of the regional labour market, their interrelationships and possible changes over time, nor the possible field of indirect influences of the core.

In order to compare the results between the FRs now formed with the PAs and with the MRs contained in each one, Table 3 presents information on population and number of municipalities for each of these delimitations in 2010.

Table 3 – Municipalities and population of the Functional Regions, and their respective Population Arrangements and Metropolitan Regions - 2010

	Municipalities	% Brazil	Population (millions)	% Brazil
FRs (26)	2153	38.69	126,392	66.26
PAs (26)	256	4.60	77,809	40.79
PAs (23)[1]	244	4.38	75,293	39.47
MRs (23)	371	6.67	77,025	40.38

1: *Without the PAs of Sorocaba, São José dos Campos and Campo Grande, which did not have MRs in 2010.*

The FRs, by their construction criteria, cover a larger number of municipalities than the other delimitations and, consequently, account for a greater part of the Brazilian population. It is noteworthy that, although the increase in proportion of Brazilian municipalities is considerable (increasing 4.6 and 8.4 times in relation to MRs and PAs, respectively), the same does not occur in relation to the population (which rises 54% compared to MRs and 62% in relation to the PAs), which is natural, since the additional municipalities of the FRs tend to be progressively smaller. Another consequence of this broader coverage of the FRs is that they have greater demographic and economic heterogeneity, which requires future analyses to characterize them under such aspects.

Notwithstanding this less than proportional variation of the population in relation to the number of municipalities in the FRs, when comparing the 23 MRs with the 23 equivalent PAs, it is noted that for each 1% increase in population in relation to the arrangements, the MRs increase the number of municipalities by 22.6%. Carrying out the same exercise for our FRs, compared to the respective PAs, we reach a municipalities-population elasticity of 11.9%. In other words, this means that the additional cities of the FRs tend to be larger in population terms than the additional cities of the MRs, and therefore, from this point of view, the MRs prove to be a less efficient configuration than the FRs.

In order to verify the intensity of flows in each of these FRs, as well as their respective positions and changes over time, Table 4 presents their average degrees, ordered according to their ranking in 2010.

Table 4 – Average degrees and rankings for the Functional Regions of the large urban concentrations

Main city of the FR	1980		2000		2010	
	Degree	Rank	*Degree*	Rank	*Degree*	Rank
São Paulo (SP)[1]	2045.29	1	1610.44	1	2471.72	1
Santos (SP)[1]	398.92	9	1610.44	1	2471.72	1
Porto Alegre (RS)	440.80	8	1030.92	4	1629.99	2
Rio de Janeiro (RJ)	1043.80	2	1083.10	2	1459.24	3
Florianópolis (SC)	633.33	4	1065.08	3	1412.36	4
S. J. dos Campos (SP)	514.66	7	880.15	5	1310.80	5
Campinas (SP)[2]	576.73	6	724.76	8	1255.98	6
Sorocaba (SP)[2]	326.45	11	724.76	8	1255.98	6
Curitiba (PR)	720.83	3	622.19	9	1129.68	7
Belo Horizonte (MG)	608.41	5	848.56	6	970.86	8
Recife (PE)	323.06	12	439.18	11	891.65	9
Natal (RN)[3]	243.34	13	467.21	10	868.55	10
João Pessoa (PB)[3]	214.68	14	413.69	12	868.55	10
Goiânia (GO)	139.59	18	357.94	14	780.07	11
Aracaju (SE)	208.92	15	371.91	13	736.42	12
Maceió (AL)	112.49	20	281.05	18	665.10	13
Brasília (DF)	111.13	21	768.24	7	640.44	14
Salvador (BA)	179.59	16	240.43	19	597.97	15
Fortaleza (CE)	105.72	22	314.27	16	550.76	16
Cuiabá (MT)	155.29	17	292.81	17	510.23	17
Vitória (ES)	380.64	10	325.96	15	475.79	18
Campo Grande (MS)	83.38	25	134.25	22	393.09	19
Teresina (PI)	84.54	23	197.17	20	330.93	20
Belém (PA)	113.46	19	141.84	21	283.08	21
São Luís (MA)	83.79	24	124.16	23	225.81	22
Manaus (AM)	2.00	26	29.25	24	89.25	23

