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Measuring Globalization: A hierarchical network approach

David Matesanz Gomez[1], Guillermo J. Ortega[2] and Benno Torgler[3]

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This paper investigates the business cycle co-movement across countries and regions since the middle of the last century as a measure for quantifying the ongoing globalization process of the world economy. Our methodological approach is based on analysis of a correlation matrix and the networks it contains. Such an approach summarizes the interaction and interdependence of all elements and it represents a more accurate measure of the global interdependence involved in the economic system. Our results show (1) that the dynamics of globalization has been more driven by synchronization in regional growth patterns than by the synchronization of the world economy as a whole in contrast with other empirical works and (2) that world crisis periods increase dramatically the global co movement in the world economy.

JEL Classifications: E320, C450, O470

Keywords: Globalization, regionalism, correlation matrix, clustering, synchronization

[1] *David Matesanz Gomez,* Applied Economics Department, University of Oviedo, Avda. Cristo s/n, 33006, Oviedo, Spain

[2] Guillermo J. Ortega, Science and Technology Department, Universidad Nacional de Quilmes and CONICET, Argentina

[3] Benno Torgler, School of Economics and Finance, Queensland University of Technology, GPO Box 2434, Brisbane, Australia 4001, CRÈME – Center for Research in Economics, Management and the Arts, Switzerland, CESifo, Germany, National Centre for Econometric Research, e-mail: Benno.Torgler@qut.edu.au

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DAVID MATESANZ GOMEZ
Applied Economics Department, University of Oviedo
Avda. Cristo s/n, 33006, Oviedo, Spain

GUILLERMO J. ORTEGA
Science and Technology Department, Universidad Nacional de Quilmes
and CONICET, Argentina

BENNO TORGLER
The School of Economics and Finance, Queensland University of Technology
GPO Box 2434, Brisbane, QLD 4001, Australia
CREMA – Center for Research in Economics, Management and the Arts, Switzerland
CESifo, Germany
National Centre for Econometric Research (NCER), Australia

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This paper investigates the business cycle co-movement across countries and regions since the middle of the last century as a measure for quantifying the ongoing globalization process of the world economy. Our methodological approach is based on analysis of a correlation matrix and the networks it contains. Such an approach summarizes the interaction and interdependence of all elements and it represents a more accurate measure of the global interdependence involved in the economic system. Our results show (1) that the dynamics of globalization has been more driven by synchronization in regional growth patterns than by the synchronization of the world economy as a whole in contrast with other empirical works and (2) that world crisis periods increase dramatically the global co movement in the world economy.

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1. Introduction

Globalization, 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 involved in the world economy. Although consubstantial with human social interaction since ancient times, during the last century, the process has undergone major acceleration. Several factors – including religion (Cleary, 2008), democracy (Li & Reuveny, 2003), transnational terrorism (Li & Schaub, 2004), values (Whalley, 2008) and industrialization (Brady & Denniston, 2006) – offer possibilities for analyzing this process; however, much of the research into the advance, effects, and consequences of globalization has focused on its economic or distributional aspects (see, e.g., Goldberg & Pavcnik, 2007).

For example, beginning in the early 1990s, the global integration of capital markets accelerated rapidly until by 2003, external assets and liabilities were, relative to output, triple 1990 levels in developed countries. The trend for developing countries was similar, even though on a smaller scale than in industrial nations (IMF, 2005). Likewise, international trade in merchandise is 30 times and volume output around 8 times as large the 1950 level, following World Trade Organization data. This rapid economic integration has been the focus of many analytical attempts to quantify globalization independent of its political, social, cultural, and/or technological aspects (Kearney, 2002; Dreher, 2006, 2008).

Such research frequently employs the terms "globality" and "globalization" to capture the ongoing large-scale growth of transplanetary – and often supraterritorial – connectivity (Scholte, 2008) and frequently measures the globalization process by the economic integration manifest in business cycles. That is, as long as international capital and goods markets are growing faster than world economies, economic interdependence should manifest in a relatively synchronized economic cycle. Thus, globalization can be defined as an increase in the similarities in global patterns of economic growth, defined as the per capita annual rate of growth in the gross domestic product (GDP). The principal aim of this study, therefore, is to analyze growth pattern similarities and cross-country liaisons arising from the evolution of globalization over the last decades. In line with Mantegna (1999), Ortega and Matesanz (2006), and Miskiewicz and Ausloos (2010), among others, our methodological approach is based on analysis of a correlation matrix and the networks it contains and centers on the connectivity and interaction in the economic performance produced by interdependence in the world economy.

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 to some extent reveals country clusters related to regional integration arrangements like the European Union or the Association of Southeast Asian Nations (ASEAN), we examine the globalization process of interdependence in the world economy through a regional lens. We conclude that the dynamics of globalization in the last decades have been more driven by synchronization in regional growth patterns than by the synchronization of the world economy as a whole. Contrary to Kose, Otrok &Whiteman (2003), 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 comevements and interdependence.

The rest of the paper is organized as follows. Section 2 presents an overview of the relevant literature on globalization 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 light of previous research and discusses their statistical and economic implications.

