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ABSTRACT

In this paper we detect the linear and nonlinear co-movements presented on the real exchange rate in a group of 28 developed and developing countries that have suffered currency and financial crises during 15 years. We have used the matrix of Pearson correlation and Phase Synchronous (PS) coefficients and an appropriate metric distance between pairs of countries in order to construct a topology and hierarchies by using the Minimum Spanning Tree (MST). In addition, we have calculated the MST cost and global correlation coefficients to observe the co-movements dynamics along the time sample. By comparing Pearson and phase synchronous information we address a new methodology that can uncover meaningful information on the contagion economic issue and, more generally, in the debate around interdependence and/or contagion among financial time series. Our results suggest some evidence of contagion in the Asian currency crises but this crisis contagion is due to previous and stable interdependence.

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KEYWORDS: econophysics, linear co-movements, phase synchronous co-movements, MST, interdependence and contagion

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I. Introduction

As happens with stocks, exchange markets are complex systems due to the high number of factors involved in the price of currencies. An important point regarding this kind of markets is to what extent currencies from different countries are correlated and moreover, the issue of whether correlations are part of stable cross-country relations or they only shows up in particular times, for example during financial crises. A strand of the (econophysics) empirical literature has analyzed topologies and hierarchy in the stock markets trying to detect linear coupling among stocks returns time series (Mantegna (1999), Plerou *et al.* (1999), Beben and Orlowski (2001), Bonanno *et. al.* (2001a and 2001b), Bonanno *et al.* (2004), Brida and Risso (2007), among others). Few authors have used non-linear cross-correlations tools in order to detect co-movements among stocks in a more wide sense. Darbellay and Wuertz (2000) and Marschinski and Kantz (2002) are two examples that have used information-theoretic tools, based on the entropy concept in order to detect non linearities in the stock markets. Coupling among currencies has arisen however, less attention on the econophysics field with fewer exceptions as for example in the works of Ortega and Matesanz (2006), Mizuno, *et al.* (2006) and Naylor *et al.* (2007) .

During the nineties the increase of global integration of capital markets has produce important volatility and crises episodes in stocks and exchange rate markets. The European Monetary System (EMS) speculative attacks in 1992-1993, The Mexican crises in December 1994; the collapse of southern Asian currencies in 1997 and 1998; The Brazilian currency devaluation on January 1999 and the Argentine currency devaluation and external debt default on January 2002, are the most relevant currency crises episodes in the 1990s, but there exists more (see for example Pérez (2005) and Kaminsky, *et al.* (1998) for a complete list of currency crises episodes). It is supposed that, in some cases, crises have spread from one country to another producing what has been labelled as *contagion or shift contagion* (Rigobon, 2001). Probably, the most accepted definition of contagion is those given by King and Wadhwani (1990) and Forbes and Rigobon (2002): an important change (increase) in cross-markets linkages after a shock to one country or group of countries. Still today, the debate in the economic contagion literature is if linkages between countries grew stronger during these crises or it is because they were already strong before the crises took place? This question has been labelled *contagion* (or shift contagion) or *interdependence* debate, respectively. However, no satisfactory procedure has been developed to answer that question (Rigobon, 2003). Works on this issue are inconclusive. For instance, Hatemi and Hacker (2005) find evidence of contagion between Thailand and Indonesia equity markets during the Asian financial crises by estimating correlations between the slopes in a regression of pairs of financial variables. Gravelle *et al.* (2006) find evidence of contagion in developed countries and uncover evidence of interdependence in Latin American countries. Arestis *et al.* (2005) use conditional correlation analysis and find evidence of contagion for most pair of countries during the Asian crises; moreover they find strong evidence of interdependence among Asian countries during tranquil times. Dungey *et al.* (2006) discover evidence of contagion in the currency markets during the Asian crises, especially from Thailand to other Asian countries. Corsetti *et al.* (2005) find some contagion effects and some interdependence effects on the Hong Kong stock market crisis of October 1997 as a case study. Candelon *et al.* (2005) find no evidence of contagion in Mexican and Asian crises but long term interdependence among involved countries. Bialkowski and Dobromil (2005) find no evidence of contagion effects between the Japanese and Hong Kong stock markets by a model that introduce the concept of causality in the markov switching framework. Finally, in Dungey *et al.* (2005) an extensive review in the methodologies and results in this issue can be found.

In this paper we detect linear and nonlinear co-movements presented in the Real Exchange Rate (*RER*) in a group of 28 developed and developing countries[1]. Within this group are included those that have suffered currency and financial crises in 15 years (see appendix for a complete list of countries). In so doing, we address a new methodology based on the construction of topological trees associated with the distance among exchange rate dynamics in order to obtain a country taxonomic description, in line with (Mantegna (1999), Bonanno *et al*. (2001a and 2001b), Ortega and Matesanz (2006), Mizuno, *et al.* (2006), Naylor *et al.* (2007), among others). The novelty of this work relies in the use of Pearson correlation and Phase Synchronous (PS) matrices, and the appropriate metric distance between pairs of countries. By comparing both matrices we present a methodology that can be useful to show meaningful insights on the contagion economic issue and, more generally, in the debate around interdependence or contagion among financial time series

[1] We have used the real exchange rate, instead of nominal exchange rate, to avoid the influence of hyperinflation episodes in some countries during the considered period.

Phase synchronization is a tool that uncovers non linear co-movements in a very special way. It quantifies the phase coupling among the involved variables, regardless their amplitudes[2]. The concept of phase synchronization was introduced by Rosenblum *et al.* (1996) in relation with chaotic oscillators. By using this concept we are able to avoid several problems found in the empirical literature of interdependence and contagion. The first one is that we do not need to separate our sample in crises and non-crises periods, avoiding the typical problem arising from large tranquil periods and short crises samples (as Arestis *et al.* (2005) have pointed out). In the same direction, we do not need to select the breakpoints corresponding to the beginning and the end of the contagion period and so we do not have to date currency crises. Therefore, our main objective is the application of phase synchronization tool to detect interdependence in a wide sense among the financial time series. To the best knowledge of the authors, information and topological structure obtained from the non-linear phase synchronous matrix has not been used in the economic literature.

The rest of the work is organized as follows. In section II we present methodology issues and data. Third section shows the main results of the analysis. Section four concludes and provides direction for future research.

II. Methodology

II.1 Data sets

Returns from *RER* in each of the time series has been calculated in the usual way,

$$rRER_i(k) = \frac{RER_i(k+1) - RER_i(k)}{RER_i(k)}$$

where $RER_i(k)$ is the monthly real exchange rate from country i, at month k, and $rRER_i(k)$ its corresponding return. The period 1992(March)-2002(December) has been used, yielding a total of $N_{dat} = 128$ data points for each country. Figure 1 shows actual time series used in all the calculations. Countries are ordered by the entropy criteria (see Matesanz and Ortega

[2] In section II. 2. the phase synchronization concept is widely explained.