1: São Paulo e Santos belong to the same FR in 2000 and 2010
2: Campinas e Sorocaba belong to the same FR in 2000 and 2010
3: Natal e João Pessoa belong to the same FR in 2000 and 2010

The FRs with higher mean degrees tend to be associated with more central and populous urban concentrations. This result may be a direct reflection of the agglomerative economies of these centres and of the other cities close to them. The size of a city is a reflection of its power of attraction, but in addition to the population living within the political boundaries of the municipality, it is necessary to take into account the population that moves to it in order to work and/or study.

In this sense, the FR of São Paulo (which is the country's largest urban concentration), after face a reduction of its average degree between 1980 and 2000, recovered attraction power in the last decade and remained at the top of the average degree ranking throughout the period. Part of the reduction of its degree in the first period can be explained by the addition of the Santos FR, which, as observed from their average degree in 1980 (only the ninth highest), contributed to reduce the total average of the new region.

Compared to Rio de Janeiro, São Paulo had an average degree 96% higher in 1980, a difference that fell to 49% in 2000, but then increased again to 69% in 2010. In general, despite the maintenance of the position of São Paulo and Rio de Janeiro as main cities in this sense, there is a reduction in the degree concentration among the 26 FRs - which may be a reflection of a process of relative deconcentration of the attractive power of the main centres.

The reduction in concentration of degrees accompanies a reduction in population concentration in the period. In 1980, São Paulo and Rio de Janeiro accounted for 11.43% of the national population, a share that fell to 9.6% in 2000 and 9.21% in 2010. Similarly, the economic concentration of these centres decreased: according to data from IPEA [2016b], both cities jointly owned 25.21% of the country's Gross Domestic Product in 1980, this proportion decreasing to 20.09% in 2000 and 16.81% in 2010.

However, it is not only the population and economic dimensions that can influence the flows dynamics. The case of the Manaus FR is quite illustrative in this sense, since it is the one with the lowest proportion of flows in all periods, considerably below the others, although it is not the smaller FR in terms of population size. This fact is mainly due to its geographical characteristics: the municipalities of the Amazon region tend to be more isolated geographically, given the transportation conditions, often done exclusively by rivers. Such conditions prevent a greater frequency of inter-municipal movements and consequently a greater connectivity of their labour markets.

Nevertheless, despite the deconcentration verified, it should be emphasized that the hierarchical structure of the great urban concentrations does not undergo substantial alterations regarding the commuting, as it is verified by the relative maintenance of the rankings between the periods. Not counting the changes occurred by the inclusion of more than one large urban concentration in the same FR (as are the cases of Campinas and Sorocaba, São Paulo and Santos, and Natal and João Pessoa), we can see that of the ten FRs with the highest average degrees in 1980, only Vitória left the same list in 2010, seeing its position drop from 10th to 18th, which was the greatest loss of attractive power between these periods.

Considering these results for the average degrees dynamics, it is possible to characterize the commuting movements in two phases: the first, between 1980 and 2000, is marked by the deconcentration of the commuting flows between these FRs, suggesting that smaller regions had greater gains in attractive power in that period (but without changing the hierarchical position of these centres); and the second, between 2000 and 2010, is marked by a more homogeneous increase of average degrees in practically all FRs, reinforcing the maintenance of the hierarchical structure and suggesting that the attractiveness gains were less unbalanced than in the first period.

