**IDENTIFYING KEY COUNTRIES IN GLOBAL PRODUCTION NETWORKS THROUGH INTERCENTRALITY MEASURES**

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**Abstract**

In this paper we used a set of measures of "centrality groups" to identify groups of countries which are the key actors of global production networks. These measures take into account the global and regional nature of international production processes and are derived from Social Networks Analysis (SNA). The information framework for these purposes are the input-output matrices of the countries considered in the WIOD.

Traditional measures in the SNA to find the key actors (in our case, countries) start to see an actor within the network as a single entity and through its relation to all the other countries in the network. Recently there have been measures named “centrality of groups" and it has been shown that a measure of centrality that makes a particular player qualify is not equal to the measure obtained, for the same player, derived from a group to whom the player belongs in the same network. Identifying actors that are the most important individuals in a network is different from selecting a set of actors that are, as a group, the key players. Thus, the role of an actor individually can be very different from its role in a subset of actors of the entire network. In our case, this measure (called intercentrality) tries to identify the contribution of a group of countries in the cohesion of the global production network, so their cohesion implies strategic complementarities among countries.

Moreover, within the context of the World-System approach, countries may be sorted hierarchically or classified according to a series of characteristics (economic, social, political and cultural) into three regions: *core*, *semi-periphery* and *periphery*. However, there is still the problem of clearly defining inclusion in any of those regions of countries when considered individually, through economic indicators such as output, income or trade.

In this exercise, we investigated the relevance of using an extended centrality index that includes groups of countries to define their inclusion on each of the regions proposed by the World-Economy approach, taking into account the global production network (40 countries), both in terms of gross value and value added.

Keywords: input-output, key player, centrality, intercentrality, core-semi-periphery-periphery.

**Introduction**

The identification of key players in social networks, known in literature as Key Players Problem (KPP) (Borgatti; 2003, 2006), is a problem that has been addressed from different perspectives, from traditional centrality measures (degree, proximity, intermediation), to group tier centrality measures (core-periphery models).

The 40 countries comprising the Word Input-Output Data Base constitute a complex network and the relative importance of each country and sector varies, whether we consider the different measures of centrality (individual and group), or the structure of world production in gross value or value added.

Phillip Bonacich (1987) held that traditional centrality measures could be improved by considering the importance of the players with which a node is related, i.e., the resulting importance and power also depend on the importance of the other nodes with which it is linked.

In applying this fundamental idea to our exercise, it turns out that both a country’s power and centrality simultaneously depend on the power of each of the other countries it is related with. The Bonacich measure counts the links arising in each individual country (not only the shortest links), weighed by a factor of importance that decreases exponentially as the links with other countries become weaker or more indirect.

A few years later, based on the game theory applied to networks, Ballester et al. (2006) analyzed the interdependency of players’ benefits from the structure of the network of links that relates them, in such a way that the strategy to balance their benefits reflects the interlinking of players in the network. In our case, the equilibrium strategy would show the strategic complementarities of countries. These authors found that when the magnitude of externalities (both global and local) is properly scaled, a unique Nash equilibrium is reached that is proportional to the Bonacich network-centrality measure. In other words, behavior towards an equilibrium strategy among players (according to the game theory), is related to the network topology that the Bonacich index reflects.

Based on the aforementioned, they propose a new network centrality measure called intercentrality to identify the groups of key players. Hence, actors with the highest intercentrality index will become the key players (those having the greatest impact on activity if removed from the network). This measure is not based on the player’s individual strategies, but on a group strategy.

And this is because individual centrality measures are different from group centrality measures. It is not the same to identify the most individually important k actors within a network as to make an optimal selection of a set of k actors which together become the key actors. It is on the basis of this idea that Temurshoev (2008) extends the measure of intercentrality to achieve a group intercentrality, meaning that a group of k players is different (in terms of centrality or importance) from the k players possessing the highest individual intercentrality. For this author, the goal is finding the group of key players in a network, while our exercise tries to identify the group of key countries in the global production network as well as in the value added of such network.

In other words, the purpose is to know, on the one hand, which is the contribution of a group of countries to the cohesion of a global production network and, on the other, which is the group of countries that contributes the highest value added, understanding that cohesion and valued added generation reveal strategic complementarities among countries.