(2008)). Vertical dotted lines marks major international crisis as stated in the literature, (see, for instance, Pérez (2005) and Kaminsky, *et al.* (1998)). *RER* is computed as the ratio of foreign price proxied by U.S. consumer price to domestic consumer price, and the result is multiplied by the nominal exchange rate of the domestic currency with U.S. dollar. All data have been drawn from International Financial Statistics in the IMF database available online (*http://ifs.apdi.net/imf/logon.aspx*)

II.2 Linear and non-linear synchronization measures

There exist several methods aimed to quantify interaction or synchronization degree between two or more variables. The most used in the literature is the cross correlation coefficient, also known as Pearson coefficient ρ. Given two time series $\overline{x}_i = x_i(k), k = 1, N_{dat}$ and $\overline{x}_j = x_j(k), k = 1, N_{dat}$ the Pearson correlation coefficient between country *i* and country *j* is defined as:

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

In our particular case, $\overline{x}_i = x_i(k), k = 1, N_{dat}$ corresponds to each of the $rRER_i(k)$ time series, in this way, $1 \leq i \leq 28$ (number of countries) and $1 \leq k \leq N_{dat}$ (number of analyzed months). However, it must be noted that $\rho_{i,j}$. is a linear measure of interdependence, that is, highly values of ρ reflects high *linear* correlation between the variables. On the contrary, low values of ρ implies absence of linear relation, but there would exists however a strong nonlinear coupling among them. In our calculations, the absolute value of $\rho_{i,j}$ has been used.

On the other side, the concept of phase synchronization, introduced by Rosenblum *et al.* (1996) in relation to chaotic oscillators has been increasingly used in the last years, especially in the field of neuroscience (Garcia Dominguez *et al.*, 2005; Rosenblum *et al.*, 2001). It has been also extended to the case of noisy oscillators (Pikovsky *et al.*, 1997). The power of the method resides in that it measures the phase relationship, independently on the signal amplitude. In order to evaluate differences between phases in two signals, one must firstly define the *instantaneous phase* of the signal, by means of the analytical signal concept. For a continuous signal $x_i(t)$ the associated analytical or complex signal is defined as:

$$z_i(t) = x_i(t) + i\tilde{x}_i(t) = A_i(t)e^{i\phi_i(t)}$$

where $\tilde{x}_i(t)$ is the Hilbert transform of $x_i(t)$

$$\tilde{x}_i(t) = \frac{1}{\pi} p.v.\int_{-\infty}^{\infty} \frac{x(t')}{t-t'}dt' \qquad (2)$$

where $p.v.$ stands for (Cauchy) Principal Value. The instantaneous phase is thus,

$$\phi_i(t) = \arctan\frac{\tilde{x}_i(t)}{x_i(t)}$$

And the phase difference between the two signals can be calculated as

$$\Delta\phi_{i,j} = \phi_i(t) - \phi_j(t) = \arctan\frac{\tilde{x}_i(t)x_j(t) - x_i(t)\tilde{x}_j(t)}{\tilde{x}_i(t)x_j(t) + x_i(t)\tilde{x}_j(t)}$$

In order to implement numerically the above definition over two time series $\bar{x}_i(k)$ and $\bar{x}_j(k)$, the mean phase coherence (R_{ij}) was introduced (Mormann *et al.* 2000):

$$R_{ij} = \left| \frac{1}{N_{dat}} \sum_{k=1}^{N_{dat}} e^{i\Delta\phi_{ij}(k)} \right| \qquad (3)$$

calculated in the time window N_{dat}, where $\Delta\phi_{ij}(k) = \phi_i(k) - \phi_j(k)$ is the instantaneous phase difference at the discretized time *k*. It is clear from Equation (3) that R_{ij} follows the same relation as Equation (1), that is $0 \le R_{ij} \le 1$. The literature (Rosenblum *et al.*, 2001) gives useful hints for the numerical calculation of the Hilbert Transform of a time series, i.e. Equation (2).

Phase synchronization and therefore $R_{i,j}$ quantify the phase coupling among the involved variables, regardless their amplitudes. Thus it is especially useful when one or both of the variables suffer from strong or abrupt changes, like crises, booms or crashes.

II.3 Ultrametric distances

The next step is to construct an ultrametric space. To do this, a distance between *rRER* time series is needed. Following Gower (1966), we define the distance $d(i,j)$ between the evolution of time series x_i and x_j as:

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

Where $\chi_{i,j}$ is one of the two synchronization measures considered, namely $\rho_{i,j}$ or $R_{i,j}$. The last equality comes from the symmetry property of the correlation $\rho_{i,j}=\rho_{j,i}$ and phase synchronization $R_{i,j}=R_{j,i}$ matrixes and normalization $\rho_{i,i}=R_{i,i}=1, \forall i$. In this way, $d(i,j)$ fulfils the three axioms of a distance for both synchronization measures:

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

The third axiom, the triangular inequality, characterizes a metric space. An ultrametric space, on the other hand, is endowed with a distance that obeys a stronger inequality, the ultrametric distance $d(i,j)^{<}$:

$$d(i,j)^{<}\le Max\{d(i,l),d(l,j)\}$$

One method to obtain $d(i,j)^{<}$ directly from the distance matrix $d(i,j)$ is through the MST method. Given a metric space (Ω, d), i.e., countries as the elements of Ω and the distance between them defined by Equation. (4); there is, associated with this space, a nondirected graph with the same elements of Ω as vertices, and links between the elements (i, j), the distances $d(i,j)$. The MST is a tree with the same vertices as in Ω but of minimal total length. Although more than one MST can be constructed on Ω, $d^{<}$ is unique. With the information provided by the MST, the distance $d(i,j)^{<}$ between two elements i and j in is given by (Rammal, Toulouse and Virasoro, 1986).

$$d(i,j)^{<}=Max\{d(w_i,w_{i+1}), 1\le i\le n-1\}$$

Where $C_{i,j} = \{(w_1, w_2), (w_2, w_3), ..., (w_{n-1}, w_n)\}$ denotes the unique path in the MST between i and j ($w_1 = i$; $w_n = j$).

In what follows, we extend the analysis and methodology already explained in the work of Mantegna (1999) for the case of stocks and Ortega and Matesanz (2006) for the case of real exchange rate, by including the non-linear information provided by the phase synchronization matrix. A comprehensive review of ultrametricity, hierarchical trees and clustering methods can be found in (Mantegna and Stanley, 2000 and Rammal, Toulouse and Virasoro, 1986).

