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Measuring Global Economic Interdependence: A Hierarchical Network Approach

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1. INTRODUCTION

GLOBALISATION, generally understood as the diffusion of goods, services, capital, technology and people (workers) across national borders, is a multifaceted process that not only significantly influences human well-being but increases the integration and interdependence of all countries and regions involved in the world economy. Although consubstantial with human social interaction since ancient times, the process has undergone major acceleration during the last decades (e.g. Dreher, 2006; Dreher et al., 2008). One instance is visible on the economic front, where the global integration of capital markets accelerated so rapidly that by 2003, external assets and liabilities were (relative to output) triple the 1990 levels in developed countries. The trend for developing countries was similar, although on a smaller scale than in industrial nations (IMF, 2005). Likewise, international trade in merchandise is 30 times and volume output around eight times larger than the 1950 level, following World Trade Organization data.

Several factors – including religion (Cleary, 2008), democracy (Li and Reuveny, 2003), transnational terrorism (Li and Schaub, 2004), values (Whalley, 2008) and industrialisation (Brady and Denniston, 2006) – offer potential avenues for analysing this process; however, much of the research into the advance, effects and consequences of globalisation has focused on its economic or distributional aspects (e.g. Dreher, 2006; Goldberg and Pavcnik, 2007; Dreher et al., 2008). Such research frequently employs the terms 'globality' and 'globalisation' to capture the ongoing large-scale growth of transplanetary – and often supraterritorial – connectivity (Scholte, 2008). One of the key issues regarding the advance of the globalisation process is whether or not the implied increasing economic interdependence among countries is fostering synchronisation in the world economic cycle (Bordo and Helbling, 2003, 2011; Kose et al., 2003a; Miskiewicz and Ausloos, 2010).

This study analyses the topology and evolution in the similarities of global patterns of economic growth in the world economy to widely investigate this key issue. Therefore, the principal aim of this study is to analyse growth clusters and cross-country liaisons arising from the evolution of interdependence over the last decades. We analyse the evolution and dynamics of these clusters without looking at why clusters form. In line with Mantegna (1999), Ortega

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and Matesanz (2006), Miskiewicz and Ausloos (2010) and Brida et al. (2011), among others, our methodological approach is based on the analysis of a correlation matrix and the networks it contains. Moreover, it centres on the connectivity and interaction in the economic performance produced by interdependence in the world economy and allows for a better description of the existing heterogeneity in the degrees and evolution of the international economic integration.[1]

Specifically, by constructing a cross-country hierarchical structure, we first identify groups of countries that exhibit similar economic growth patterns within the world economy and other countries that seem more isolated in terms of dynamic integration with other nations. Next, because this topological hierarchical structure reveals country clusters related to regional integration arrangements like the European Union or the Association of South-East Asian Nations (ASEAN), we examine the globalisation process of interdependence in the world economy through a regional lens. We conclude that the dynamics of globalisation in the last decades have been more driven by synchronisation in regional growth patterns than by the synchronisation of the world economy as a whole. Contrary to Kose et al. (2003b), we find evidence for regional specific fluctuations rather than the existence of a world business cycle. Within a longer sample analysis, 1880–2009, Artis et al. (2011) support this idea of regionalism in world co-movements and interdependence.

The rest of the paper is organised as follows. Section 2 presents an overview of the relevant literature on globalisation and economic integration. Section 3 describes the database and methodology, and Section 4 reports our results at both a global and regional level. Finally, Section 5 interprets our findings in the light of previous research and discusses their statistical and economic implications.

2. ECONOMIC INTEGRATION AND GLOBALISATION

Although the economic aspects of globalisation have attracted much attention over the past 20 years (e.g. Williamson, 1996; Rodrik, 1998; Baldwin and Martin, 1999; Arribas Fernández et al., 2007; Goldberg and Pavcnik, 2007), one particularly important strand of this vast literature examines interdependence and integration in the globalisation process by analysing business cycle synchronisation in the economy (Helbling and Bayoumi, 2003; Kose et al., 2003a, 2003b, 2008b; Doyle and Faust, 2005; Artis and Okubo, 2009; Miskiewicz and Ausloos, 2010; Artis et al., 2011; Aruoba et al., 2011; Crucini et al., 2011; Antonakakis, 2012; Antonakakis and Scharler, 2012; Lee, 2012a, 2012b).[2] However, although such research typically measures synchronisation as the correlation coefficient between the business cycles of two countries or groups of countries, the methodologies and results are diverse and controversial. For instance, Kose et al.'s (2003a) analysis of co-movements in 76 developed and developing countries between 1960 and 1999, which is based on the growth rate of the composite measure of world output, provides at best limited support for the conventional wisdom that globalisation leads to an increase in the degree of business cycle synchronisation worldwide. Antonakakis and

[1] A similar approach also based on complex networks has been used to properly describe the architecture and evolution of the globalisation using trade data (e.g. Kali and Reyes, 2007; Fagiolo et al., 2010; Reyes et al., 2010), where weighted links between countries were determined by its international import/export data.

[2] Another strand of this literature has dealt with business cycle synchronisation at a regional level (e.g. Carlino and Sill, 2001; Owyang et al., 2009). In the present study, we instead uncover tight local and regional economic liaisons among countries.

Scharler (2012), on the other hand, use conditional correlation analysis and identify unusually high synchronised output growth dynamics in G7 countries during the recent international recession (2007–09) compared with an earlier period beginning in 1960. Antonakakis (2012) extends this analysis from 1870 confirming the previous result. Research along the same lines by Aruoba et al. (2011) uses dynamic factor models and reports that the 2009 recession is the deepest and most synchronised recession within the G7 countries in the post-war era. Artis et al.'s (2011) analysis of 25 advanced and emerging market economies from 1880 to 2009 suggests that one only observes a secular increase in international business cycle synchronisation within a group of European and English-speaking countries. Therefore, their results show a limited and more regional world picture of increasing synchronisation and globalisation.