2. Economic integration and globalization

Although the economic aspects of globalization have attracted much attention over the past 20 years (see, e.g., Williamson, 1996; Rodrik, 1998; Baldwin & Martin, 1999, Arribas Fernandez et al., 2007; Goldberg & Pavcnik, 2007), one particularly important strand of this vast literature examines interdependence and integration in the globalization process by analyzing business cycle synchronization in the economy (Artis et al., 2011; Aruoba et al., 2011; Miskiewicz &Ausloos, 2010; Anatonakakis & Scharler, 2010; Claessens et al., 2009; Artis & Okubo, 2009; Crucini et al., 2008; Kose, Otrok, & Whiteman, 2008; Doyle & Faust, 2005; Helbling & Bayoumi, 2003; Kose, Otrok, & Whiteman, 2003; Kose, Prasad & Terrones, 2003). However, although such research typically measures synchronization 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, Prasad & Terrones's (2003) analysis of comovements in 76 developed and developing countries between 1960 to 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 globalization leads to an increase in the degree of business cycle synchronization worldwide. Anatonakakis and Scharler (2010), on the other hand, using conditional correlation analysis, identify unusually high synchronized output growth dynamics in G7 countries during the recent international recession (2007–2009) compared to an earlier period beginning in 1960. In the same line, by using dynamic factor models Aruoba et al. (2011) report that the 2009 recession is the deepest and most synchronized recession in the post war era within the G-7 countries. 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 synchronization within a group of European and English-speaking countries. Therefore, their results show a limited and more regional world picture of increasing synchronization and globalization.

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

Although most of this literature analyzes synchronization based on an increased correlation between some measure of “world” output and its occurrence in each country (Anatonakakis & Scharler, 2010; Adalet & Oz, 2010; Artis & Okubo, 2009; Crucini et al., 2008; Helbling & Bayoumi, 2003, Kose, Otrok, & Whiteman, 2003; Kose, Prasad & Terrones, 2003), one important stream addresses the notion of the “decoupling” of developed and developing business country cycles (Kose, Otrok, & Prasad, 2008; Levy-Yeyati, 2009; Wälti 2009). Nonetheless, findings on this issue are again mixed and contradictory. 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 organization of the correlation matrix according with the closeness relation among its constituents (or elements) , and the construction of a network derived from it (see Mantegna, 1999, Ortega & Matesanz, 2006; Miskiewicz & Ausloos, 2010 among others). Because such an approach summarizes the interaction and interdependence of all elements, it represents a more accurate measure of the global interdependence involved in the economic system.

To achieve this goal, 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., 2009). 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 synchronization could be occurring within different regions rather than at a global level in the world economy (Baumol, 1986; Quah, 1993, 1997). Finally, to examine the evolution of the globalization 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 this 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 progress to globalization. It should also be noted that our regional clusters, rather than being exogenously obtained as in most other papers (see, e.g., Bordo and Helbling, 2003, 2010) are endogenously generated from the output synchronization itself. Second, our observation of cycle synchronization through overlapping windows produces a more accurate picture of comovement evolution over time.

3. Data and methodology

3.1 Data

This work analyzes 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 U.S. dollars converted into Geary Khamis 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 recently. The 103 countries analyzed 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 the returns from GDP (*rGDP*) in each of the 103 time series in the usual way:

$$rGDP_i(k) = \frac{GDP_i(k+1) - GDP_i(k)}{GDP_i(k)} \tag{1}$$

where $GDP_i(k)$ is the annual GDP value in country i at month k and $rGDP_i(k)$ is the corresponding return. Our dataset thus conforms to a matrix of 59 files (yearly returns) and 103 columns (countries).

3.2 Numerical methods

3.2.1 Hierarchical analysis

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

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

In our particular case, $\bar{x}_i = x_i(k), k = 1, N_{dat}$ corresponds to each of the $rGDP_i(k)$ time series so that $1 \le i \le 103$ (number of countries) and $1 \le k \le N_{win}$ (number of analyzed years). To transform correlations, $\rho_{i,j}$, into distances, we follow Gower (1966) and define the distance $d(i,j)$ between the evolution 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 correlation coefficient and $d(i,j)$ fulfils the three axioms of a distance:

- $d(i,j) = 0$ if and only if $i = j$
- $d(i,j) = d(j,i)$
- $d(i,j) \le d(i,l) + d(l,j)$ (4)

Armed with the nodes (103 countries) and the corresponding links (distances) among them, it is therefore straightforward constructed (e.g. using the Kruskal algorithm (Kruskal, 1956) the minimum spanning tree (MST) associated at 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 synchronization) 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 organization, 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 dendogram to illustrate the clustering characteristics of the data organization. In fact, clustering data into groups of members with tight connections among them is a usual way to define *communities* (Wasserman & 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). The simplest one of these methods is based on the analysis of the dendogram, because a simple horizontal cut of a hierarchical tree at a particular distance automatically yields clusters/communities of tightly connected members. In the rest of the paper we will use a more refined method (Langfelder, Zhang, & Horvath, 2008) to extract communities from a hierarchical tree analysing the structure of the hierarchical tree dynamically and extracting from it the relevant clusters/communities.

3.2.2. Time windows analysis

To examine the temporal behavior of interdependence relations among elements of the business cycle, we also calculate distance correlation matrices for overlapping windows of 5, 10, and 15 years forward in time and move each temporal window over the entire sample period in 1-year increments beginning with 1950. To enable comparisons among different clusters of unequal number of countries, we sum the matrices coefficients for each window and normalize them to the number of countries. Each dataset 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 by summing all the distances represented in each tree branch and normalizing them in the same way as previously to produce the measure that we term *MST cost*.