III. Results

We have constructed the MST´s directly from the distances matrices $\rho_{i,j}$ and $R_{i,j}$. This is a straightforward construction, as it is explained in Mantegna (1999) and Ortega and Matesanz (2006). We shall call correlation MST (*cMST*) the corresponding MST obtained directly from correlation distances and phase MST (*pMST*) the one obtained directly from phase synchronization MST. Figures 2 and 3 show the *cMST* and *pMST* with its corresponding dendograms. In addition, Figures 4 and 5 show the correlation and PS distance matrices.

Y-axis in Figure 1 and both *x* and *y*-axis in Figures 4 and 5 correspond to countries ordered by the entropy criterion. In short, each country is identified with the Shannon entropy of its *rRER* time series. As we have shown recently (Matesanz and Ortega, 2008), more prone crisis countries tend to have lower entropy values. Thus, countries are ordered in ascending order by their *rRER* entropy value in the analyzed period, from Argentine (lower) to Australia (higher).

In the *cMST* (Figure 2) we obtained approximately[3] the same results that in Ortega and Matesanz (2006) where three groups of countries were clearly seen. EU countries group appears in first place with the smallest distances among them; Asian countries follow and in

[3] Different number of data points has been used in both cases; 155 months in Ortega and Matesanz (2006) and 128 months in the present work.

third place Latin American countries have shown higher distances between their countries than the other two first groups. European Union suffered between 1992 and 1995 currency crises in several countries in what were called the European Storms. Italy, Spain, United Kingdom and Denmark were supposed to have passed currency crises at this time. Anyway, intense connections in EU group are due to common exchange rate policy in the so called European Monetary System until 1998 and the change to a common currency, the Euro, in January, 1999. Interesting enough, Denmark (DEN) is the most linked country into the group unless it has not joined to Euro suggesting that could be not necessary for countries to give up the currency in order to get stability with commercial and regional partners. During 1997 and first months of 1998 Asian currencies were devaluated intensely and contagion effects was supposed to appear from Thailand to other countries such as Malaysia, etc. As can be appreciated countries in this group are tightly connected among them with Thailand clearly in the centre of the links. Finally, Latin America seems to be a more disconnected region showing that it is not a homogeneous group, unless we could see how Brazil plays a central position in the exchange rate dynamics of the region. Other countries are isolated in strange positions such as Mexico, India or Turkey. The corresponding dendogram in Figure 2 shows clearly the same three regional groups.

In Figure 4 the Pearson correlation distance matrix among all countries is shown. Black squares means perfect linear correlation and consequently $d(i;j)=0;$ White squares implies absence of linear correlation and $d(i;j)=1$. We can observe how the EU countries have presented closeness dynamics and distances are short among them, especially among "Northern countries" where, again, Denmark is the most connected and "Southern countries" with Spain and Portugal showing very short distances. Similarly, Asian countries show an intense linear coupling among them where Thailand and Malaysia show the shortest distances in the group. Interesting enough in this group is the Singapore situation, with intense relation with Asian countries and quite coupling with the EU group and, in general, with developed countries. Of course, the role of Singapore as a world financial centre is the explanation of this fact and its location in the *cMST*, just in the middle of the European and Asian countries. Finally, Latin American group do not show regional co-movement, only Brazil has some coupling with Chile, Colombia and Peru.

The methodology used however suffers the same problem arising in the empirical economic literature. Namely, we do not know whether our regional taxonomy showed in Figure 4 is mainly due to the crises effects or represents an accurate picture of the underlying long run dynamics of exchange rate.

The distinction made before is important for the following causal reason. If the taxonomic picture represent an actual interdependence among countries then, currency crises has spread due to this fact and in the direction given by the strongest links. On the contrary, it would be possible that those crises, mainly due to its strong and sudden changes are really "configuring" the taxonomy displayed. This last fact is certainly possible when a linear statistics, as the correlation coefficient, is used to quantify the interaction among countries.

In Figure 3 we have plotted the *pMST*. By using PS instead of usual linear correlation we aimed to answer the previous question. Although this topology is slightly different from the linear *cMST* showed in Figure 2, we could appreciate important similarities between them. From a global point of view, we obtained the same three regional groups: EU countries, Asian group and Latin American countries. For instance, European countries are also tightly connected and, again, Denmark is at the middle of the group. Identically, Mediterranean countries (SPA, ITA and POR) form the same sub-group that in the *cMST*. In the same fashion, we can observe the central position of Thailand in the Asian group and Singapore with intense and more diversified links repeating previous results. Latin American countries now appear more connected than in the *cMST* with Brazil and Argentina showing short distances between them. Again we find some countries isolated and with no economic sense position. For instance, Ecuador is linked directly to Greece which has no economic explanation. India and Mexico follow quite isolated. Ireland and Australia continue together, linked to the Asian group.

The PS distance matrix presented in Figure 5, supports results from the *pMST*, as happened with *cMST* and the correlation distance matrix. EU countries are the most compact group, Asian countries are quite connected themselves and Latin American countries are the most isolated as a group. There exist some novelties in the PS distance matrix: for instance, Argentine has co-movements with Brazil which were no identified in linear correlation or Thailand and Mexico which seems to be quite connected with developed countries as occurs with Singapore. The corresponding dendogram in Figure 5 clarifies and supports the *pMST* topology. From our point of view, what is important from Figures 3 and 5 is that by avoiding the intense volatility of the crises events (which is reflected in the PS matrix) regional connections and co-movements continue at the centre of the *RER* dynamics. Of course, it remains unexplained linkages from an economic point of view such as connections of Ecuador with Greece, for instance.

By comparing information obtained from the *cMST* and *pMST* and the corresponding distance matrices, we can conclude that the important similarities among the exchange rate topology and co-movement are reflecting economic liaisons among regional groups of countries (or more isolated countries). Figures 2 to 5[4] illustrate that connections and coupling among currencies are quite stable and *previous* to currency crises events. From this point of view, currency crises in the nineties were spreading due to increasing interdependence in the international arena and contagion effects did not seem to occur.

IV. Dynamic analysis

In order to further dig into de temporal behaviour of interdependence relations between the analyzed countries, the following calculations has been done. Distance correlation and PS matrices has been calculated in overlapping windows of 16 months, forward in time. This temporal window has been moved along the whole period, in steps of 1 month, starting at March 1992. In each window, the matrices coefficients have been summed up and normalized to the maximum value in the whole period. Therefore, each data point plotted in Figures 6 and 7 represents the sum of distances among all countries in the past 16 months, so September 1993 is our first point of analysis, reflecting coupling from March 1992 to August 1993. In addition, we have calculated the corresponding MST´s in each window of 16 months. Results of Pearson and Phase Synchronous are displayed in Figure 6 and 7, respectively. In each one, we have plotted the sum of the distances *d(i; j)* between pair of countries (bold line) and the MST cost (dotted line). MST cost is the sum of the distances in the MST, namely, the sum of all the branches in the tree. Less value of the MST cost, more tight connections among the countries. Similarly, the sum of all the matrices coefficients

[4] We have called *structural* (or static) to that analysis including the 128 data points. Figures 2 to 5 plot the results of this analysis. In contrast, we have labelled *dynamic* to the analysis develop in section IV. As we shall explain below, this is based on overlapping windows of 16 data points, forward in time.

gives an idea of the interdependence among all countries, what we have called *global correlation*. Again, less value in the sum of distances, tighter coupling among the countries is inferred.