Besides, this exercise is an empirical test for classifying countries from a perspective of the World System approach, according to which the global economy is integrated by economic (and also political, social and cultural) operation rules and spatial relations represented by three regions: core-semi-periphery-periphery. “The regions constitute a partition of all countries in the world system and is not necessarily contiguous. Actual determination of regional inclusion is based on the dominant production processes and commodity chains that link the sources of raw materials to the site of terminal production and distribution”.[[1]](#footnote-1)

Hence, the specific objectives for this exercise are three: a) to show the resulting differences when centrality measures are applied to the identification of both key countries and groups of key countries in global production; b) point out the importance of distinguishing in the map the global production networks and the structure of countries generating the highest value added, and c) establish a core-semi-periphery-periphery map based on the World System theory. To do so, we will use both the Bonacich centrality index (1987) as well as the intercentrality indicators proposed by Temurshoev (2008) from the work of Ballester et al. (2006).

The first section describes the methodology used; the second section compares the individual centrality indexes of Bonacich and Ballester et al., and the third and final section, shows the empirical findings and proposes a regionalization of countries on the basis of the Temurshoev index, following a core-semi-periphery-periphery scheme of the World System theory. We finally conclude the exercise with some final considerations.

**Methodology**

In an early stage, the methodology consists of using an Inter Country Input Output Model (ICIO) model, to determine the global production matrices, both in gross value and value added.

*Calculation of production and global bilateral value added matrices*

In the World Input-Output Matrices of the WIOD[[2]](#footnote-2), inter-industrial exchanges are represented standardized to 35 industries for the 40 main world economies and the rest of the world. The tabular representation is presented below:

Table 1. World Input-Output Matrix (IOM)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Country 1** | **Country 2** | **...** | **Country 40** | **Rest of the world** | **Final demand** | **PGV** |
| **Country 1** | $Z\_{1,1}$ | $$E\_{1,2}$$ | **...** | $$E\_{1,40}$$ | $$E\_{1,41}$$ | $FD\_{1}$ | $PGV\_{1}$ |
| **Country 2** | $$E\_{1,1}$$ | $$Z\_{1,2}$$ | **...** | $$E\_{1,40}$$ | $$E\_{1,41}$$ | $$FD\_{2}$$ | $$PGV\_{2}$$ |
| **...** | **...** | **...** | $$Z$$ | **...** | **...** | $$FD$$ | $$PGV$$ |
| **Country 40** | $$E\_{1,1}$$ | $$E\_{1,2}$$ | **...** | $$Z\_{1,40}$$ | $$E\_{1,41}$$ | $$FD\_{40}$$ | $$PGV\_{40}$$ |
| **Rest of the world** | $$E\_{1,1}$$ | $$E\_{1,2}$$ | **...** | $$E\_{1,40}$$ | $$Z\_{1,41}$$ | $$FD\_{41}$$ | $$PGV\_{41}$$ |
| **Value added** | $VA\_{1}$ | $$VA\_{2}$$ | $$VA$$ | $$VA\_{40}$$ | $$VA\_{41}$$ | **0** | **0** |
| **PGV** | $PGV\_{1}$ | $$PGV\_{2}$$ | $$PGV$$ | $$PGV\_{40}$$ | $$PGV\_{41}$$ | **0** | **0** |

Source: Prepared by the authors

As can be seen in the previous table, the world IOM is a matrix of matrices where the elements of the $Z\_{i,i} (i=1,…41)$ main diagonal represent the domestic inter-industrial exchanges among the 35 economic sectors of a $i-th $country, while the $E\_{i,j} \left( i\ne j\right) $matrices, located outside the main diagonal, represent the exports of country $i$ to country $j$. In turn, vectors $FD\_{i}$ and $PGV\_{i}$stand for the country’s final demand and the production gross value, respectively. Note that the final demand vectors do not include exports, since these are included in the inter-industrial transaction matrix. Additionally, the world IOM is a symmetric matrix in the sense that the column total is equal to the row total, i e., the global production gross value $(PGV)$**.**

Let $Z$be the world inter-industrial transaction (domestic and export) matrix and $ FD, VA$and$PGV$the total global production final demand, value added and gross value vectors, respectively (see Table 1). Following the input-output methodology proposed by Leontief, we have that:

$$A∙PGV+FD=PGV$$

Where $A$ is the technical coefficient matrix derived from the inter-industrial matrix $Z$. By solving the production gross value and diagonalizing vector$FD$, we find that with the expression:

$$PGV=(I-A)^{-1}∙\hat{FD}……………………………. (1)$$

a $1435×1435 $global production matrix is obtained, where the element $pgv\_{ij}$ represents, in absolute terms, the $i-th $sector production that is needed by sector $j-th$.

Moreover, by diagonalizing the coefficient $VA$ between $PGV$and then post-multiplying by $(1)$**,** we get the following expression:

$$\hat{\frac{VA}{PGV}}∙\hat{PGV}=\hat{\frac{VA}{PGV}}∙\left(I-A\right)^{-1}∙\hat{FD} $$

$$VA=\hat{\frac{VA}{PGV}}∙\left(I-A\right)^{-1}∙\hat{FD}……………………….. (2)$$

Likewise, $VA$ is a $1435×1435$ matrix that registers the global value added, in this case element $va\_{ij}$ is, in absolute terms, the value added incorporated in the sales of sector $i-th$ to sector $j-th$.