The sum of all the matrices coefficients signifies the interdependence among all countries, which we call the *global correlation*, while the MST cost represents the evolution of the interdependence of the closest connections in the business cycle for each country. The higher the value of the normalized 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 comovement 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.

4. Empirical results

4.1. Cross-country hierarchical structure

Fig. 1(a) and (b), constructed using Pearson-correlation based metric distances, shows the MST and HT, respectively, of the GDP per capita in the 103 countries analyzed for the entire 1950 to 2009 sample. The structure displayed in Fig. 1(a) gives a rough idea of the topological organization in the 103 countries considered, where proximity between two countries is marked by a direct link between them. However, it is impossible from this sole construction to know how close two linked members are. We therefore turn to the construction of the HT as in Fig. 1(b) which gives a hierarchical structure accordingly with the 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 numbers 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. 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 U.S. 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.

[Figure 1 (a) and (b) around here]

Fig. 2 (a) and (b) summarizes 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 (Fig. 2a). Inclusion in the analysis of the country pairings (Fig. 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 U.S., and other Eastern countries in a group to which Australia is linked.

[Figure 2 (a) and (b) around here]

Because the time period is extensive in economic terms, to test the robustness of the country groupings given in Fig. 1, we divide the sample into two subperiods (1950−1980 and 1980−2009) for which we also calculate the MST and HT. Comparing (a) and (b) plots in Fig. 3 we can observe how the regional blocs seem to aligned along the time sample we are analyzing. In Fig. 3 (a) the regional economic dynamics seem to be more disorganized than beforehand. For instance, Spain, Greece and even Germany are not in the Western European group or South Asian countries are less integrated among them than in Fig.1. However, in the period 1980-2009, Fig. 3 (b), the clusters are aligned in a more regional arrangement suggesting that clubs synchronization is a dynamical process where time is fundamental to adjust the economic rhythms among members.

To characterize 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 Fig. 2 has been created over time; that is, regional communities have become more defined since the 1990s than during the 1950s and 1960s.[1] 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 such institutional economic arrangements as the European Union, the Soviet bloc, and the ASEAN, 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 globalization process *inside* the group. We test this assumption in the next section.

[Figure 3 (a) and (b) around here]

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

4.2. Regional and dynamic analysis.

Fig. 4 plots the normalized correlation coefficients and MST cost for 103 countries in the 10-year overlapping windows and also depicts trends. Each data point in the figure represents the normalized 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 sample, the first during the early years of the 1970s (coinciding with the first world oil recession) and the second at the end of the last century period, especially since 2002. Interestingly, when the current world crisis period, 2008-2009, is included in the calculations, the correlation coefficients increase strongly, reaching the highest value in the period analyzed. 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 synchronization increases strongly during global economic crises, there is no post-crisis return to the previous synchronization condition. Hence, the trend to a more integrated world economic output is seemingly driven by episodes of world economic tension and change.

[Figure 4 around here]

To illustrate the dynamic of output comovement in our regional "clubs" and other selected areas, Figures 5 and 6 depict the normalized correlation coefficients and MST cost, respectively (countries included in each region are listed in Appendix). The most interesting finding (see Fig. 5) − which involves Europe, East Asia, and to some extent Eastern Europe − appears related to the increased cycle synchronization in developed countries and the rapid economic growth in transition countries in Eastern Europe potentially driven by the EU enlargement and Europeanization process . In Europe, the launching of the European common market in 1993 and the Monetary Union in 1999 generates a faster integration of the economic cycle in the region. In contrast, Africa and Latin America, which are characterized by no regional clusters (see Fig. 1 (a) and (b)) not only show the shortest levels of correlation, but alsono advance in output integration in either region is found. The fact that crisis periods tend to increase comovements in regional cycles is particularly well illustrated in East Asia by the economic collapse and structural transformations that follow the 1997−1998 financial crisis and in Eastern Europe by those that following the fall of the Berlin Wall.

[Figure 5 and 6 around here]

Fig. 6 outlines the MST cost evolution over time in the same regions as in the previous figure. 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 Fig. 6 appears to be related to a more restrictive type of interdependence and synchronization. That is, developed regions show a higher degree of synchronization (less metric distance). Once again, this observation holds particularly true for United States and Canada[2], the European countries and East Asia, while Africa and Latin America show the smallest degree of comovement. The similarity of the results in Figs. 5 and 6 strongly supports the conjecture, generated by the cluster analysis in Section 4.1, that regional convergence clubs play a major role in globalization. Otherwise, the first distances for each country (i.e., the MST cost) would have to be deeper in terms of comovement than in the global correlation (which includes bilateral correlations between all countries inside each cluster).

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

5. Concluding remarks

The notion of globalization reflects the current ongoing large-scale growth of transplanetary connectivity and consequently the notion of growing world interdependence. A major implication of this notion is that countries and regions should exhibit an increasing degree of synchronization in their economic cycles. This paper therefore evaluates the synchronization manifest in business cycles in order 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 (see Mantegna, 1999: Ortega & Matesanz, 2006; Miskiewicz & Ausloos, 2010) produced several interesting results.