In Figure 6 and 7 we observe several results from this dynamical point of view. Firstly, both figures show a first part (approximately until data point 50 –first months of 1996) where global correlation is very near from the MST cost and sometimes below it. After that, the MST cost is almost always below the global correlation. This first result is signaling that since the middle of the nineties the first connections of countries (which are observed in the corresponding MST, called MST cost) became more intense than the global correlation. The first neighbor links of all the countries increase their importance in terms of the global correlations. Therefore, since mid nineties the linear and non-linear topology we have obtained, becomes more relevant than in previous periods suggesting that financial agents paid more attention to closer and first links.

Second, we observe how Pearson global correlation and corresponding MST cost increase (distances diminish in Figure 6) clearly since 1995 to the beginning of the new century approximately. This long period seem to be a more connected one in currency markets. We observe recurrent peaks in the intensity of the correlation but they are not clearly related with the currency crisis dates.

In the PS distances plotted in Figure 7, we do not observe such decrease in the distance coefficients in the global correlation. In this case, our results are indicating that co-movement in this wide non-linear sense has been quite flat. Contrary, the PS MST cost reaches its minimum around the Asian currency crises. This implies that at this point PS distances into the MST are the shortest of the period. Because we do not know which countries are responsible for those short distances, we have plotted in Figure 8 the number of connections of each country inside the PS MST in every pack of 16 correlation data points, where dark squares means a high number of connections and light squares means a short number of connections in the MST (the minimum connections of any country is, of course, 1 and the maximum reported here is 6 in Thailand and Norway). From this Figure, we can observe that links are quite diffuse and maybe only Thailand and Singapore around the Asian crises gets more intense, suggesting some evidence in favor of the existence of contagion effects during this period. The originating country seems to be Thailand with its maximum links along the period (6) at this time

V. Conclusions

In this paper we have detected linear and nonlinear co-movements presented on the real exchange rate in a group of 28 developed and developing countries that have suffered currency and financial crises during 15 years. The matrix of Pearson correlation and Phase Synchronous coefficients have been used to construct topological and hierarchical pictures of our country sample. With this methodology structural (long term) and dynamical (short term) linkages among currency markets has been analyzed. The use of phase synchronization matrix has demonstrated to be useful for better understanding of cross-correlations and linkages in the financial markets and especially in the contagion-interdependence inconclusive debate. Regarding the currency markets, our main conclusions are:

1) The Structural information obtained from the Pearson and phase synchronous MST´s and corresponding dendograms presented in Figures 2-5, suggest that exchange rate hierarchical taxonomy is reflecting stable economics liaisons among regional groups of countries (or more isolated countries). European Union, Asian group and Latin American countries appears as three different exchange rate areas, even though there are some countries having diffused connections such as Chile or even with more "isolated" currency dynamics such as India or Ecuador. The overall results point out that structural linkages connect global currency markets dynamics and imply that currency crises in the nineties were spreading principally due to interdependence in the international arena in line with works such as (Candelon et al. 2005 and Bialkowski and Dobromil (2005).

2) From our dynamical analysis point of view, Figures 6 and 7 shows two additional results. First is that the MST cost is below the global correlation since 1996, approximately. This situation is reflecting that currency markets have been more connected with their first links than with other countries. Because both *cMST* and *pMST* have shown a regional construction, these results suggest that markets agents understood that currency turbulences

became regional more than global. Structural linkages presented in MST figures (4-5) support this conclusion.

Secondly, we observe how co-movements became more connected, revealing an increase in the correlation coefficients around the Asian crises. This situation is due to the increase of regional correlation (PS MST cost in Figure 7) and clearly related to the Asian countries (see Figure 8) satisfying the definition of contagion firstly exposed by King and Wadhwani (1990) and Forbes and Rigobon (2002). However, Asian contagion responded to structural and stable linkages as it is seen in our global topologies in Figures 4 and, specially, 5.

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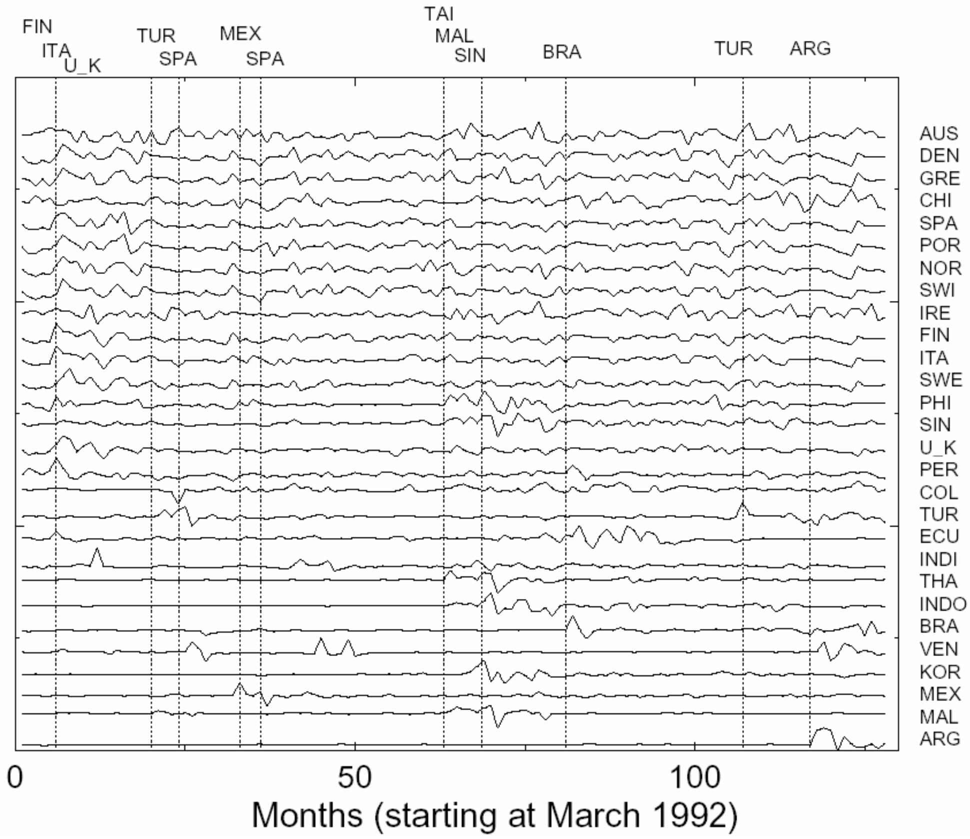
Appendix