The $1435×1435$ production and value added matrices show the 35 sectors for each of the 40 countries plus the rest of the world. Given that this analysis is confined to the study of total bilateral domestic production and value added, matrices$(1)$and $(2)$were partitioned in $35×35 $sub-matrices, the total of each sub-matrix was obtained resulting in production and value added matrices per country ($41×41)$. Then, the last row and column of said matrices were eliminated, since the analysis does not consider the rest of the world, and the elements of the main diagonal were suppressed to consider only bilateral exchanges.

Now, since these are extremely large matrices that the conventional programs of game theory do not support, the flow matrices by countries were compacted by countries and, using a spectral analysis, they were transformed into Hermitian matrices, based on a selected critical value of 99 per cent of the accumulated variance, as described in the following paragraphs.

According to the group intercentrality measure proposed by Temurshoev (2008), it is possible to identify key groups in the global production and value added networks derived from the World Input-Product Matrices (IOM) of the Word Input Output Database (WIOD) for each year during the period 1995-2011.

*Filtering and binarization of bilateral production and value added matrices*

In order to apply the group intercentrality measure to production and value added matrices, these must be expressed as adjacency matrices reflecting relevant bilateral relations in terms of the monetary flow exchanged. Hence, an adjacent matrix is derived from the observation matrix (with the original metric), in such a way that the adjacency matrix represents the relative complementarity of the different country pairs. This matrix registers the direct connections of one country with those by which it is complemented strategically. Tests were conducted on the connectivity of this matrix to later identify cohesive groups or communities.

To obtain the adjacency matrices, a filtering strategy was used derived from the calculation of the Hermitian matrix, which is defined as:

$$H=(M+iM^{T})e^{-i\frac{π}{4}}$$

where: $M$ is a flow matrix.

The Hermitian matrix is a square matrix of complex elements that matches the conjugate transpose. If $M$is the bilateral production matrix, then elements $h\_{i,j}$ of $H$ represent in a single figure the purchases and sales of country $i$ to country $j$. If $M$ is the bilateral value added matrix, $h\_{i,j}$ accounts for the foreign and domestic value added incorporated to such purchases and sales.

Since all the proper values of $H$ are real, the sum of their squares is the data variance, it is possible to identify those relations (links among nodes) that mostly explain the information variance[[3]](#footnote-3). In this case, the first $i,j-$links were identified that explained in 99% the variance of the bilateral production and added value matrices. When the link was representative of variance, a numeral 1 was recorded, or 0 if otherwise. In such way, binary $40×40 $adjacency matrices representative of the countries’ trade relations were obtained.

*Definition of key group size* $k$

From the observation of different cohesive groups we found the average of countries in each community and used it to determine the size k of a group of key actors (which turned to be 5).

The key group size $k$ was determined as the group average derived from applying a community search spectral algorithm to each of the production and value added adjacency matrices for each year during the period 1995-2011. The average size was of $5$ elements, hence $k=5$.

*Determination of intercentrality by groups*

A key group is understood as the groups of k-actors which, when removed, produce an optimal disruptive impact on the network activity. To determine it, the group intercentrality measure proposed by Temurshoev (2008) was used, that is a generalization of the key actor[[4]](#footnote-4) and basically of the individual intercentrality measure proposed by Ballester *et. al*. (2006). Hence, we applied the Temurshoev intercentrality measures to find the group of key countries in each network and then compared it with conventional measures.

As pointed out by Temurshoev (2008, p.18), k-actors having the highest individual intercentrality are not necessarily part of the key group size k since they may be quite similar in terms of their links structure[[5]](#footnote-5). Hence, the key group components are expected not to be redundant in their relations with third parties.

Let us consider a network $g$ with an adjacency matrix $G$and a $a=1/λ⁡$ scalar, where $λ$ is the maximum proper value of $G$and$ a$ is a decay factor that smoothes the weight of the geodesic trajectories containing node $i-th$, hence, $B\left(g,a\right)=\left[I-aG\right]^{-1}$is adequately defined and is not negative. Consequently, the $k-th $order group with $i\_{1},…,i\_{k}$ actors is:

$$c\_{\left\{i\_{1},… ,i\_{k}\right\}}\left(g,a\right)=i^{'}BE(E'BE)^{-1}E^{'}b (3)$$

Where $E$is a $n×k$ order matrix defined as $E=(e\_{i\_{1}},…,e\_{i\_{k}})$, so that $e\_{i\_{r}} $is the $i\_{r}-th$ column of the identity matrix and $1\leq k\leq n$ where $n$ is equal to the number of actors (nodes in network) and $b$isa Katz-Bonacich (KB) vector of centralities.