Our most important finding is that globalization, defined as synchronization in world output, is a regional rather than a truly global process in line with recent research (Artis et al. 2011) and in contrast to other empirical results (Kose, Otrok & Whiteman, 2003). 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 synchronization. Therefore, as suggested by Dreher (2006), Ming-Chang (2007) and Bordo and Helbling (2010), a regional approach is central to understanding the globalization process

A second primary finding is that global crises, such as the 1970's 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 synchronization. Most particularly, although a certain degree of desynchronization is observable after a crisis, as Bordo and Helbling (2010) point out, the tendency over time is to increasing output integration and the production by output crises of anomalous behavior. 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)

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APPENDIX

List of countries. Alphabetical order

Austria *AUS*, Belgium *BEL*, Cyprus *CYP*, Denmark *DEN,* Finland *FIN,* France *FRA,* Germany *GER,* Greece *GRE,* Iceland *ICE,* Ireland *IRE,* Italy *ITA,* Luxembourg *LUX,* Malta *MAL,* Netherlands *HOL,* Norway *NOR,* Portugal *POR,* Spain *SPA,* Sweden *SWE,* Switzerland *SWI,* Turkey *TUR,* United Kingdom *UK,* Canada *CAN,* United States *US,* Australia *AUT,* New Zealand *NZE,* Albania *ALB,* Bulgaria *BUL,* Czechoslovakia *CZR,* Hungary *HUN,* Poland *POL,* Romania *ROM,* USSR *USSR,* Bangladesh *BNG,* Cambodia *CAM,* China *CHI,* Hong Kong *HKG,* India *INDI,* Indonesia *INDO,* Japan *JPN,* Malaysia *MLY,* Myanmar *MYA,* Pakistan *PAK,* Philippines *PHI,* Singapore *SIN,* South Korea *SOK,* Sri Lanka *SRL,* Taiwan *TAW,* Thailand *THA,* Vietnam *VIE,* 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 & Tobago *TRI,* Uruguay *URU,* Venezuela *VEN,* Bahrain *BAH,* Iran *IRAN,* Iraq *IRAQ,* Israel *ISR,* Jordan *JOR,* Kuwait *KWT,* Oman *OMN*, Qatar *QAT,* Saudi Arabia *ARS,* Syria *SYR,* United Arab Emirates *EAU,* Yemen *YEM,* 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*

Countries by region

Africa

Algeria,Angola, Burkina Faso, Cameroon, Côte'Ivoire, DR Congo, Egypt, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Mali, Morocco, Mozambique, Niger, Nigeria, Senegal, South Africa, Sudan, Tanzania, Tunisia, Uganda, Zambia, Zimbabwe

East Europe

Albania, Bulgaria, Czechoslovakia, Hungary, Romania (South Africa has been excluded unless makes part of this group as seen in figure1(b). Anyway, proofs including it do not change the results. After 1989 we continue using Czechoslovakia as an aggregate of Czech Republic and Slovakia.

East Asia

Hong Kong, Indonesia, Malaysia, Singapore, South Korea, Thailand

Europe

Austria, Belgium, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, Switzerland

Latin America

Argentina, Barbados, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Guatemala, Jamaica, Mexico, Peru, St Lucia, Trinidad & Tobago, Uruguay, Venezuela