Nonetheless, Miskiewicz and Ausloos (2010) use different distance measures generated from cluster network and entropy analysis to measure the increased similarities in 1950–2007 growth patterns in 20 countries, suggesting that globalisation reached a maximum during the 1970–2000 period, and was then followed by a subsequent process of deglobalisation.

In this paper, therefore, rather than measuring dynamic interdependence in the international arena based on a correlation coefficient between the business cycles of two countries or groups of countries, we employ a more general approximation based on the organisation of the correlation matrix according to the closeness relation among its constituents (or elements), and the construction of a network derived from it (e.g. Mantegna, 1999; Ortega and Matesanz, 2006; Miskiewicz and Ausloos, 2010). Because such an approach summarises the interaction and interdependence of all elements, it represents a more accurate measure of the global interdependence involved in the economic system. In this study, we are not directly concerned about the analysis of the common and specific factors affecting synchronisation in the business cycles. Our clustering approach offers information regarding regional and country-specific cycles. In this sense, we expect that countries' clusters are more affected by common factors in their growth path in comparison with isolated countries in the network. The vast literature dealing with this issue has not arrived at a consensus on the determinants driving common business cycle co-movement. Some studies have pointed to trade as an important determinant (e.g. Frankel and Rose, 1998; Baxter and Kouparitsas, 2005). However, Imbs (2004) has pointed out that as countries become more integrated, they are able to specialise to a higher degree. This produces desynchronisation among countries as countries may be affected by sector-specific shocks. Other studies have emphasised the role of other key factors affecting the evolution of synchronisation, such as financial linkages, fiscal policies, institutional settings or market regulations (e.g. Baxter and Kouparitsas, 2005; De Grauwe, 2006; Jansen and Stokman, 2011). As already mentioned, this paper studies the structure and evolution of growth clusters but does not aim to explain factors driving the formation of these growth clusters.

To measure integration in the world economic system, we construct correlation and distance matrices for the GDP *per capita* in a group of 103 developed and developing countries over the 1950–2009 period. Based on these matrices, we build nested hierarchical structures of interactions that enable analysis of the system topology and hierarchy affecting overall dynamics (Tumminello et al., 2010). Clustering countries in such a way permits the identification of common regional dynamics in world output linkages. The results of this topological approach suggest that, as the notion of *convergence clubs* implies, business cycle synchronisation could be occurring within different regions rather than at a global level in the world economy (Baumol, 1986; Quah, 1993, 1997; Brida et al., 2011). Finally, to examine the evolution of the globalisation process along our time sample, we carry out a dynamic analysis by constructing moving windows associated with the correlation matrix and its nested networks.

The contributions of the paper are twofold. First, we show that clustering hierarchical structures not only differentiates countries with relatively common cycle dynamics from nations that are more isolated in their economic growth path but reveals that the two groups of countries exhibit different dynamics in their co-movement growth paths. It should also be noted that our regional clusters, rather than being exogenously obtained as in most other papers (e.g. Bordo and Helbling, 2003, 2011; Kose et al., 2003b), are endogenously generated from the output synchronisation itself. Second, our observation of cycle synchronisation through overlapping windows produces a more accurate picture of co-movement evolution over time. Finally, this approach uncovers the important diversity and heterogeneity in economic growth paths which is in favour of the view that a unique interpretative model is likely to fail to properly describe growth and development experiences (Brida et al., 2011)

3. DATA AND METHODOLOGY

a. Data

This work analyses the gross domestic product *per capita* (GDP) as reported by the Groningen Growth and Development Centre at the University of Groningen (data are available online in that institution's Total Economy Database: http://www.ggdc.net/databases/ted.htm). GDP *per capita* is presented in 1990 US dollars converted into Geary Khamis purchasing power parities (PPPs) to permit international and time comparisons across the entire database. The time interval chosen, from 1950 to 2009, covers the world economy from the end of the Second World War until recent years. The 103 countries analysed include all developed nations and a considerable number of developing countries from Asia, Latin America, the Middle East, and Africa (see Appendix A for a complete list of countries and their corresponding acronyms).

We calculate GDP growth rates (g_i) in country i, where i = 1,2,….., 103, as:

$$g_i(k) = \frac{\mathrm{GDP}_i(k+1) - \mathrm{GDP}_i(k)}{\mathrm{GDP}_i(k)}, \tag{1}$$

where $\mathrm{GDP}_i(k)$ is the annual GDP value in country i at year k and $g_i(k)$ is the corresponding growth rate. Our data set thus conforms to a matrix of 59 rows (annual growth rates) and 103 columns (countries).

b. Numerical Methods

(i) Hierarchical Analysis

Although several methods exist for quantifying the degree of interaction or synchronisation between two or more time series, the method most commonly used in the literature is the Pearson's cross-correlation coefficient, $\rho_{i,j}$. Given two time series $\bar{x}_i = x_i(k), k = 1, N_{dat}$ and $\bar{x}_j = x_j(k), k = 1, N_{dat}$, the Pearson's correlation coefficient between country i and country j, in a time window of N_{dat} is defined as

$$\rho_{i,j} = \frac{\sum_{k=1}^{N_{dat}} (x_i(k) - \overline{x_i})(x_j(k) - \overline{x_j})}{\sqrt{\sum_{k=1}^{N_{dat}} (x_i(k) - \overline{x_i})^2 \sum_{k=1}^{N_{dat}} (x_j(k) - \overline{x_j})^2}}. \tag{2}$$