The group intercentrality measure is the sum of all KB centralities of all the members of $\left\{i\_{1},…,i\_{k}\right\}$ group and their contribution to each of the KB centralities of the rest of the players (Temurshoev, 2008, p.9).

In our case, $k=5$ and $n=40$ (number of nodes/countries in the network). To determine the key group size $5$, the group intercentrality of the clusters $C\_{k}^{n}=C\_{5}^{40}=658,008$ of possible size 5 must be calculated. The group with the greatest group intercentrality is the key group, the calculation routine of which, written in Mathematica 9 and adapted from the routine proposed by Temurshoev (2008), is included in the appendix.

**Centrality Indexes (Bonacich vs. Ballester et al.)**

For the purpose of comparing the Bonacich and Ballester et al. individual centrality indexes, both for the production gross value and value added networks, we used the Spearman’s rank correlation coefficient (Spearman’s rco).

The calculation ot this coefficient requires ordering data first to compare then the degree of overlapping of this order with another resulting from a similar ordering, *i.e.*, the coefficient compares the level of similarity between the rankings of two sets of data.

In this case, the two data sets correspond to the ranking of each of the 40 countries sorted in decreasing order according to the measure of both indexes, for each of the seveenten study years. Therefore, the degree of similarity is compared for each year of the country rankings, on the basis of the most important key actor definition by each index.

Spearman’s coefficient is defined as follows:

$$r\_{s}=1-\frac{6\sum\_{i=1}^{N}d\_{i}^{2}}{N^{3}-N}$$

where N is the number of pairs (17 years) and di is the difference between the observations ranks. The index takes values between -1 and +1, pointing to a direct or indirect matching, which may even be null if the coefficient is close to 0.

Considering that the Bonacich and Ballester *et al.* indexes are related, although not equal, since the latter also measures the number of times that a country appears in the trajectory of third countries, although an overlapping is expected in order, when the Spearman’s rho is low, it may point to a greater activity of the countries in the network; if the coefficient is high, it will indicate the opposite, *i.e.,* a lower mobility. The country ordering based on whether they are relevant, both in the trajectories stemming from them (already weighted by the link’s degree of weakeness), as well as in those they are part of as a bridge actor, is similar.

Chart 1 1. Production gross value network and Production value added network: Spearman’s coefficient (1995-2011)

Source: Chart 5 of Annex 1

Chart 1 shows the results of the Spearman’s coefficient calculation, both for the production gross value and value added networks. Except for the years 1995, 1996, 1999, and 2001, the coefficient values for the production gross value network are greater than those of the production value added network. Hence, in the latter, there is lower overlapping in the country ordering, according to the value of both indexes, which points to a greater activity of the countries in such network *versus* in the production gross value network.

It can be seen that, from 2002, the Spearman’s coefficient remained lower in the production value added network as compared to the production gross value network, but also that the difference between 2007 and 2009 increased. Hence, changes in the value added network showed an increasing trend during the crisis years.

For the production gross value network, the lowest coefficient value was that of 1995, while in the years 2000, 2003, 2005, 2006, and 2007, its value was over 0.95. Similarly as in the case of the production value added network, the coefficient value falls in 2008 and 2009. Therefore, there is a greater similarity in country ordering according to both indexes, which in turn points to a lower activity in the network and a greater permanence and power of the key countries.

**Key countries in global production and value added networks**

 *Global production network*

In the 1980’s, the world economy was much more integrated than on previous decades and approximately one third of the World-System comprised a densely interconnected core (Clark y Beckfield, 2010). As globalization increases, the interconnection among economies also does, given the segmentation of the different phases in the productive process, leading to an unequal dependency and exchange pattern among core and periphery countries.

That being said, following the World-Economy approach of Wallerstein et al., there is an intermediate region, the semi-periphery, which is fundamental to absorb the contradictions between opposite poles and to provide stability to the system as a whole; however, its definition is not so clear. “The accepted definition of the semiperiphery is that both core and periphery social and economic characteristics may be exhibited by a single country (Wallerstein 1974a; Chase-Dunn, 1998). Thus, the semiperipheral region defines countries exhibiting particular blends of core and peripheral activities but does not describe a unique class of specific activities. The semiperiphery provides an important region of intermediate countries in the world-economy that serves to mitigate conflict between the core and periphery as well as a stage of development for upwardly mobile peripheral states. Consequently, the countries of the semiperipheral region exhibit a wider variety of relations with the core and periphery resulting in greater economic variability than for either the core or periphery”[[6]](#footnote-6) In the case of global production networks, the identification of the most important countries shows the group(s) that maximized the joint productive coordination effort along time. They were classified in the three previously mentioned regions as per the Temurshoev intercentrality index.