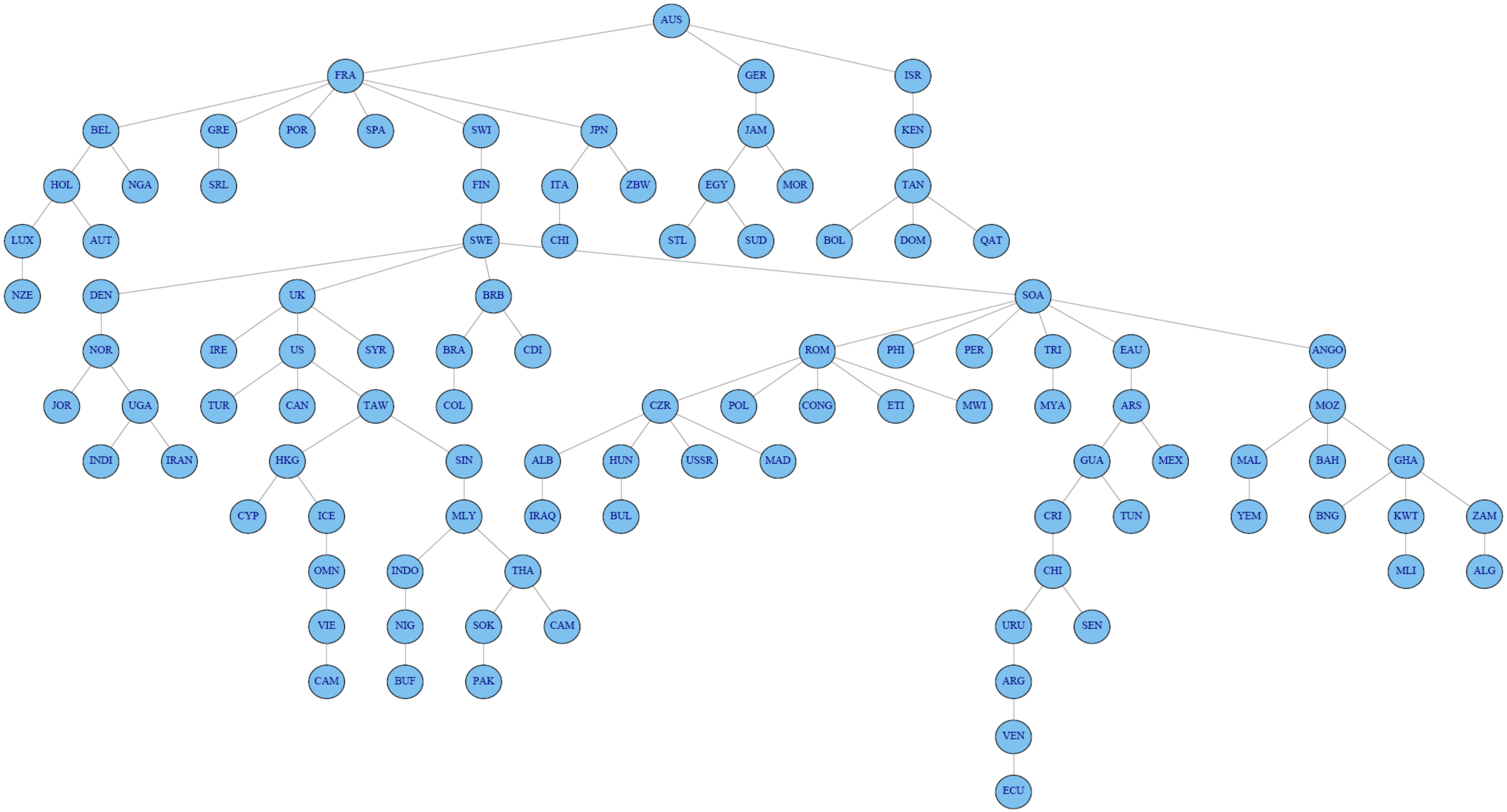


Figure 1(a). Minimum spanning tree: GDP per capita, 1950–2009, for 