The 28 countries included in this work are as follows (order by increasing entropy):

Argentine (ARG), Malaysia (MAL), Thailand (THA), Mexico (MEX), Korea (KOR), Indonesia (INDO), Brazil (BRA), Venezuela (VEN), Peru (PER), India (INDI), Ecuador (ECU), Turkey (TUR), Colombia (COL), Singapore (SIN), Philippines (PHI), United Kingdom (U_K), Sweden (SWE), Italy (ITA), Ireland (IRE), Finland (FIN), Chile (CHI), Greece (GRE), Portugal (POR), Switzerland (SWI), Denmark (DEN), Spain (SPA), Norway (NOR), Australia (AUS)

Figures



<u>Figure 1</u>: Returns in Real Exchange Rate (*rRER*) in 28 countries, from March, 1992 to December, 2002. Vertical dotted lines mark major international crisis and the supposedly originating countries (upper *x*-axis). Countries ordered by entropy criterion, as explained in the text, are ordered at the right *y*-axis. Countries are labelled accordingly with the symbols listed in the Appendix.

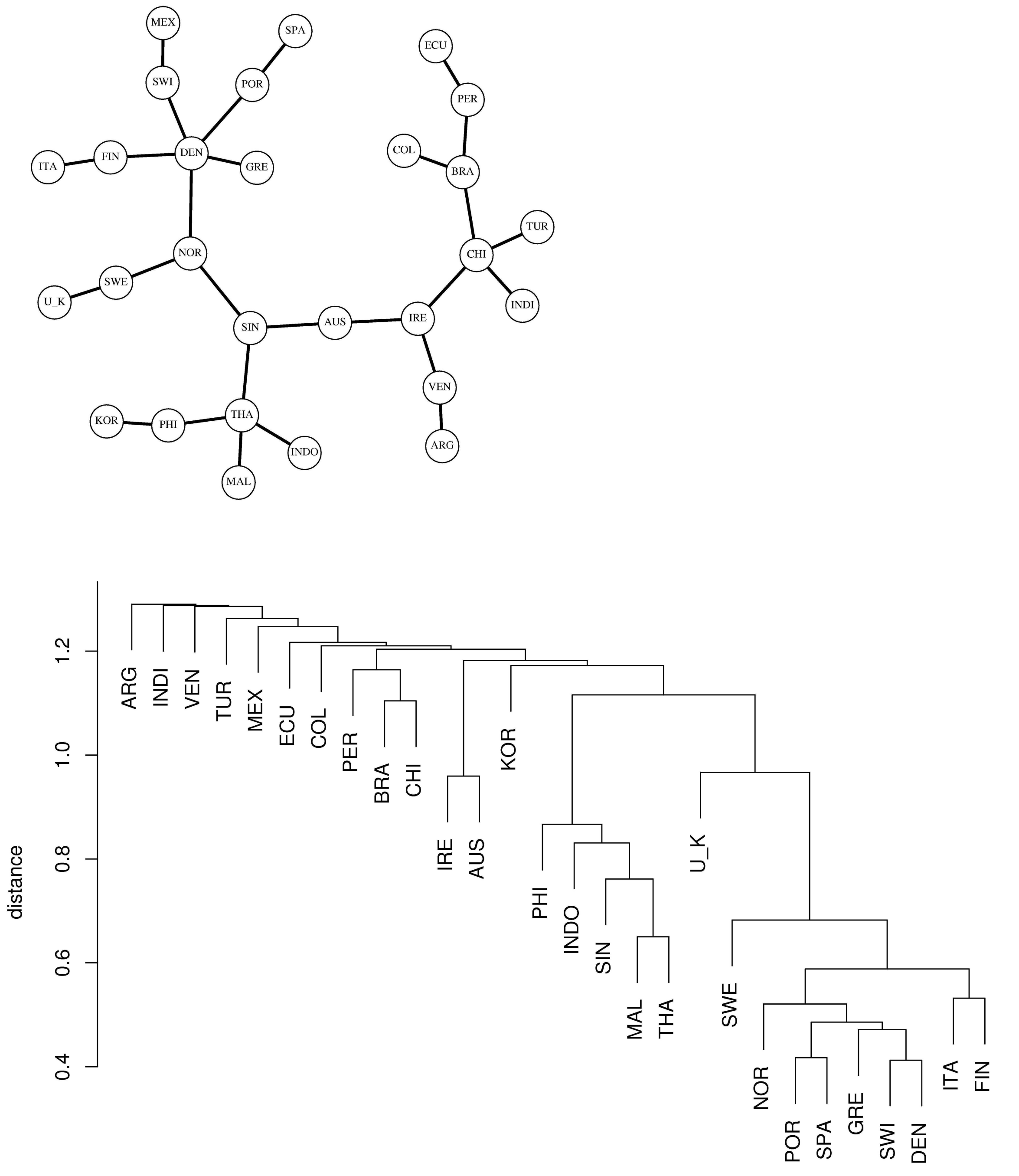


Figure 2. Pearson correlation Minimum Spanning Tree and corresponding dendogram. Countries are labelled accordingly with the symbols listed in the Appendix