In this way, the selection of disconnected countries with the highest intercentrality index led us to an eight-block classification of countries starting from the core. The countries belonging to the core display the highest intercentrality indexes: blocks one and two; those in the semi-periphery, correspond to blocks three, four, and five, while countries in the periphery (with the lowest intercentrality index), belong to blocks six, seven, and eight, as in Chart 1.

As can be observed, the intercentrality index varies during the period considered but, in this comparative statistics exercise, movement is parallel in blocks 1 and 2 (core), as well as in blocks 3, 4, and 5 (semi-periphery). In all cases, there is a decrease, in greater or lesser degree, in the amount of the intercentrality index starting in 2008 that tends to stabilize towards the end period. In other words, it seems that the crisis that began in the last quarter of 2008 had greater effects in the core and semi-periphery countries of the global production network.

Chart 1. Production network gross value: Temurshoev index per block

 (1995-2011) Source: Chart 1 of Appendix 1.

In terms of global production, the region with the greater number of countries is the periphery with 17 countries, while the semi-periphery and core include only 14 and 9 countries, respectively.

The countries in the core are Germany, the US, France, Great Britain, Russia, China, Italy, Japan, and Korea. The Netherlands, Finland, Belgium, Sweden, Taiwan, Australia, Canada, Brazil, Poland, Spain, India, Ireland, Austria, and Indonesia are included in the semi-periphery, while the Czech Republic, Mexico, Denmark, Luxembourg, Turkey, Hungary, Slovenia, Latvia, Malta, Lithuania, Estonia, Bulgaria, Cyprus, and Greece are located in the periphery.

The core comprised the key countries of the global production network, i.e., those having the maximum impact on the network activity if removed. Germany, the US, France, Great Britain, and Russia displayed a higher intercentrality index *versus* the rest in most of the years considered. The role of China in production chains is clear as of 2005, becoming part of the first block since that year, while Korea started to be included in the second block since 1998. Japan and Italy were part of the second most important key group for a number of years.

The first empirical step towards the study of country group formation, according to the World-Economy approach, is the classification criteria to determine which countries are part of which regions. The next problem is analyzing the time structure of the classification achieved and observing the core-semi-periphery-periphery structure stability by measuring the transition of countries in the different regions.

Some authors have used Markov chains to measure the change dynamics of countries in the regions (Dezzani 2002). Others have used methods to partition networks on the basis of the actors’ structural equivalence; some others have based their measures in regular equivalence, and others have built ideal trichotomous partitions to compare their results. The literature is vast and we will not refer to it because our objective in that sense is more modest: to simply classify countries in the different regions of the World-Economy on the basis of the intercentrality index and, in a simple manner, through a comparative statistical analysis, following the behavior of the three regions during a relatively short period of time.

Chart 2. Absolute differences among regions (production gross value)



Source: Chart 3 of Appendix 1

As can be seen, the greatest difference is found between semi-periphery and periphery. Such difference remains constant in 1996 and 1997 and then in the 1998-2002 period. From 2007, the difference in importance in both region groups tends to decrease systematically and then notoriously stabilizes in the last year, although at levels quite below the observed at the beginning of the analyzed period. In other words, the difference in importance in global production between the semi-periphery and periphery is lower each time, particularly since 2008.

There is a contrast between the behavior if this series and the one measuring the difference between the core and periphery: between these two regions, their difference in importance in global production remains practically constant and the effect of the crisis since 2008 in these two regions is quite small.

It is worth remembering that in each point of the previous charts, there are different countries and that it is not easy to determine the individual mobility of countries. Indeed, this possibility is cancelled from the moment a group centrality index is attempted to be built. However, China and Korea represent what Kim and Shin (2002) called a mobile economy, which arises from the middle tier of countries given the greater interconnection of the world trade network during 1959-1996. However, when Dezzani (2002) analyzes the general structure of the World-Economy of the period 1960-1990, he points out it has not changed significantly. The empirical results suggest that little impact is observed in the World-Economy because countries that are moving upwards in the three region sequence of the world economy are almost balanced by the countries moving downwards in that same sequence.

Although identifying country mobility in the global production network is difficult when considering a relatively short period of time, such as the 17-year period considered in this study, one can get an idea of country mobility if the number of times they belonged to each of the initial groups making up the three regions is considered, in such a way as to determine which is the region with the highest mobility through the zones, maybe even better as has been considered traditionally. The presence of mobility is an important characteristic of the capitalist world, since capital is moving constantly to the most productive places (Clark and Beckfield, 2010).