In our particular case, $\bar{x}_i = x_i(k), k = 1, N_{dat}$ corresponds to each of the $g_i(k)$ time series so that $1 \leq i \leq 103$ (number of countries) and $1 \leq k \leq N_{dat}$ (number of analysed years). To transform correlations, $\rho_{i,j,}$ into distances, we follow Gower (1966) and define the distance *d(i,j)* between the evolution[3] of the two time series x_i and x_j as

$$d(i,j) = \sqrt{\rho_{i,i} + \rho_{j,j} - 2\rho_{i,j}} = \sqrt{2(1 - \rho_{i,j})}, \tag{3}$$

where $\rho_{i,j}$ is the Pearson's correlation coefficient and *d(i,j)* fulfils the three axioms of a distance:

$$\begin{aligned} &d(i,j) = 0 \text{ if and only if } i = j \\ &d(i,j) = d(j,i) \\ &d(i,j) \leq d(i,l) + d(l,j). \end{aligned} \tag{4}$$

Armed with the nodes (103 countries) and the corresponding links (distances) among them, it is therefore straightforward to construct (e.g. using the Kruskal algorithm; Kruskal, 1956) the minimum spanning tree (MST) associated with the interactions network. The MST is a simple loop-free network that can comprehensively display the most important links and communities in a complex network. We can then calculate the 'cost' of the MST by summing up all the links among all the MST nodes. MST cost sheds light on the degree of correlation (or synchronisation) among the whole set of elements in the network: the lower the cost, the less distance between the MST members and thus the tighter the links among them.

It is also possible to construct a hierarchical organisation, a hierarchical tree (HT), of the data using the single-linkage clustering algorithm (Johnson, 1967) in which 'similar' objects (i.e. single countries or group of countries) are clustered in each step according to their characteristics. This classical agglomerative single-linkage algorithm enables construction of a hierarchical dendrogram to illustrate the clustering characteristics of the data organisation. In fact, clustering data into groups of members with the tightest connections among them is a usual way to define *communities* (Wasserman and Faust, 1994) in a complex network of interactions, where each member of a particular community shares some characteristics with the other members of the same community. There exist several algorithms aimed at detecting communities in a network (Boccaletti et al., 2006). Among the several existing ways to construct a hierarchical tree, the single-linkage method has much in common with the construction of the MST, a graphical construction used to visualise the main connectivity characteristics of the network. Moreover, as recently demonstrated by Tola et al. (2008), the single-linkage procedure seems to better detect the degree of heterogeneity presented in the distribution of wealth across countries.[4]

The simplest one of these methods is based on the analysis of the dendrogram, because a simple horizontal cut of a hierarchical tree at a particular distance automatically yields

[3] Both measures, equations (2) and (3), will be calculated either for the whole interval (1950 to 2009) or for shorter time windows. In the last case, superscripts will be used to identify $\rho_{i,j}$ and *d(i,j)* with the corresponding windows (see Section 3b(ii)).

[4] The study by Tola et al. (2008) uses cluster analysis for stock portfolio optimisation, and therefore, the degree of heterogeneity (or homogeneity) is focused on the distribution of money invested in each stock. In this sense, the use of the single-linkage procedure better detects the uneven distribution of wealth across portfolios or, in our study, countries.

clusters/communities of tightly connected members. In the rest of the paper, we will use a more refined method (Langfelder et al., 2008) to extract communities from a hierarchical tree, by analysing adaptively the structure and shape of the hierarchical tree and extracting from it the relevant clusters/communities.[5]

(ii) Time Windows Analysis

To examine the temporal behaviour of interdependence relations among elements of the business cycle, we also calculate distance correlation matrices for overlapping windows of 10 years[6] and move each temporal window forward in time over the entire sample period, in one-year increments beginning with 1950. In this way, equations (2) and (3) are calculated for each temporal window such that $N_{dat} = 10$ and $\rho_{i,j}$ and $d(i,j)$ take values for each window, $\rho_{i,j}{}^{1960}, \rho_{i,j}{}^{1961}, \rho_{i,j}{}^{1962}$, ... and $d(i,j)^{1960}$, $d(i,j)^{1961}$, $d(i,j)^{1962}$, etc. As an example, $\rho_{i,j}{}^{1960}$ is calculated using equation (2) with $N_{dat} = 10$, where $k = 1$ corresponds to the year 1950 and $k = 10$ to the year 1959, and $\boldsymbol{x}_i$ and $\boldsymbol{x}_j$ are, respectively, g_i and g_j, GDP growth rates of countries i and j, as calculated in equation (1).

To enable comparisons among different clusters comprising unequal numbers of countries, we sum the matrix coefficients for each window and normalise them to the number of countries. Each data set thus represents the sum of the distances among all countries in the past time window. We also calculate the corresponding MSTs in each time window and sum up all the distances represented in each tree branch, normalising them in the same way as previously to produce the measure we have termed *MST cost*.

The sum of all the matrix coefficients can be interpreted as the interdependence among all countries, which we call the *global correlation*, while the MST cost represents the interdependence of the closest connections in the business cycle for each country. The higher the value of the normalised correlation coefficients, the tighter the coupling inferred among all countries. Conversely, the shorter the value of the sum of distances represented in the MST cost, the tighter the co-movement of the first distances among countries.

We then extend this static hierarchical analysis by examining the evolution of the convergence clusters with a community analysis that measures this evolution using overlapping windows of 10, 20 and 30 years forward in time. To test the robustness of the hierarchical clusters identified, we also calculate the community network of these clusters for the whole period.

[5] To check for robustness of our results, we have additionally employed both a different quantifier for co-movements, the Kendall correlation coefficient, and a different clustering method ('average' clustering algorithm). The Kendall non-linear coefficient summarises the number of times every pair of data series move in the same direction from every point in time to the next one, regardless the intensity of the movement itself. The 'average' clustering algorithm takes into account not only the most important connection but their average distance to every other ones (as does Kruskal's algorithm). Results from this additional checking roughly yield the same communities: Western Europe, East Asia, East Europe and some country pairs such as North America and Canada, Uruguay and Argentina or United Arab Emirates and Saudi Arabia come up in all proofs supporting the robustness on the cluster we have obtained. These additional results can be directly obtained from the authors.