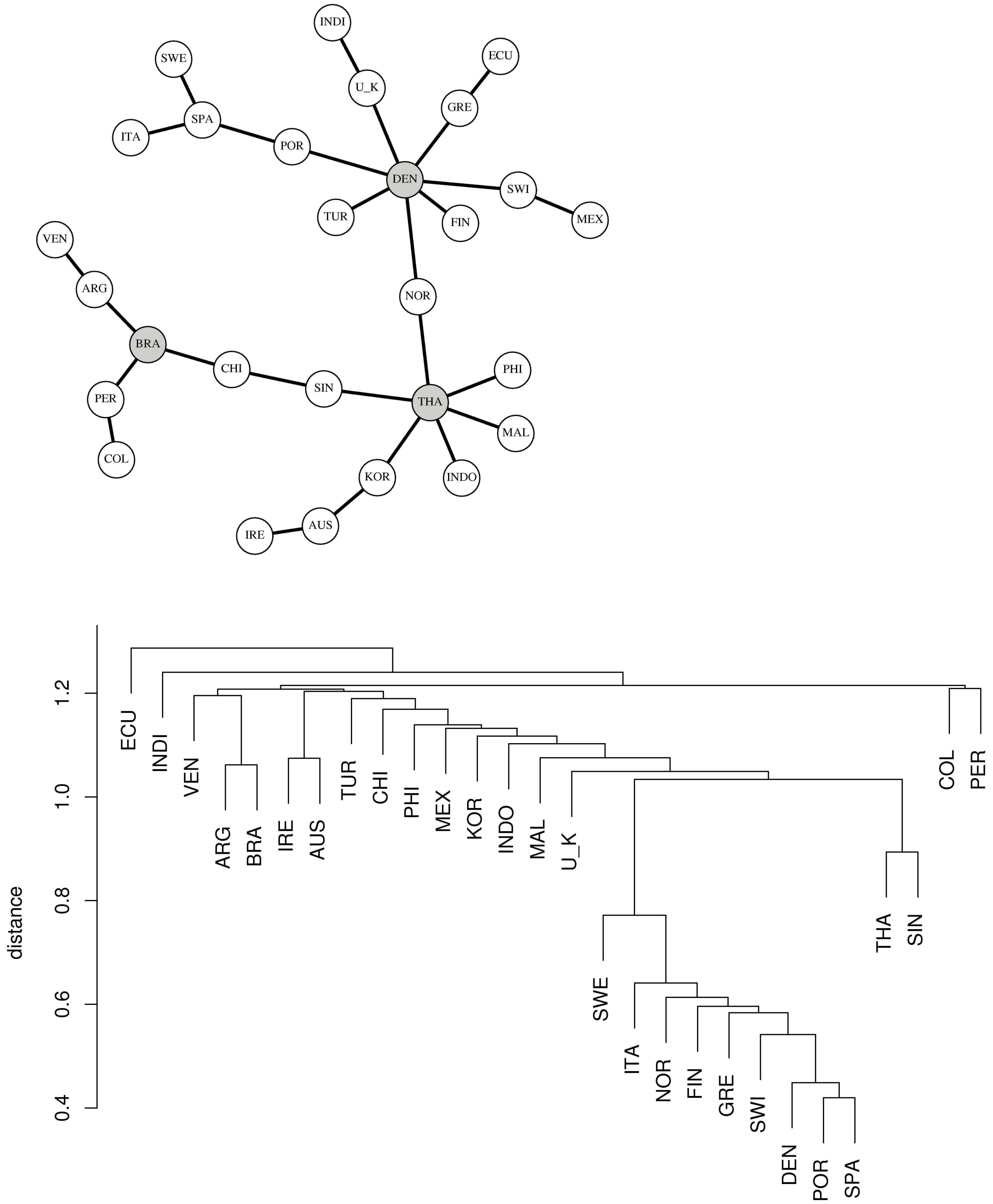


Figure 3. Phase Synchronous correlation Minimum Spanning Tree and corresponding dendogram. Countries are labelled accordingly with the symbols listed in the Appendix. Gray circles display most connected countries in each region.

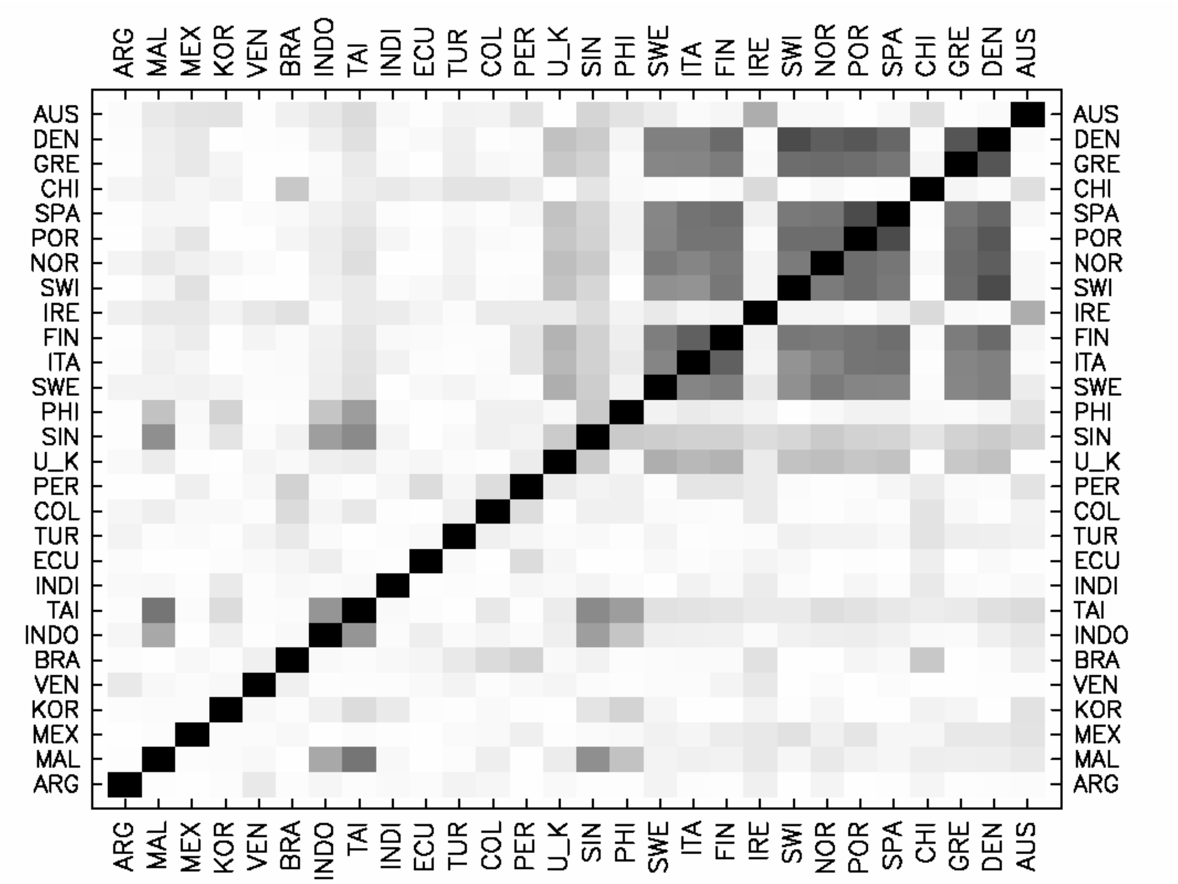
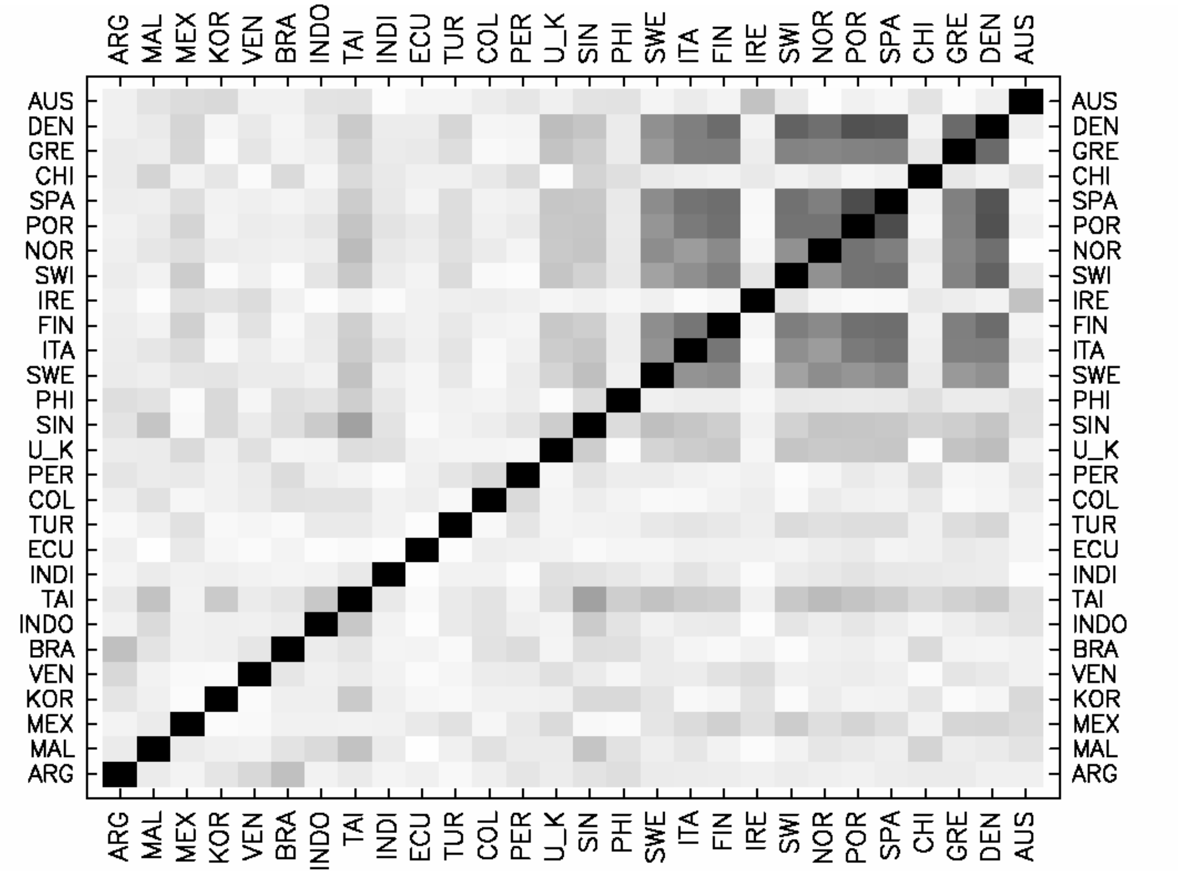