If we compare the number of times that countries belong to each of the eight initial groups, according to their inclusion in the core, semi-periphery and periphery, a greater mobility is evident in the semi-periphery, given that the countries in this group belonged to three groups on average, while those in the core and periphery belonged only to two. Though this difference may be considered as not so significant, it may be said that, in terms of the dynamic characteristics of the World-Economy, the region with the highest activity is the semi-periphery (Chase-Dunn, 1998; Arrighi, 1994). There seems to be no doubt that a greater mobility is present in semi-periphery countries *versus* those in the core and periphery. Besides, while the zone limits may change along time, since states experiment upward and downward changes, it is the core/periphery hierarchy which keeps on being fundamental and may also be analyzed as a *continum* (Clark y Beckfield, 2010).

From the perspective of the global production network, the possibility increases that, over the years and given the continuous fragmentation of productive processes, some semi-periphery countries may become part of the periphery. Such is the case of Poland, Austria and Indonesia, since they have been located more times in the group with the lowest intercentrality (fifth group) within the semi-periphery. Likewise, there is the case of Mexico, which could move from the periphery to the semi-periphery. Altogether these countries are located in the limits of such regions and consequently they could be expected to display a greater mobility in the following years.

In the case of the core countries, there is less mobility in the production network, although a greater mobility may also be observed in the limits with the countries of the region and the semi-periphery, involving countries such as Japan, Korea, the Netherlands and Finland.

*Production network value added*

In regards to production value added, the identification of the most important countries shows the country group(s) possessing the economies that generate more value added, i.e., those that have achieved the higher benefit (in terms of wages and profits) of that joint productive community.

Chart 3. Production network value added: Temurshoev index per block (1995-2011)

Source: Chart 2 of Appendix 1

As in the previous case, the selection of disconnected countries with the highest intercentrality index leads to a classification of eight country blocks starting from the core; the intercentrality index changes in the period considered, as can be observed in Chart 3:

 What captures our attention first is that the intercentrality index for the production network value added shows a completely different behavior: this index is rising since 1999 for the core and semi-periphery, although there are two significant “leaps” in 2003 and 2007. In the critical years of 2008-09, it shows a considerable decrease (the effect is most visible when gross value production is considered), but then it increases again until in 2010-11 it reaches levels never attained before by the blocks of core countries and, to a lower degree, by the groups of semi-periphery countries. In other words, the core and semi-periphery have become more and more important in the generation of value added and, although the global crisis affected them considerably, the way they came out of it benefited them even more.

 These observations are in clear contrast with the behavior of the periphery countries that generate increasingly more value added in the community of 40 countries considered.

Chart 4. Absolute differences among regions (production value added)



Source: Chart 4 of Appendix 1

Now, are the regions comprised by the same countries depending on whether world production is considered in gross value or in added value? The answer is evidently not. The group of core countries still includes 9 with the inclusion of Australia and Brazil, but they are replacing France and Korea as countries that generate a higher value added. The periphery is also modified, both in number and structure: it decreases to 15 since the previous countries, which moved from the semi-periphery to the core, are replaced by Mexico and Denmark coming from the periphery, depending on the production network in gross values. The semi-periphery is also modified simultaneously and remains with only 16 countries.

 The order within each region is also modified, since Japan, Russia, the US, and China had a higher level of intercentrality, displacing Germany and France. We believe this is due to the fact that these European countries have relocated their productive chains to a greater extent to satellite countries within the geographical region where they operate, relocating consequently the generation of value added.

 One of the main empirical findings is that the use of the intercentrality index applied to the global production matrix value added, allows distinguishing more clearly the behavior among regions.

As is shown in Chart 4, the differences between the Core and Semi-periphery are consistently growing. As was mentioned before, these differences decreased with the crisis and then increase again much more rapidly. In other words, these differences among regions are growing, but they become explosive when the behavior of the Temurshoev index in the semi-periphery and periphery is compared along time: from 2000 onwards, the differences among the three regions have been similar in only three or four years (2002, 2006, and 2009), while in all the remaining years the gap separating the semi-periphery and periphery has broadened and the turbulence displayed by data surely accounts for the intense movement in these two regions.

 In summary, world production represented by this country sample tends to become more polarized each day, a trend that is even more marked in the generation of value added.

**Final considerations**

In this paper, individual centrality and inter-centrality measures (group centrality) were calculated to identify the most important countries for both production and value added networks.