These results are also aligned with the restricted deconcentration described by Azzoni [1986], which emphasizes the movements within the agglomerative field of São Paulo; and Diniz [1993], which describes the deconcentration inside the boundaries of the polygon located between the central region of Minas Gerais and the northeast of Rio Grande do Sul. This limited deconcentration is later corroborated by studies such as that of Diniz and Crocco [1996], which note a larger industrial deconcentration towards the interior of the São Paulo state, the south region and the centre of Minas Gerais. For the authors, technological and organizational changes tend to give more emphasis to this phenomenon, so that the more technologically modern activities would be closer to the already more industrialized areas of the country, something that is confirmed by Domingues and Ruiz [2006], which verified the greater concentration of innovative firms and patents in the polygon described by Diniz, as well as the greater combination between technological and industrial agglomerations in this area.

Lemos et al. [2003] also illustrates such facts when characterizing the country's economic regions, as they note the concentration of industrial poles between Belo Horizonte and Porto Alegre. Still, Silva and Silveira Neto [2009] verified that, between 1994 and 2004, there was a lower deconcentration of the capital-intensive sectors in relation to the ones that are intensive in natural resources. Since the capital-intensive sectors are more concentrated in the polygon defined by Diniz [1993], this implies precisely a limited and quite selective deconcentration of sectors such as manufacturing, which is still the one most associated with commuting in Brazil.

As the average degree level can be considered as an indicator of how integrated a given regional labour market is, the FRs with more intense flows have a greater proportion of their workforce moving within their limits, increasing the connectivity and the relations between the municipalities.

This integration and its dynamics can be qualified in at least two ways. The first relates to the concentration of flows, whose increases can occur both through a greater dependence of peripheral cities on the centre (i.e. a relative intensification of the flows destined for the centre), and by an increase in the interdependence between different peripheral cities (i.e. a relative increase in flows to other surrounding cities). The first case can be called concentrated or unipolarized integration; while the second may be called deconcentrated or multipolarized integration.

Another possible classification with regard to integration can be in terms of the origin and destination flows. When integration is increased mainly by unidirectional movements - that is, municipalities that expel and those that attract commuters intensify these respective roles - it can be said that a subordinate or vertical integration takes place, reinforcing the hierarchy between these cities. On the other hand, if there is an increase in integration by bidirectional movements - that is, when municipalities observe both an increase in outgoing and inbound movements - then is the case of a horizontal integration.

A preponderant factor on these aspects concerns the productive structure of each FR and their distribution in space. As economic activities are more concentrated in a few municipalities, they will provide vertical and unipolar integrations, while horizontal and multipolarized integrations will be more associated with a less concentrated distribution of activities. This distinction can also be derived from the location of the sectors most associated with commuting, as is the case in manufacturing.

In terms of the population and economic concentration of the FRs, Table 5 shows their national participation in these aspects for the given periods. Between 1980 and 2010 there was a population gain for the FRs and a slight reduction in their economic share. While they gained 6.6 percentage points in national participation between 1980 and 2010, their GDP share declined by 0.6 percentage points over the same period.

Evaluating separately the central cities and their surroundings, it can be noticed that the population gain comes almost exclusively from the surroundings, whereas the reduction of the GDP participation is associated with the loss of importance of the cores - in contrast to the surroundings, that increased their share of the national GDP in the period.

The population share of the centres remains stable in the periods, representing almost a quarter of all the inhabitants of the country. In the surroundings, however, the population share increases by almost 7 percentage points, implying an almost equal amount loss for regions outside these FRs. In terms of GDP share, of the 6.82 percentage points lost by the centres, 6.23 points (or 91.3%) were gained by the surroundings, while only 0.59 points (or 8.7%) were gained by the remaining of the country.