Figure 4: Pearson Correlation distances between *rRER* in pairs of countries. Black squares means distance = 0 and white squares means absence of linear correlation, distance = 1. The *x*-axis and *y*-axis are countries ordered by the entropy criterion.



<u>Figure 5</u>: Phase Synchronous correlation distances between *rRER* in pairs of countries. Black squares means distance = 0 and white squares means absence of PS correlation. The *x*-axis and *y*-axis are countries ordered by the entropy criterion.

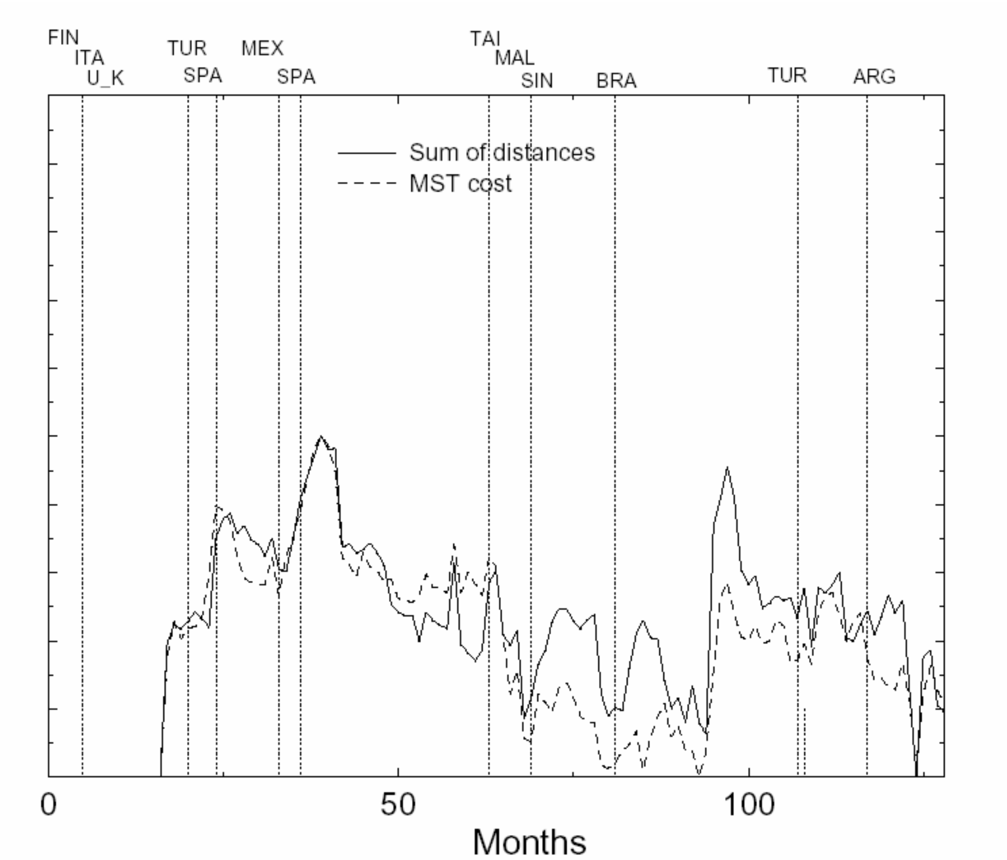


Figure 6: Dynamic Pearson correlation distances. Bold line shows the normalized sum of the distances among all countries. Dotted line shows the sum of MST distances. Every point represents the normalized sum of distances of the previous 16 months.