On the one hand, the study focused on calculating the individual centrality indexes of Bonacich and Ballester et al., which were compared using the Spearman coefficient. A greater similarity was found in the ordering of key countries in the gross production network, according to the value of indexes and a greater activity of the countries in the value added network when the coefficient index was lower.

On the second hand, key country groups were identified on the basis of the Temursoev inter-centrality measure, emphasizing that it is not the same to identify a group of key elements as to identify the k players displaying the highest individual inter-centrality. A size of k=5 was defined in the formation of groups and, through the selection of distinct countries, eight blocks were formed based on their inter-centrality measures. In general, the evolution of the inter-centrality measure along the seventeen-year study points to a decrease in the importance of key countries in the production gross value network during the critical years of 2007-2009. In other words, the importance of key countries in terms of production gross value was lower in those years. On the contrary, in the case of the value added network, although the index also decreased in such period, it increased again considerably from 2010, showing a greater power in the network of the groups of countries with the highest inter-centrality.

When investigating the relevance of using the extended inter-centrality index, which includes groups of countries, to determine their inclusion in each of the regions proposed by the World-Economy approach, considering the World production network (40 countries) both in gross value and value added, we found it was possible to bring together the eight blocks of countries under three main regions: core, semi-periphery and periphery. For most countries, their inclusion in these different regions is uncontested; however, this is not a classification that endures through time, since we identified some countries that display a higher mobility (those that belonged to a greater number of blocks) and because the semi-periphery was found to have the greatest mobility, both in terms of production and value added networks.

Despite the trend toward mobility in countries within the region, the peripheral region will remain the largest one, considering that some countries in the semi-periphery will become part of it. In other words, this exercise allowed us to observe an increasing polarization of the countries in the world economy, both in the global production network, and the network of countries that generate the highest value added.

**Appendix 1.**

Chart 1. Blocks of representative countries in global production

 (Temurshoev Index)



Chart 2. Blocks of representative countries in the generation of value added.

(Temurshoev Index)



Chart 3. Absolute differences among regions in terms of production gross value



Chart 4. Absolute differences among regions in terms of production value added



Chart 5. Production gross value network and Production value added network: Spearman’s coefficient (1995-2011)

|  |  |  |
| --- | --- | --- |
| **Year** | Production gross value network | Production value added network |
| 1995 | 0.57673546 | 0.706191370 |
| 1996 | 0.65328330 | 0.708630394 |
| 1997 | 0.87467167 | 0.675046904 |
| 1998 | 0.86904315 | 0.824202627 |
| 1999 | 0.67804878 | 0.756660413 |
| 2000 | 0.98480300 | 0.511069418 |
| 2001 | 0.75684803 | 0.879924953 |
| 2002 | 0.756848030 | 0.658348968 |
| 2003 | 0.999249531 | 0.910131332 |
| 2004 | 0.621013133 | 0.573358349 |
| 2005 | 0.990806754 | 0.742589118 |
| 2006 | 0.957786116 | 0.830393996 |
| 2007 | 0.984803002 | 0.358348968 |
| 2008 | 0.696060038 | 0.324765478 |
| 2009 | 0.619324578 | 0.378424015 |
| 2010 | 0.839962477 | 0.660412758 |
| 2011 | 0.744840525 | 0.375046904 |

**Appendix 2. Computer program written in Mathematica 9**.

SetDirectory["C:\\Users\\Roberto\\Orozco\\Desktop\\LOS\\Ensayo\\MATRICESLUIS\\MatProd"];

nCr[n\_, r\_] := Factorial[n]/(Factorial[r]\*Factorial[n - r]);

Needs["JLink`"]

ReinstallJava[JVMArguments -> "-Xmx16384m"];

Country = {"AUS", "AUT", "BEL", "BGR", "BRA", "CAN", "CHN", "CYP", "CZE","DEU", "DNK", "ESP", "EST", "FIN","FRA","GBR", "GRC", "HUN", "IDN", "IND", "IRL", "ITA", "JPN", "KOR", "LTU", "LUX", "LVA", "MEX", "MLT", "NLD", "POL", "PRT", "ROU", "RUS", "SVK", "SVN", "SWE", "TUR", "TWN", "USA"};

(\*Data import. Production and value added matrices\*)

Period = Range[1995, 2011];

Data = "MatProd" <> ToString[#] <> ".csv" & /@ Period;

Data1 = Table[Import[Datos[[i]]], {i, 1, Length[Period]}];

For[ iter = 1, iter <= Length[Period], iter++,

 A = Data1[[iter]] - DiagonalMatrix[Diagonal[Data1[[iter]]]

];

 (\*HerminianFilter\*)

kk = 40;

 eu = ConstantArray[1, kk];

 MatHermitiana = {A + I\*Transpose[A]}\*E^(- I\*Pi/4);

 valProp = Eigenvalues[MatHermitiana];