103 countries.

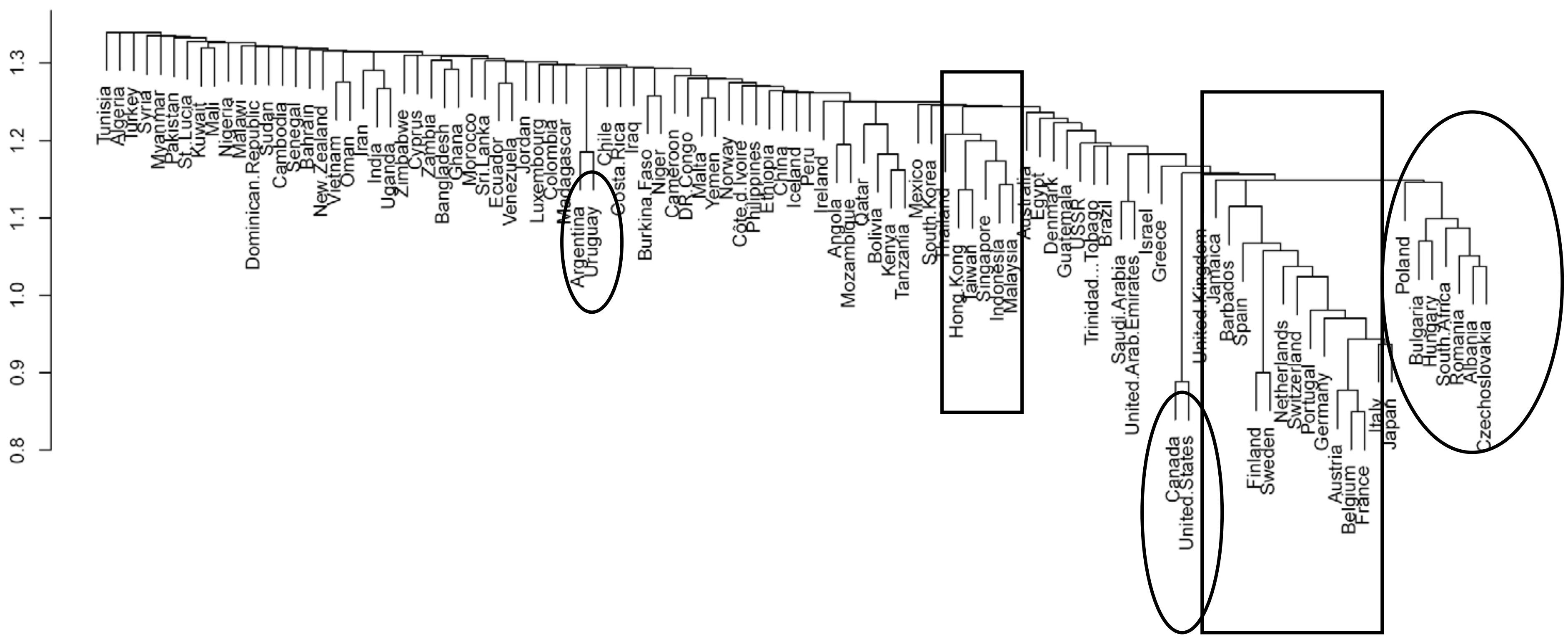
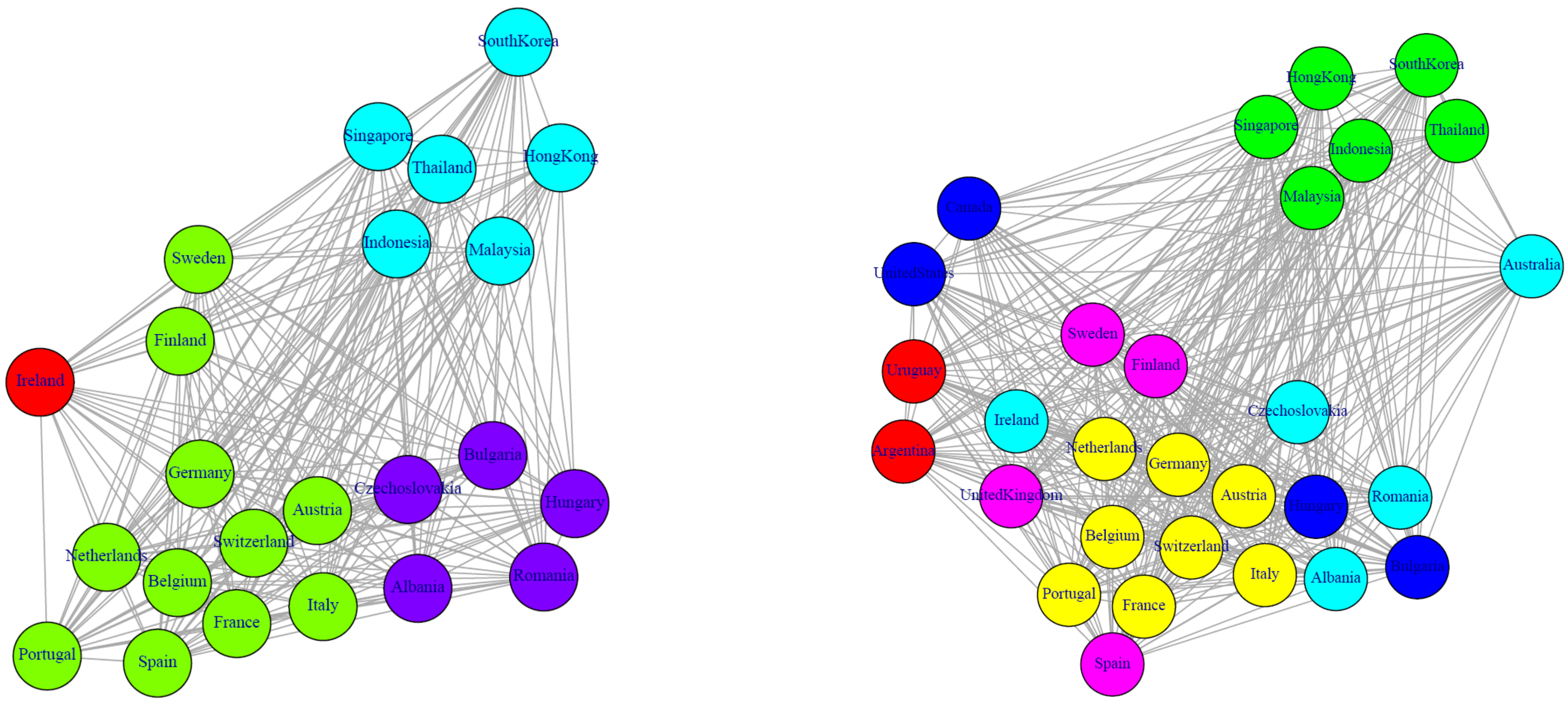