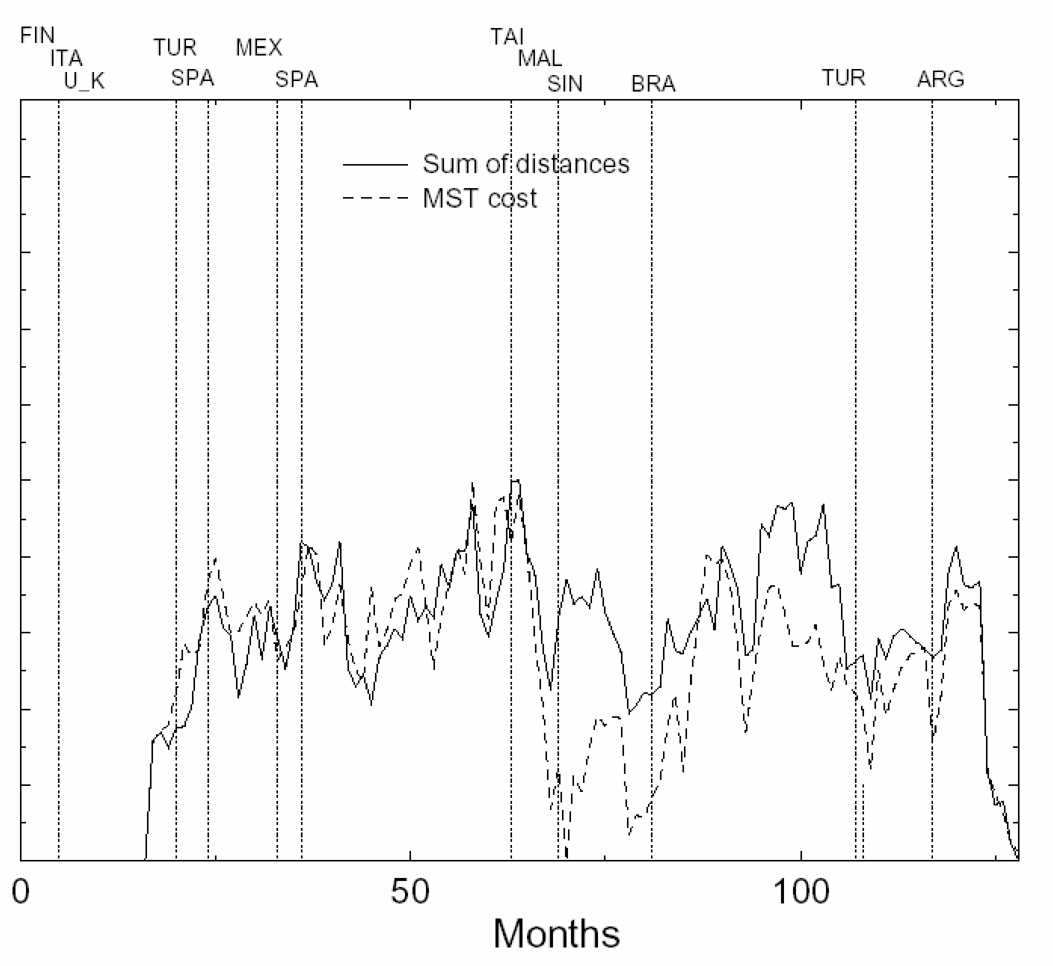


Figure 7: Dynamic Phase Synchronous correlation distances. Bold line shows the normalized sum of the distances among all countries. Dotted line shows the sum of MST distances. Every point represents the normalized sum of distances in a previous temporal window of 16 months.

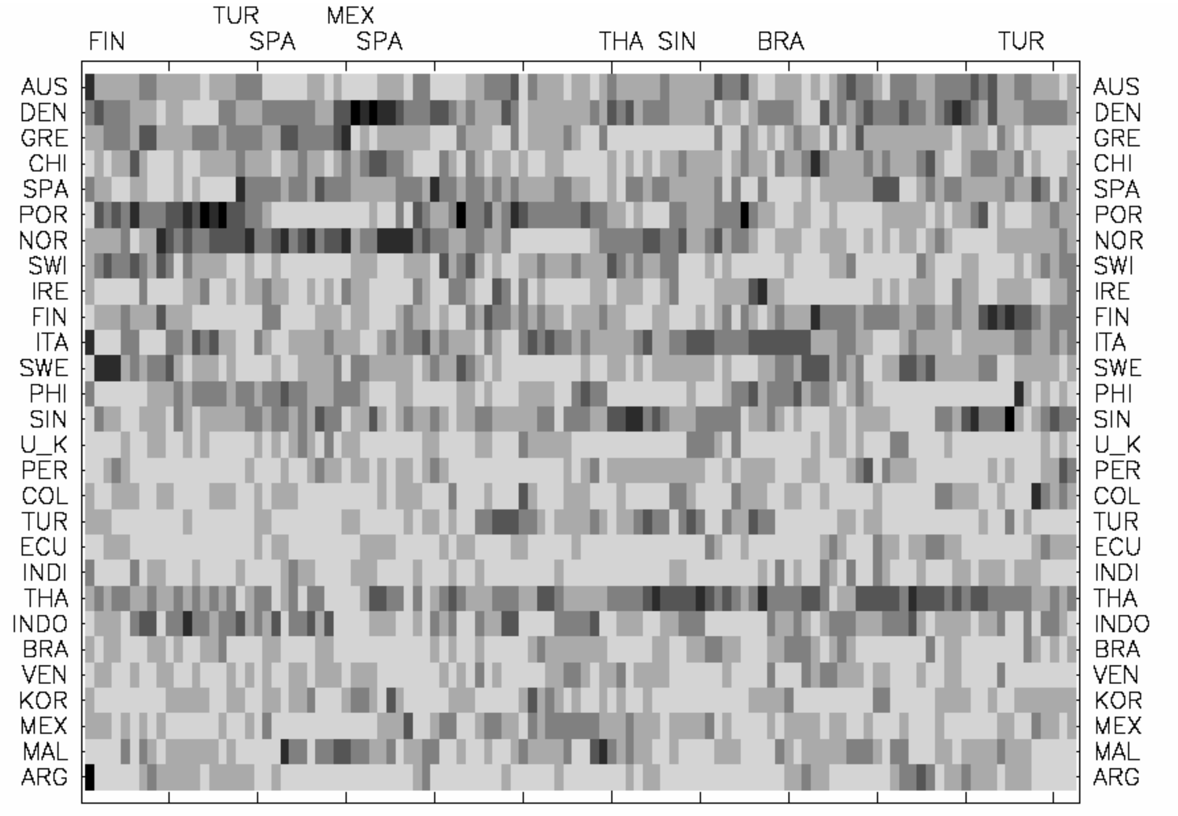


Figure 8: Dynamic Phase Synchronous MST connections. Darker squares mean more linkages of a country in the MST. Each square represents the number of connections of each country in the MST constructed in a temporal window of 16 months.