[6] To check for robustness, we have repeated these calculations in windows of 5 and 15 years. No substantial changes appear using these other windows' length. These results can be obtained from the authors.

c. Statistical Validation

All analysis conducted in the present work strongly depends upon equations (1) and (2). The first analysis provides the calculations of GDP growth rates (equation (1)) and can be considered as a transformation of the raw data (GDP) by detrending the original time series and making them suitable for further analysis. The second critical step is the multivariate correlation analysis as stated in equation (2).

Due to the importance of these critical steps in the remaining work, two different procedures were performed to assess the statistical robustness of each equation, as explained in the next subsections.

(i) Hodrick–Prescott Filter

The calculation of GDP growth rates as estimated by equation (1) are one way of stabilising or removing trends in the long-run growth path of the GDP. However, this is not the only method. In fact, removing linear or exponential trending is one of the simplest ways to accomplish this task. An alternative and popular way of detrending a macroeconomic time series is using the so-called Hodrick–Prescott (Hodrick and Prescott, 1997) filter (although originally proposed by Whittaker, 1923), which basically fits the time series with a sum of a linear trending plus a cyclic component. To detrend the macroeconomic time series, the fitted curve is subtracted from the original time series, GDP. We have implemented this procedure in order to compare and validate the use of growth rates to analyse GDP fluctuations.

(ii) Surrogate Time Series

As explained above, the construction of hierarchical trees and MST are performed using the notion of distance (equation 3) between GDP dynamics, which in turn, is defined by the correlation between the corresponding GDP growth rate time series. One further issue to be considered is whether global correlations and MST cost in the country sample, as defined above, can be significantly differentiated from random data with no correlation structure. Surrogate data (a form of bootstrapping, see Theiler et al., 1992) have been used to address this issue. Essentially, we have generated new samples of the GDP time series set by randomly shuffling each time series. In this process, the first-order statistic (histogram) is preserved for each individual time series while simultaneously destroying the temporal auto-correlation structure. We use the term 'surrogate sample' for the new 103 GDP time series generated this way. The surrogate method is simply a hypothesis test in which a certain statistic, in this case, the global correlation or the MST cost in the original sample, is compared against the surrogate samples. To do that, a (high) number of surrogates' samples are generated and a *Z*-score is performed such that:

$$Z = \frac{|\mu_O - \mu_S|}{\sigma_S}, \tag{5}$$

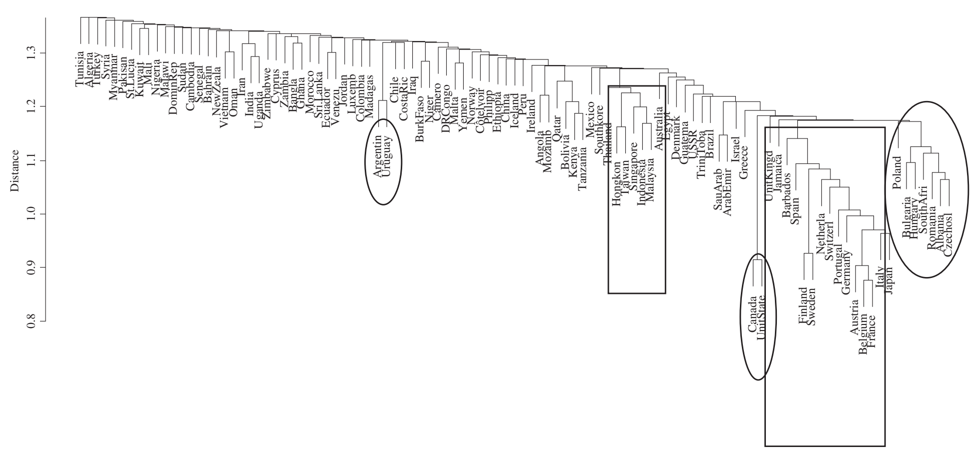
where μ_O is the global correlation or MST cost, μ_S and σ_s are, respectively, the mean value and standard deviation of global correlation or MST cost in the surrogates' sample. To perform the test, H_0, the null hypothesis would be that μ_O belongs to the distribution of surrogates. Hence, to reject the null hypothesis (i.e. global correlation and MST cost are not spurious correlations) at a 95 per cent level of confidence, Z must be greater than 1.96.

4. EMPIRICAL RESULTS

a. Cross-country Hierarchical Structure

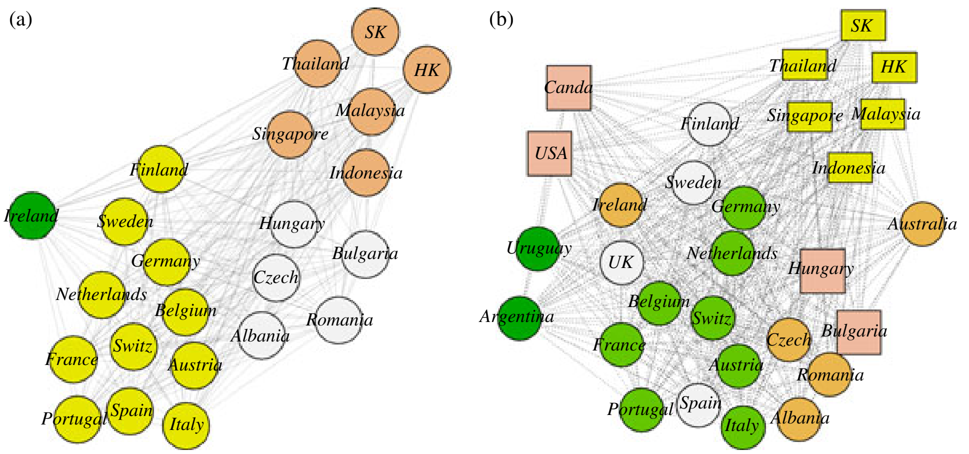
Figure 1 is constructed using Pearson's correlation based metric distances and shows the HT of the GDP *per capita* growth rates, *g*, in the 103 countries analysed for the entire 1950 to 2009 sample. This construction provides a hierarchical structure according to proximity in the GDP *per capita* dynamics (the deeper the links in the HT, for instance USA and Canada, the closer its GDP *per capita* movements in relation with other countries). This figure immediately reveals that the growth patterns of a large number of countries are seemingly unlinked to those of other countries or groups of countries, suggesting that these nations have experienced major autonomous economic growth during recent decades. Moreover, the metric distance coefficients links in these countries are significantly higher than in country clusters, supporting the idea of more specific and self-output growth path. Most of these countries that belong to no cluster or 'growth club' in the structure are located in Latin America, Africa or Asia. For instance, Tunisia, Algeria, the Dominican Republic and Cyprus are quite isolated in their growth paths. In contrast, Western European countries form clear clusters in their economic growth cycles, while Eastern European and South-East Asian countries belong to two different well-defined clusters. Certain countries, such as Canada and the United States, Argentina and Uruguay, Ecuador and Venezuela, and Saudi Arabia and the United Arab Emirates, are paired off in their economic growth paths. The first two pairings and the final pairing make clear economic sense: Canada and the United States and Argentina and Uruguay are geographically nested and have strong economic liaisons, while the growth paths of Saudi Arabia and the United Arab Emirates are both linked to oil prices on international markets. Other connections, however, such as those between Vietnam and Oman or Malta and Yemen, are not so clearly economic.[7]