Figure 1(b). Hierarchical tree (HT): GDP per capita, 1950–2009, for 103 countries.



(a)* **(b)**

Figure 2. Community network: GDP per capita, 1950–2009: **(a)** Western and East Europe and East Asia; **(b)** Western and East Europe, East Asia, Uruguay, Argentina, United States, Canada, United Kingdom.

*After 1989 we continue using Czechoslovakia as an aggregate of Czech Republic and Slovakia.

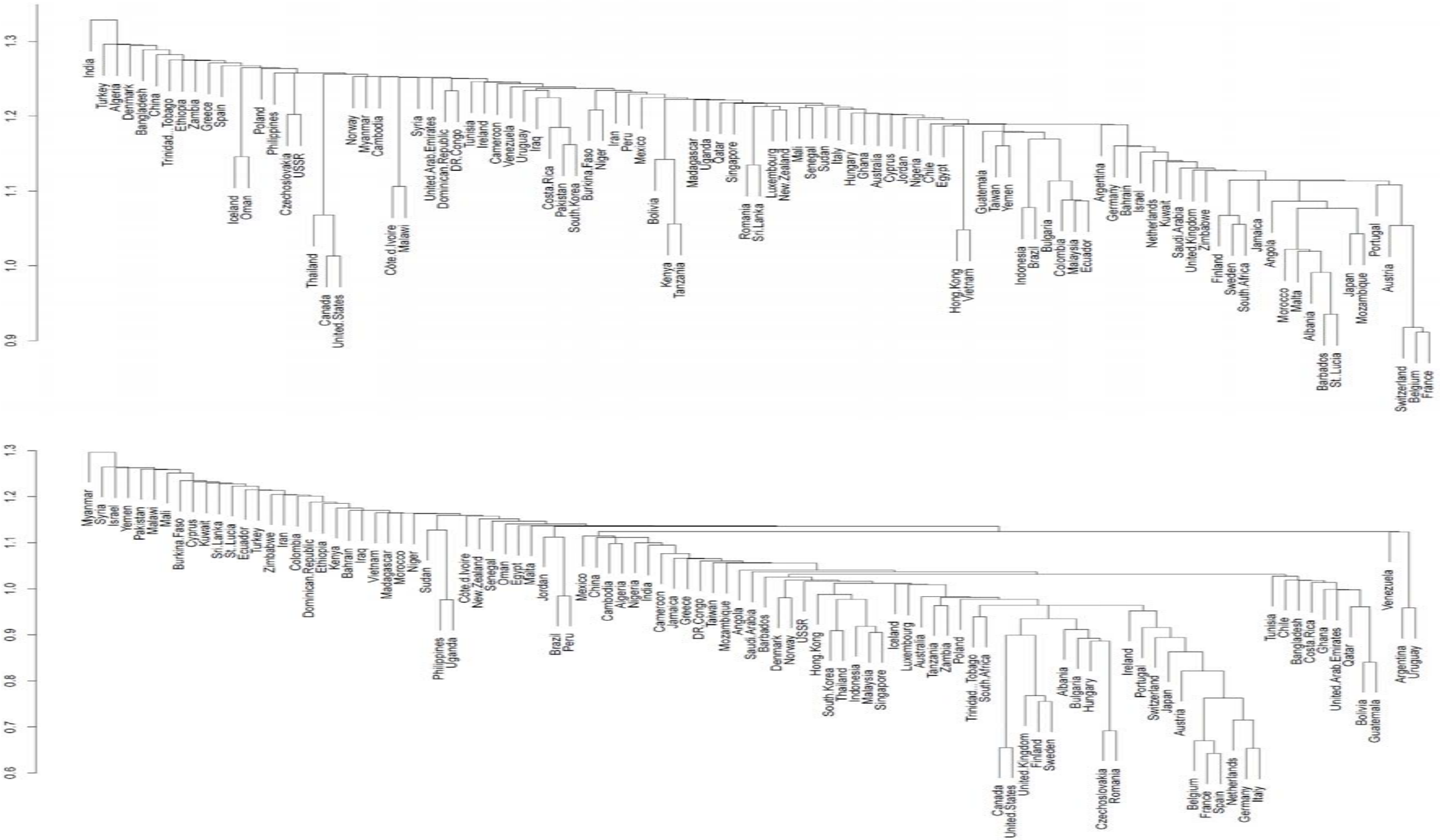


Figure 3. Hierarchical tree (HT): GDP per capita, for 103 countries. **(a)** 1950–1980, **(b)** 1980-2009.

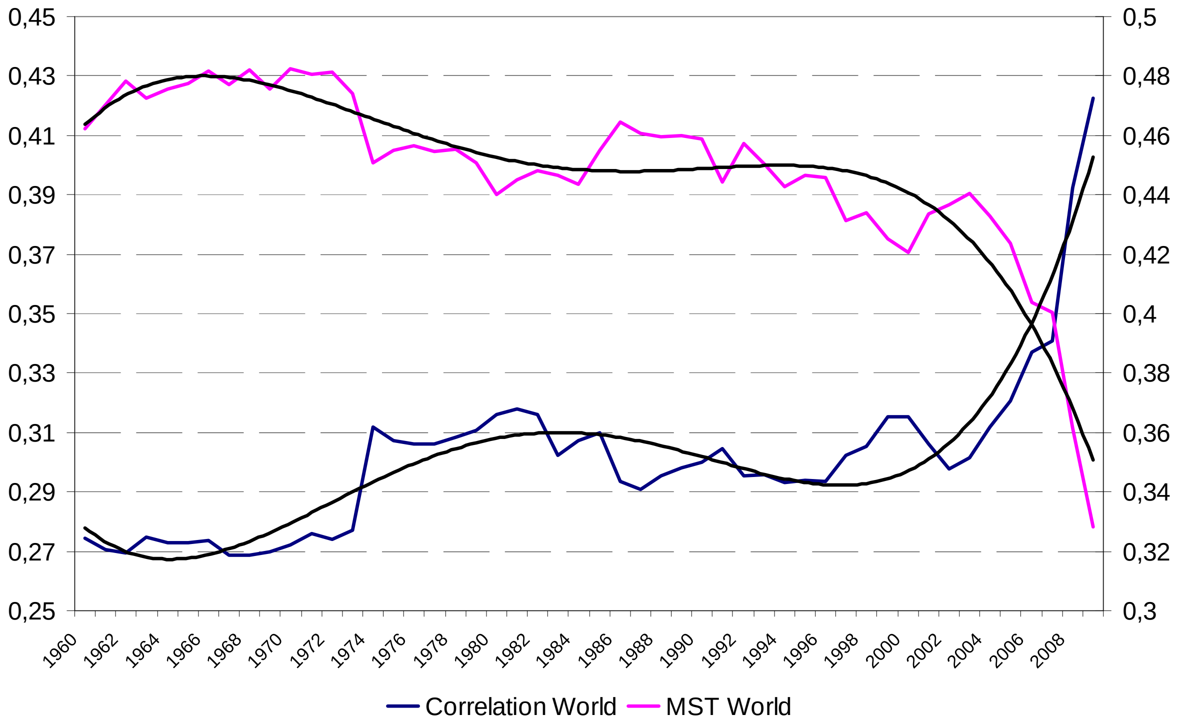


Figure 4. Normalized correlation coefficients (left scale) and MST cost (right scale): 10-year overlapping windows for 103 countries.