Table 5 – Population and economic share of the Functional Regions

Functional Regions			
	1980	2000	2010
Share on national population (%)	59.64	63.18	66.26
Share on national GDP (%)	74.55	73.95	73.96
Cores			
	1980	2000	2010
Share on national population (%)	24.59	24.57	24.38
Share on national GDP (%)	42.95	39.63	36.12
Surroundings			
	1980	2000	2010
Share on national population (%)	35.05	38.61	41.88
Share on national GDP (%)	31.61	34.32	37.84
Remaining of the country			
	1980	2000	2010
Share on national population (%)	40.36	36.82	33.74
Share on national GDP (%)	25.45	26.05	26.04

Considering only the FRs it can be observed that the centre’s share in the GDP of these regions decreased from 57.61% to 48.84% between 1980 and 2010 - that is, the surrounding areas began to account for a fraction of the product slightly higher than the central cities, which is also noticeable by the growth rates of the product: while in the cores the GDP increased 1.84 times over that time, in the surroundings the increase was of 2.62 times. In terms of population, the centre’s share dropped from 41.24% to 36.80%, due to lower growth compared to the surroundings: while the population in these grew by 1.88 times in the period, in the centres it increased by 1.56 times.

These findings indicate a process of productive deconcentration from the centres, which extends to the surroundings and to the other regions, whereas there is a population concentration in the surroundings, whose counterpart is a relative reduction of the more interior populations. The reflex of these movements is a reduction of the per capita GDP of the cores in relation to the national average: while in 1980 their per capita GDP ratio in relation to the country was 1.75, in 2010 such value decreased to 1.48. Meanwhile, the surroundings maintained this ratio at 0.90 over the same period. In contrast, regions outside the FRs saw such a ratio rise from 0.63 to 0.77 over the same period, denoting a convergence of GDP per capita between such geographical dimensions.

The productive spread out of the surroundings, however, is not intense enough to suggest a significant internalization of the economic activities, since the participation of these areas in the national GDP only had a little increase during the thirty years considered. The information presented reinforces the notion of restricted deconcentration, since this tends to be directed more strongly to the surroundings of the large centres, which suggests that the location of activities is still strongly influenced by the distance of such centres. As they exhibit agglomeration diseconomies, activities may find greater locational advantages in nearby municipalities, avoiding such diseconomies but still being able to take advantage of the agglomerative benefits of the centre to some extent.

Changes in population and productive participation may also indicate changes in the use of productive factors in each of these regions. Outside the FRs, the growth of the product pari passu the reduction of population participation suggests that they had a growth mainly in less labour-intensive activities, and/or that they had introduced labour-saving technologies, such as machinery in the agricultural activities, which tend to be more localized in such regions.

Such changes may have aided in the process of population displacement headed for the surroundings, where population growth was more substantial than the productive growth, indicating that this process was more labour-intensive. Such growth has probably occurred in the more traditional sectors of manufacturing, commerce and services, where the technological level is not high.