FIGURE 1
Hierarchical tree (HT): returns of GDP *per capita*, 1950–2009, for 103 countries



[7] One should remember that these clustering methods link every node to the network, even though some connections are very weak or, in economic terms, are not synchronised.

FIGURE 2
Community network: GDP *per capita*, 1950–2009: (a) Western and East Europe and East Asia; (b) Western and East Europe, East Asia, Argentina, Australia, Canada, United Kingdom, United States, Uruguay. After 1989 we continue using Czechoslovakia as an aggregate of Czech Republic and Slovakia. USA stands for United States of America, UK for United Kingdom, Czech for Czechoslovakia, SK for South Korea and HK for Hong Kong and Switz for Switzerland



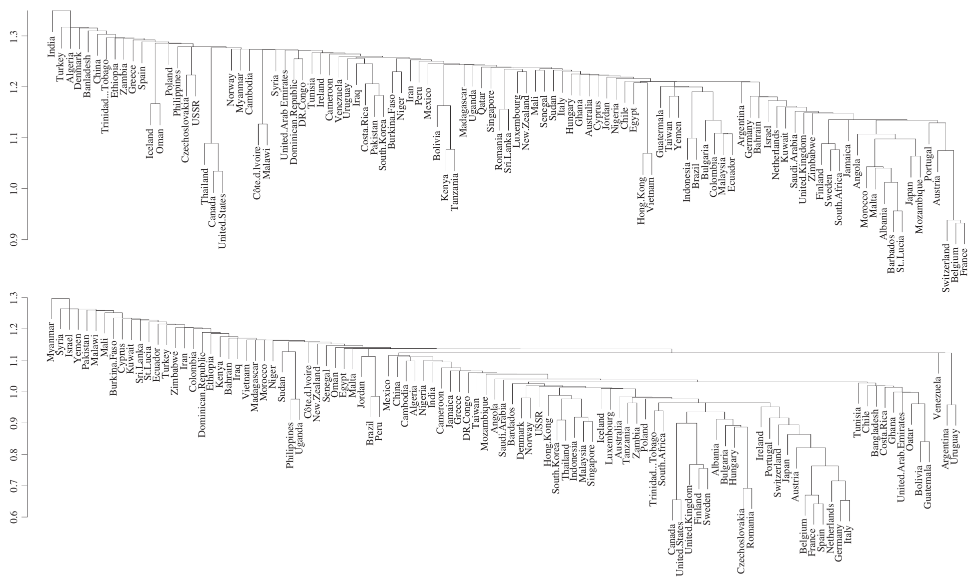
To validate the above analysis, we have also constructed a hierarchical tree using a Hodrick–Prescott filter over the real GDP growth, instead of using growth rates, as explained in section Hodrick–Prescott Filter. The hierarchical tree we obtain presents a structure which is very alike in many aspects, most important being the main features highlighted in the above paragraph with respect to several groups of tightly linked countries (Figure S1).

Figure 2 summarises the community analysis of the previously obtained hierarchical clusters for the entire time sample. Here, the regional clusters are well defined and only Ireland exhibits an autonomous economic growth path (Figure 2a). Inclusion in the analysis of the country pairings (Figure 2b) also results in well-defined regional clusters; however, the inclusion of Anglo-Saxon countries modifies the Western and East European clusters. In Europe, a northern group emerges to which Spain is linked, while Hungary and Bulgaria connect to Canada, the United States and other Eastern countries in a group to which Australia is linked (to better observed the regional clusters, a colourful version of Figure 2 can be obtained online).

Because the time period is extensive in economic terms, we divide the sample into two subperiods (1950–80 and 1980–2009) for which we also calculate the MST and HT to test the robustness of the country groupings given in Figure 1. Comparing (a) and (b) plots in Figure 3, we can observe how the regional blocs seem to align along the time sample being analysed. In Figure 3(a), the regional economic dynamics seem to be more disorganised than beforehand. For instance, Spain, Greece and even Germany are not in the Western European group; and South Asian countries are less integrated than in Figure 1. However, in the period 1980–2009, Figure 3(b), the clusters are aligned in a more regional arrangement suggesting that ‘clubs synchronisation’ is a dynamical process where time is fundamental in adjusting the economic rhythms among members. Moreover, the closeness of co-movements measured in the vertical axis of both figures is higher in the second period, which supports the notion that time is important for deepening the connections of clusters.