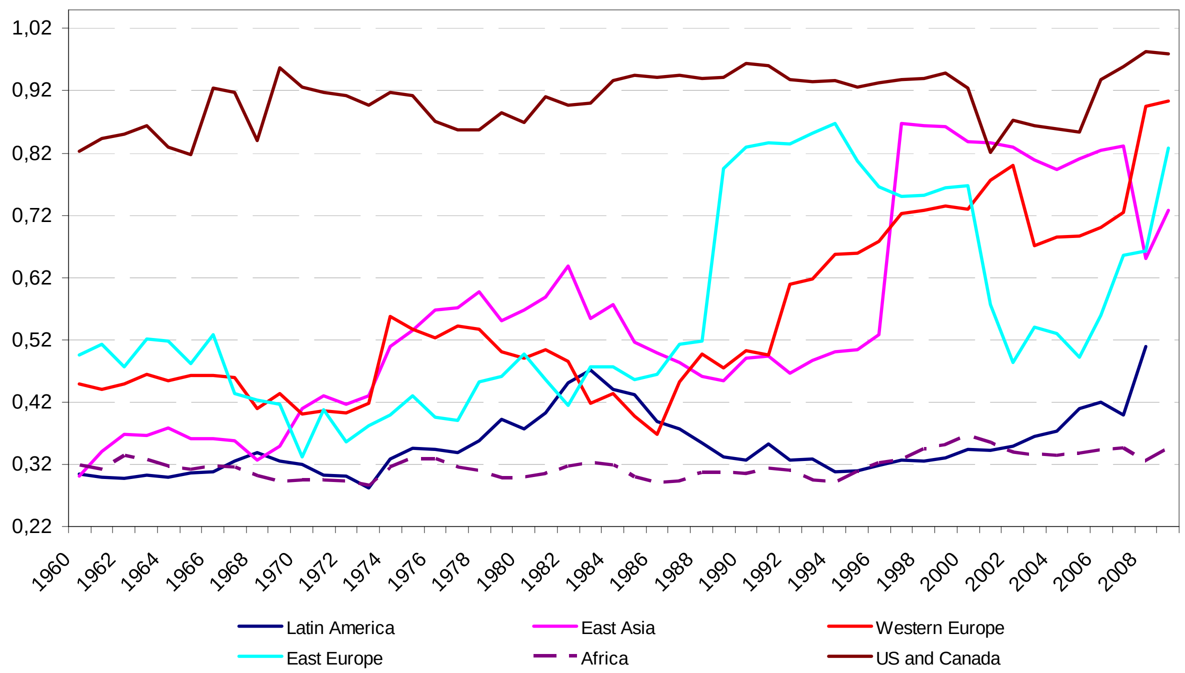


Figure 5. Normalized correlation coefficients: 10-year overlapping windows, selected regions.

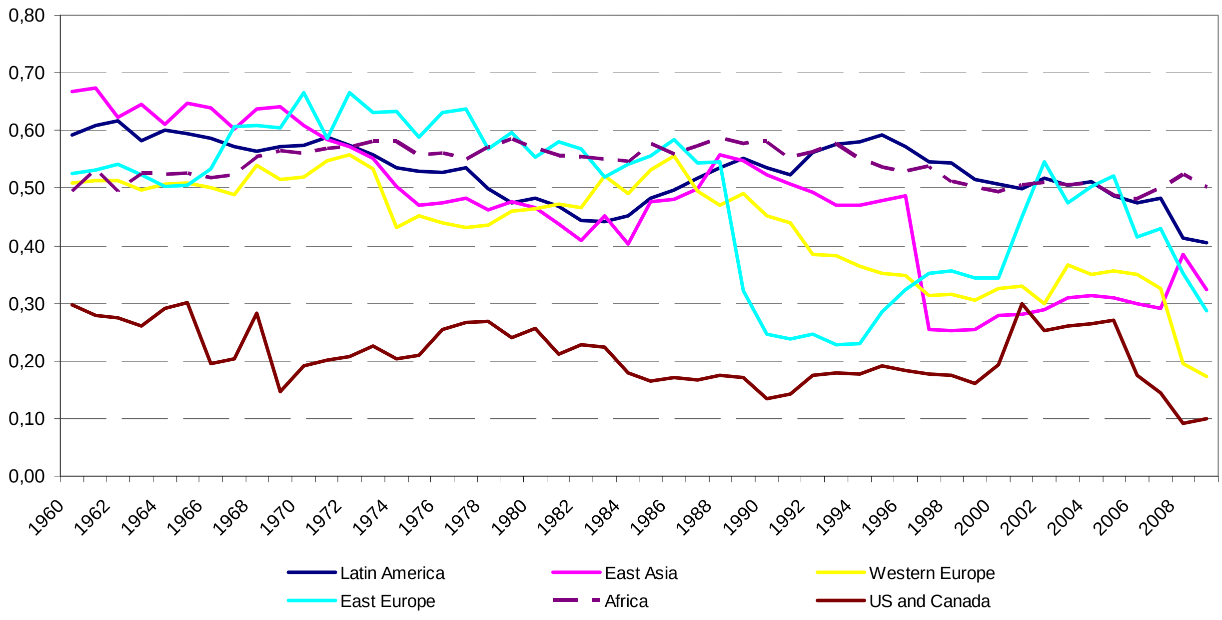


Figure 6. Normalized MST cost: 10-year overlapping windows, selected regions.