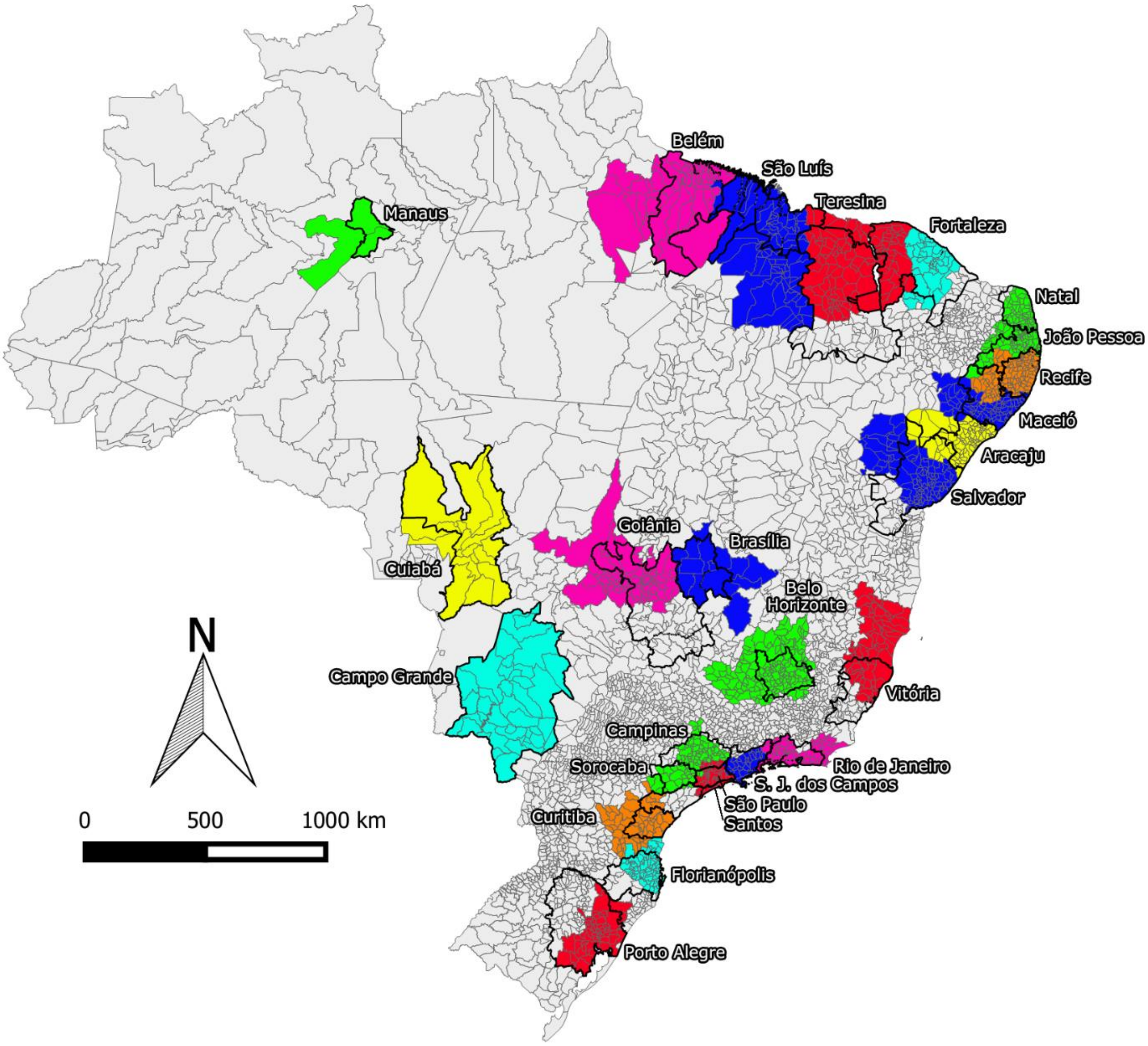

Figure 8 - Changes in Functional Regions for large urban concentrations between 1980 and 2010

The Functional Regions for 1980 are shown in a black contour, and the ones for 2010 are in color.

In the cores, in turn, the maintenance of population participation allied with a reduction in productive participation may also indicate a more labour intensive growth, but in this case it is more likely to be of those with higher qualification. In other words, it would be a more intensive growth in human capital, which occurs mainly in activities that are more complex and of a higher technological content, such as financial sectors, information technology, and those that involve research and development activities.

One way to visualize the changes of the FRs in time is to overlap them on the same map. However, it is also necessary to take into account the creation of new municipalities over time. In this way, Figure 8 compares the results between the periods of 1980 and 2010, adapted to the Minimum Comparable Areas (MCAs). To maintain the contiguity of the FRs, a final calibration was applied, which involved the reallocation of four municipalities in 2010[6].