FIGURE 3

Hierarchical tree (HT): GDP (*per capita*) growth rate, for 103 countries. (a) 1950–80, (b) 1980–2009



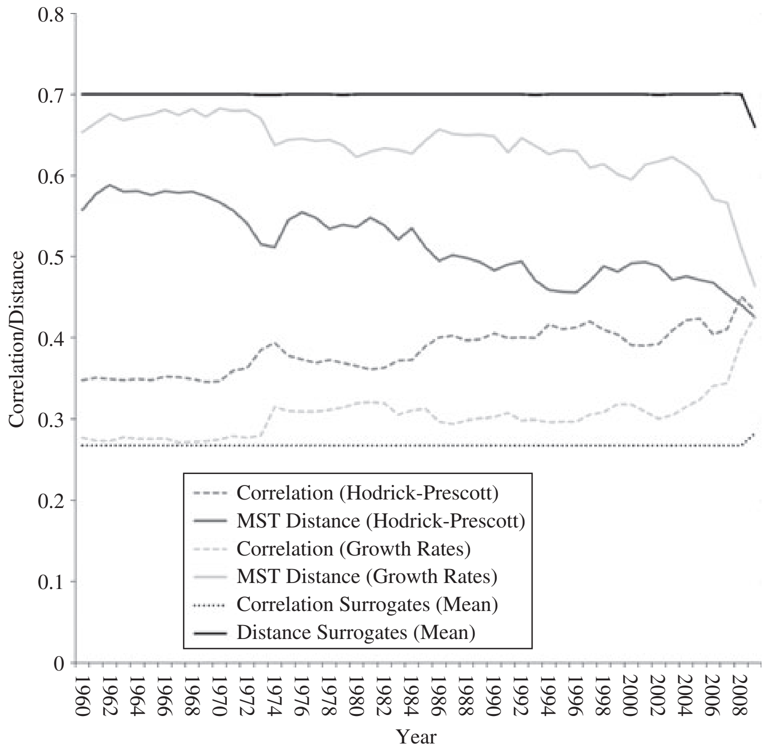
To characterise the evolution and formation of such regional blocs, we also expand the community analysis using 10-year overlapping windows that move forward in time. We find that the clear definition of the regional blocs shown in Figure 2 has been created over time; that is, regional communities have become more defined since the 1990s than during the 1950s and 1960s.[8] This observation implies that such ‘regional clubs’ must be related to the formation and advancement of the integration processes launched after the Second World War; most particularly, economic growth cycles tend to converge within the memberships of institutional economic arrangements such as the European Union, the Soviet bloc and the AS-EAN, suggesting that these coalitions foster economic ‘growth clubs’. We therefore anticipate that country clusters will exhibit a high and/or increasing integration in their business cycles, one that signals an advancing globalisation process *inside* the group. We test this assumption in the next section.

b. Regional and Dynamic Analysis

Figure 4 plots the normalised correlation coefficients and MST cost for 103 countries in the 10-year overlapping windows. To assess the robustness of the method, we have again made these calculations for both GDP growth rates and Hodrick–Prescott filtered GDP time series, as explained in section Hodrick–Prescott filter. Figure 4 displays global correlation (solid lines) and MST cost (dashed lines) using GDP growth rates (light grey) and Hodrick–Prescott filter (dark grey). Each data point in the figure represents the normalised sum of the correlation coefficients (global correlation) and distances (MST cost) over the past 10 years. As the figure clearly shows, global correlation exhibits two strong leaps during the time

[8] The community overlap figures are directly available from the authors.

FIGURE 4
GDP correlations and MST cost, 10-year overlapping windows for 103 countries.
Hodrick-Prescott filter in dark grey, growth rates (equation 1) in light grey and surrogates data in black.
See text for a statistical explanation



sample, the first during the early years of the 1970s (coinciding with the first world oil recession) and the second occurs at the end of the last century, especially since 2002. Interestingly, when the current world crisis period, 2008–09, is included in the calculations, the correlation coefficients increase strongly, reaching the highest value in the period analysed. This result is in line with recent findings by Antonakakis (2012), Antonakakis and Scharler (2012) and Aruoba et al. (2011). Moreover, Antonakakis (2012) claims that 2007–09 recession, compared with any of the 30 recession episodes since the 1870s in the United States, increased business cycle synchronisation across the G7 countries to unprecedented levels. Our analysis confirms this result but including a significantly higher number of countries. In the interim period, between 1972/3 and 2002, the correlation coefficients remain flat or even show a slight decrease. These results suggest that although business cycle synchronisation increases strongly during global economic crises, there is no post-crisis return to the previous synchronisation condition. Hence, the trend towards a more integrated world economic output is seemingly driven by episodes of world economic tension and change. To further assess the statistical validity of the above results, surrogate mean values of GDP growth rates (black lines) have also been included in the figure (in line with Section 3c(ii)). The solid black line displays the mean values of global correlations and the dashed back line displays the mean values of MST costs. In each temporal window of 10 years, 1000 surrogates are generated (in the manner described in Section 3c(ii)) and the mean value and standard deviation of global correlation or MST cost are calculated. By using equation (5), a *Z*-score can be calculated and the statistical significance can thus be inferred. It must be noted that standard deviations are small, such that:

Maximum standard deviation for surrogate global correlation = 0.0026
Maximum standard deviation for surrogate MST cost = 0.011

With this in mind, it is clear in Figure 4 that the *Z*-score will almost always attain values much greater than 1.96 or even 3 (>99 per cent). The exceptions are mostly around the year 1967 for both correlation (light grey dashed line) and distance (light grey solid line). In any case, the surrogate procedure clearly demonstrates the robustness of global correlation and MST distance calculations.