 AccumulatedVariance = Accumulate[(Re[valProp]^2)/((Re[valProp]^2).eu)];

 Aux = 0; flt = 1;

 While[Aux < .99, Aux = AccumulatedVariance [[flt]]; flt++];

 flt;

 (\*BinaryMatrix\*)

 A1 = Flatten[A];

 B2 = DeleteDuplicates[Sort[Flatten[Position[A, #] & /@ Flatten[A1], 1]]];

 B3 = Reverse[SortBy[Table[Join[{A1[[i]]}, {B2[[i]]}], {i, 1, Length[A1]}], 1]];

 BinaryMatrix = ConstantArray[0, {kk, kk}];

 B4 = B3[[1 ;; All, 2]];

 Table[MatrizBinaria[[B4[[i]][[1]], B4[[i]][[2]]]] = 1, {i, 1, flt\*kk}];

(\*Determination of *k*\*)

 F = FindGraphCommunities[AdjacencyGraph[MatrizBinaria], Method -> "Spectral"];

 k = Total[Table[Length[F[[i]]], {i, 1, Length[F]}]]/Length[F];

 (\*Defining parameters for calculating group intercentrality\*)

 G = BinaryMatrix;

 n = Dimensions[G][[1]];

 mu = N[Eigenvalues[G]][[1]] ; (\*Greatest proper value\*)

 Id = IdentityMatrix[n]; (\*IdentityMatrix\*)

 amax = 1/mu;

 a = .05;

 B = Inverse[Id - a\*G];

 b = B.ConstantArray[1, n]; (\*Katz-Bonacich Centralities\*)

 (\*Key actor problem, key group size 1\*)

 c1 = Inverse[DiagonalMatrix[Diagonal[B]]].(b^2);

 Aux = Join[{{"Actor", "Boaccich Centrality"}},Reverse[SortBy[Join[{Table[Pais[[i]], {i, 1, n}]}, {b}]T, Last]]];

 Aux1 = Join[{{"Actor", "Inter-centrality"}}, Reverse[SortBy[ Join[{Table[Pais[[i]], {i, 1, n}]}, {c1}]T, Last]]];

 (\*Number of combinations of n actors taken 5 by 5\*)

t = nCr[n, 5];

(\*Problem of key group size 5\*)

 R = ConstantArray[0, t];

 m = 1;

 For[i = 1, i <= n, i++,

 For[j = i + 1, j <= n, j++,

 For[k = j + 1, k <= n, k++,

 For[l = k + 1, l <= n, l++,

 For[p = l + 1, p <= n, p++,

 Em = Join[{Id[[All, i]]}, {Id[[All, j]]}, {Id[[All, k]]}, {Id[[All, l]]}, {Id[[All, p]]}]T;

 c = b.Em.Inverse[EmT.B.Em].EmT.b;

(\*Group inter-centrality measure. Equation 3\*)

 R[[m]] = Join[{Country[[i]]}, {Country[[j]]}, {Country[[k]]}, {Country[[l]]}, {Country[[p]]}, {c}];

 m = m + 1;

 ]

 ]

 ]

 ]

 ];

 Aux5 = Join[{{"Actor", "Actor", "Actor", "Actor", "Actor",

 "Inter-centrality"}}, Reverse[SortBy[R, Last]]];

 Export["Inter-centralityMatProd" <> ToString[Periodo[[iter]]] <>

".xlsx", {"CentralityBocich" -> Aux, "Inter-centrality(1)" -> Aux1, "Inter-centrality(5)" -> Aux5}];

]

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1. Dezzani, R. P. (2002), “Measuring transition and mobility in the hierarchical World-Economy”. Journal of Regional Science. Vol. 42, No. 3, page 596 [↑](#footnote-ref-1)
2. For a detailed description of the WIOD, see Dietzenbacher *et. al.* (2013) [↑](#footnote-ref-2)
3. A thorough explanation of the Hermitian matrix and its application to input-output matrices is found in García and Solís, (2014). [↑](#footnote-ref-3)
4. Identifying the key actor in a network is a fundamental problem in the analysis of social networks. To address it, centrality measures have been proposed based on the degree, intermediation and proximity that quantify, respectively, popularity, control capacity and level of independence of an actor (Freeman, 1979). Likewise, rank and/or prestige measures have been developed to estimate the structural importance of an actor according to the importance of the actors with which it relates (Bonacich, 1987). [↑](#footnote-ref-4)
5. This characteristic is known as assembly problem (Borgatti, 2006) [↑](#footnote-ref-5)
6. Dezzani, R. Op. Cit. p. 597. [↑](#footnote-ref-6)