It is possible to notice some interiorization of the FRs of Aracaju, Belém, Belo Horizonte, Brasília, Curitiba, Recife and São Luís. This process is more marginal in the Manaus and Cuiabá FRs. In the cases of Goiânia and Salvador, a change takes place in the interiorization direction, from the south to the northwest, while in the Maceió FR the change is from the north to the west, and in Teresina and Vitória such movement occurs from the south to the north. Other centres present these changes more moderately, as occurs in Campinas/Sorocaba, Florianópolis, Natal/João Pessoa, Rio de Janeiro and São Paulo/Santos. Campo Grande, in turn, did not change. Finally, there are those regions that had their areas almost exclusively contracted, as is the case of Fortaleza, Porto Alegre and São José dos Campos.

Considering the number of municipalities in each FR, between 1980 and 2010 there was a growth in 19 regions, with the highest rates (discounting the FRs that incorporated others, as mentioned above) observed in the FRs of Curitiba (137.5%), São Luís (114.29%), Belo Horizonte (111.84%) and Brasilia (87.5%). On the other hand, 6 regions declined over the three decades, with the main cases being Porto Alegre (-56.59%), Fortaleza (-52.33%), Goiânia (-23.71%) and São José dos Campos (-19.51%). Campo Grande remained with the same number of municipalities.

4. Final Remarks

With the recent resumption of interest in concepts that seek to expand the spatial delimitation of socioeconomic phenomena - among which is the idea of city-region -, the methodological attempts to establish the geographical amplitude of these phenomena have also gained strength. It is within this scope that the present work is inserted, seeking to define Functional Regions in terms of the dynamics of commuting movements for work and study.

The regions thus obtained differ substantially from the current regions in Brazil, both those existing in the literature and the ones politically defined. When considering only the FRs that comprise the 26 largest Population Arrangements, we can notice that the regions formed have a greater geographical extension than such arrangements. As a reflection of the method used, this makes it possible to attest that the municipalities that make up such clusters have a more intense relation of commuting flows one with another than with municipalities of other clusters.

It is also possible to notice changes in the spatial morphology of the FRs over the period of 1980 to 2010, which reveals their non-static nature and reflects possible changes in both economic factors internal to the them - fundamentally, the intensity of the (dis)agglomeration economies - as well as broader political choices, such as the evolution of the road network connecting the municipalities and the expansion of the higher education, factors leading to increases in commuting flows.

[6] Paranaíba (MS), Passo Fundo (RS), Pelotas (RS) and Trindade (GO).

This change over time can also be visualized by the results that points both to an intensification in the level of commuting (weighted by the population) and a greater connectivity of the network of Brazilian municipalities over these three decades.

The possible choice for the proposed regionalization in future investigations and even in possible regional policies has advantages and disadvantages. Among the advantages is the possibility of having a greater scope for dynamic phenomena in space in relation to Metropolitan Regions or Population Arrangements, especially in relation to phenomena related to labour markets. Thus, the Functional Regions also allow understanding possible diffusion of policies focused in specific localities of those regions. Also, because they are not static, the FRs allow to observe changes in their morphologies time, providing updated spatial delimitations as a function of the changes in the commuting flows and the factors that influence them, which provides an alternative to static definitions, such as the MRs or other political delimitations, such as the micro and mesoregions. For these reasons, FRs can be particularly advantageous for analysing changes in regional productive structures.

As for the disadvantages, it can be mentioned first that this analysis depends fundamentally on the availability of ample information on commuting flows, which occurs, at best, once every ten years with the Censuses. Second, there is a greater spatial heterogeneity that results from widening the scope, which can lead to increasing analytical difficulties. Third, there is the limitation of being based on the dynamics of flows to work and study, not covering other types of flows between municipalities (e.g. of goods). Moreover, non-static regions impose an additional difficulty for the elaboration and adoption of joint policies among the municipalities that compose them.

In view of the results found, and considering the pros and cons resulting from the choice of the present regionalization, there is an open road to new investigations that seek to bring light to the more specific reasons that may lie behind the current configuration of the Functional Regions and their changes in time. Among these reasons are the sectorial and urban dynamics, the spatial division of labour, and changes in centrifugal and centripetal economic forces. These factors will be considered in our future researches.

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