To illustrate the dynamic of output co-movement in our regional 'clubs' and other selected areas, Figures 5 and 6 depict the normalised correlation coefficients and MST cost, respectively (countries included in each region are listed in Appendix A). The most interesting finding (see Figure 5) – which involves Europe, East Asia and to some extent Eastern Europe – appears in relation to the increased cycle synchronisation in developed countries and the rapid economic growth in transition countries in Eastern Europe. This is potentially driven by the EU enlargement and Europeanisation process as the launch of the European common market in 1993 and the Monetary Union in 1999 generated a faster integration of the economic cycle in the region (as suggested among others by Lee, 2012a, 2012b). In contrast, Africa and Latin America, which are characterised by no regional clusters (see Figure 1), not only show the lowest levels of correlation, but also no advance in output integration in either region. The fact that crisis periods tend to increase co-movements in regional cycles is particularly well illustrated in East Asia by the economic collapse and structural transformations that follow the 1997–98 financial crisis and in Eastern Europe by those that following the fall of the Berlin Wall.

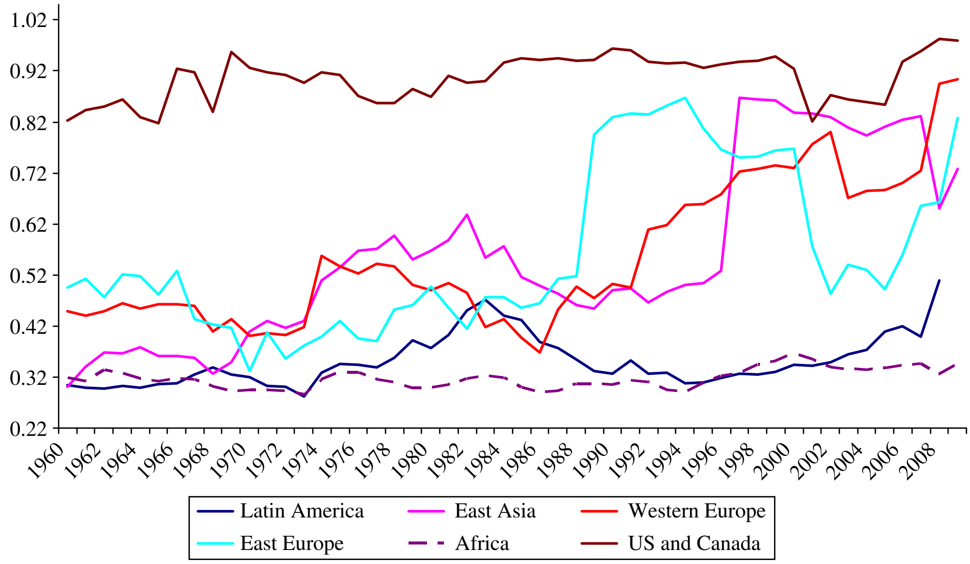
Figure 6 outlines the MST cost evolution over time in the same regions as in Figure 5. As long as the MST cost reflects the dynamic of the metric distances in the first link for each country inside the region (i.e. the sum of all MST branches over the number of countries), the information provided in Figure 6 appears to be related to a more restrictive type of interdependence and synchronisation. That is, developed regions show a higher degree of synchronisation (less metric distance). Once again, this observation holds particularly true for United States and Canada[9], the European countries and East Asia, while Africa and Latin America show the smallest degree of co-movement. The similarity of the results in Figures 5 and 6 strongly supports the conjecture generated by the cluster analysis above that regional convergence clubs play a major role in globalisation. Otherwise, the first distances for each country (i.e. the MST cost) would have to be deeper in terms of co-movement than in the global correlation (which includes bilateral correlations between all countries inside each cluster).

5. CONCLUDING REMARKS

The notion of globalisation reflects the current ongoing large-scale growth of transplanetary connectivity and consequently the notion of growing world interdependence. This paper evalu-

[9] Of course, when only two countries are analysed the correlation coefficient and the MST Cost give the same information.

FIGURE 5
Normalised correlation coefficients: 10-year overlapping windows, selected regions

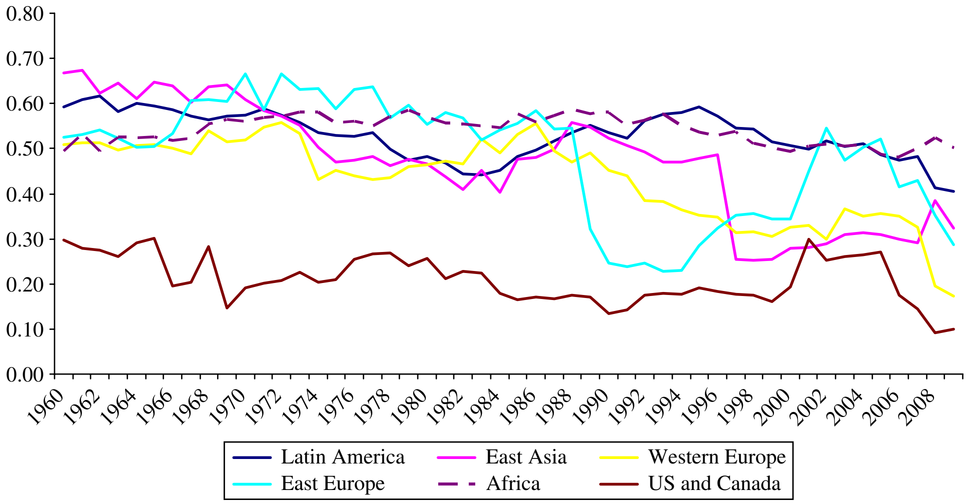


ates the synchronisation manifest in business cycles to assess the connectivity and interaction in economic performance that arises from interdependence in the world economy. Our methodological approach based on the analysis of the correlation matrix and the networks they contain (e.g. Mantegna, 1999; Ortega and Matesanz, 2006; Miskiewicz and Ausloos, 2010) produced several interesting results.

Our most important finding is that economic globalisation is a regional rather than a truly global process which is in line with recent research (Artis et al., 2011) and in contrast to other empirical results (Kose et al., 2003a, 2003b). That is, advances in world economic interdependence are driven by geographical, political, economic and cultural regional clubs, which tend to exhibit a higher degree of and a more rapid increase in synchronisation. Moreover, advances in synchronisation of economic growth paths are related to regional integration arrangements like the European Union (Lee, 2012a, 2012b) and the ASEAN where output linkages are significantly higher than in other groups of countries. Importantly, the hierarchical clustering procedure is able to detect countries belonging to the same region without requiring any supervision of the clustering procedure. At the same time, the method is able to observe endogenously isolated single-country economic dynamics. Therefore, as suggested by Dreher (2006), Ming-Chang (2007) and Bordo and Helbling (2011), a regional approach is central to understanding the globalisation process and the economic interdependence in the world economy. This is in line also with Kali and Reyes (2007), Fagiolo et al. (2010) and Reyes et al. (2010). In their results, most countries are connected by weak trade links; however, regional clubs exist with very strong relations, creating therefore a core-periphery global structure.

A second primary finding is that global crises, such as the 1970s oil crisis and the recent financial crises, produce strong leaps in the degree of output integration in these regional clubs, whereas downturns in economic activity produce greater output synchronisation. In line with Antonakakis (2012) and Antonakakis and Scharler (2012), the 2007–09 recession has

FIGURE 6
Normalised MST cost: 10-year overlapping windows, selected regions



increased output synchronisation to unprecedented levels, not only in developed countries but in world business cycle. Most particularly, even though a certain degree of desynchronisation is observable after a crisis (as pointed out by Bordo and Helbling, 2011), the tendency over time is towards increasing output integration and the production by output crises of anomalous behaviour. In contrast to these authors, however, we find that this tendency does not hold for all regions and countries; rather, some exhibit autonomous dynamics within convergence clubs, which underscores the importance of this notion (Baumol, 1986; Quah, 1993, 1997). Moreover, the existence of these convergence clubs contradicts the inexorable output growth towards a steady state and therefore convergence to the same economic path that is predicted by traditional analyses of convergence. This point was made by Brida et al. (2011) in a recent methodologically similar paper.

The use of network dynamic methodology enables the uncovering of interesting findings, which are otherwise not observable through standard approaches based on correlation coefficients between pairs of countries or based on some measure of a global world output trend as a reference towards synchronisation for single countries. This approximation suggests an interesting route for the study of global and regional interdependence by taking into account the fundamental role of different regions and more isolated economic growth paths. Additionally, this methodology allows the inclusion of other variables to test global synchronisation such us exports/imports, consumption, investment and also institutional or social aspects of globalisation.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Figure S1. Hierarchical tree (HT): Hodrick-Prescott filter of GDP *per capita*, 1950–2009, for 103 countries.

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APPENDIX

LIST OF COUNTRIES (COUNTRIES ARE ORDER BY REGIONS AS USED IN FIGURE 5, THE REMAINING COUNTRIES HAVE BEEN INCLUDED IN *OTHERS* INDEPENDENTLY OF THE REGION THEY ARE IN)

Africa

Algeria *ALG,* Angola *ANGO,* Burkina Faso *BUF,* Cameroon *CAM,* Côte d'Ivoire *CDI,* DR Congo *CONG,* Egypt *EGY,* Ethiopia *ETI,* Ghana *GHA,* Kenya *KEN,* Madagascar *MAD,* Malawi *MWI,* Mali *MLI,* Morocco *MOR,* Mozambique *MOZ,* Niger *NIG,* Nigeria *NGA,* Senegal *SEN,* South Africa *SOA,* Sudan *SUD,* Tanzania *TAN,* Tunisia *TUN,* Uganda *UGA,* Zambia *ZAM,* Zimbabwe *ZBW.*

East Europe

Albania *ALB,* Bulgaria *BUL,* Czechoslovakia *CZR,* Hungary *HUN,* Poland *POL,* Romania *ROM. After 1989 we continue using Czechoslovakia as an aggregate of Czech Republic and Slovakia.*

East Asia

Hong Kong *HKG,* Indonesia *INDO,* Malaysia *MLY,* Singapore *SIN,* South Korea *SOK,* Thailand *THA*.

Western Europe

Austria *AUS*, Belgium *BEL*, Denmark *DEN,* Finland *FIN,* France *FRA,* Germany *GER,* Ireland *IRE,* Italy *ITA,* Netherlands *HOL,* Portugal *POR,* Spain *SPA,* Sweden *SWE,* Switzerland *SWI.*

Latin America

Argentina *ARG,* Barbados *BRB,* Bolivia *BOL,* Brazil *BRA,* Chile *CHI,* Colombia *COL,* Costa Rica *CRI,* Dominican Republic *DOM,* Ecuador *ECU,* Guatemala *GUA,* Jamaica *JAM,* Mexico *MEX,* Peru *PER,* St. Lucia *STL,* Trinidad and Tobago *TRI,* Uruguay *URU,* Venezuela *VEN,*

Others

Australia *AUT,* Bahrain *BAH,* Bangladesh *BNG,* Cambodia *CAM,* Canada *CAN,* China *CHI,* Cyprus *CYP*, Greece *GRE,* Iceland *ICE,* India *INDI,* Iran *IRAN,* Iraq *IRAQ,* Israel *ISR,* Japan *JPN,* Jordan *JOR,* Kuwait *KWT,* Luxembourg *LUX,* Malta *MAL,* Myanmar *MYA,* New Zealand *NZE,* Norway *NOR,* Oman *OMN*, Pakistan *PAK,* Philippines *PHI,* Qatar *QAT* Saudi Arabia *ARS,,* Sri Lanka *SRL,* Syria *SYR,* Taiwan *TAW,* Turkey *TUR,* United Arab Emirates *EAU,* United Kingdom *UK,* United States *US,* USSR *USSR,* Vietnam *VIE,* Yemen *YEM.*