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Dynamical Hierarchical Tree in Currency Markets*

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Abstract

In this paper we introduce a new method to describe dynamical patterns of the real exchange rate movements time series and to analyze contagion in currency crisis. The method combines the tools of Symbolic Time Series Analysis [19] with the nearest neighbor single linkage clustering algorithm [35]. Data symbolization allows to obtain a metric distance between two different time series that is used to construct an ultrametric distance. By analyzing the data of various countries, we derive a hierarchical organization, constructing minimal-spanning and hierarchical trees. From these trees we detect different clusters of countries according to their proximity. We show that the derived clusters corresponds with the geographical location of the countries. The obtained classification of countries can be used to study the contagion phenomena in currency crisis.

Keywords: Symbolic Time Series Analysis; real exchange rate; hierarchical tree

JEL classification: C10, C14, F31,

1 Introduction

There is no doubt that currency markets are extremely important. As highlighted by [37] they represent the largest market in the world, having daily transactions totalling trillions of dollars, exceeding the yearly GDP of most countries. This global integration of capital markets has accelerated since the early 1990s, as illustrated, for example, by the rapid simultaneous increase in foreign assets and liabilities. The trend toward larger external assets and liabilities has been particularly relevant for industrial countries, where, relative to output, both average external assets and liabilities about tripled between

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1990 and 2003. In emerging markets global trend has been similar, unless much smaller than in industrial countries. Hence it is not surprising the high interest both in predicting currency crises and understanding how a country without any apparent problem can be contagious.

European Monetary System (EMS) speculative attacks in 1992, "Tequila crisis" originated in Mexico in December 1994 and collapse of southern Asian currencies from mid 1997 to first months 1998; Brazilian currency devaluation on January 1999 and Argentine currency board collapse and external debt default on January 2002, are the most relevant episodes in the 1990s generating interest in both academic and policy circles in the potential causes on symptoms of currency crisis and contagion.

Precisely the objective of this work is to understand the structure and dynamics of cross-country exchange rate liaisons to inquiry on the contagion phenomenon in currency markets. [40] use Minimal Spanning Tree (MST) methodology in order to detect clusters of countries which could be affected when a crisis occurs.[1] Constructing a cross-country hierarchical structure they detect three groups of countries which are clearly divided in regional dimension (EU, Asian countries, and Latin-American). In this paper we will study the same problem, but applying a different methodology and including cross-country analysis of the structures and linkages when countries are swimming into more volatile periods and currency crises events. We will combine the Symbolic Time Series tools with the nearest neighbor single linkage clustering algorithm in order to construct different MST that can be used to represent the evolution of the phenomena. The theoretical setup of Symbolic Time Series Analysis is based on [19], [10] and [11]. In the first stage we introduce a partition of the space of states. Using this partition, all the values of the time series data are transformed into a finite string of symbols. This converts the original signal into a symbolic sequence, from where symbolic sequence statistics can be computed. In particular we apply concepts from information theory and symbolic dynamics to process the symbolic sequence.

The paper is organized as follows. In the next section we briefly review the theoretical literature in currency crisis and contagion and we state some possible causes of contagion during currency crisis. In the section 3 we introduce the Minimal Spanning Tree, the ultrametric distance and the hierarchical tree, constructed from the Pearson correlation coefficient. Section 4 describes the data, introduces a criteria for data symbolization and the Symbolic Time Series tools. Next, by analyzing the data of various countries, we derive a hierarchical organization, constructing minimal-spanning and hierarchical trees constructed from different distances. From these trees we detect different clusters of countries according to their proximity. In the last section we draw our conclusions and present some future lines of studying.

[1] Recently, the correlations between economic data have been studied by using techniques and tools formerly used by physicists. See [5] (where the hierarchical structure of a portfolio of US stocks is constructed using a metric distance between stocks), [7] and [34]

2 Theoretical Literature about Currency Crisis and Contagion

Nowadays theoretical literature in currency crisis continues to grow but we can recognizes three generation of models. First generation-models have flourished following seminal Krugman's paper [32]. This literature establishes that crises were caused by weak "economic fundamentals". It was proposed that assuming fixed exchange rate, both excessively expansionary fiscal and monetary policies would result in a persistent loss of international reserves provoking speculative attacks against the currency and finally forcing the authorities to abandon the exchange rate value. Krugman's model has been extended to incorporate deviations from purchasing power parity, capital controls, uncertainty about monetary and fiscal policies and portfolio optimization by investors. However these kind of models only worked explaining few cases of countries with histories of high inflation (Mexico and Chile in 1970s; France and Italy in the early 1980s). In fact [21] highlights that fundamentals did not predict the timing of the 1992 attack on the EMS.

This literature marks that crisis may develope without a significant change in fundamentals departing from assumptions and prediction of canonical Krugman model. For this reason, in the 1990s appear a second generation of models based on Obstfeld's model [39] .Ozkan and Sutherland [41] present a model where authorities has and objective function depending positively on keeping the exchange rate fixed and negatively on the deviations of output from a certain target level. Hence an increase in foreign interests rate lead to higher domestic interest rates and lower levels of output, making it more costly for the authorities to maintain the parity. This model then highlights a trade-off between output targets and monetary policy. According to [20] the prediction of this model are consistent with European experience in 1992-93, when speculative attacks coincided with a deepening recession that aggravated existing levels of unemployment. [36] also concludes that high unemployment increased the perceived probability that government would abandon the sterling parity in the UK.

According to [45] first generation and second-generation models focus on different aspects of a currency crisis. The first generation models focus less on the underlying reasons for the speculative attack, for instance it is not clear why the government is financing its budget deficit by printing money. This kind of models care more on describing the speculative attack process.

The second generation models focus on a description of the underlying reasons for the speculative attack. Note that they take into account the cost-benefit analysis made by the government.

However second generation models were not successful explaining the East Asia Crisis. Even more, Sachs [46] asserts that there was no "fundamental" reason for Asia's financial calamity except financial panic itself. Hence a third generation model surged also known as "twin crisis", these models propose that a weak bank sector can precipitate the beginning of both currency and financial crises.

Finally (and maybe more relevant in the present work), some papers have focused on contagion. Some recent crises concern about contagion. EMS crises of 1992-93, "Tequila Crisis" in Latin America 1994-95, the "Asian flu" starting with the crisis in Thailand. The spread is almost always regional however the August 1998 Russian crisis spread to Brazil in the fall, triggering the January 1999 crisis. According to Tirole [48] there are several hypothesis for the contagious aspects of crisis. First hypothesis of contagion is known as *portfolio rebalancing hypothesis* states that after losing money in one country foreign investors have to readjust their positions in other countries. A second hypothesis is the *trading links hypothesis*, [24] highlights that devaluation in one country leads its trading partners to devalue in order to avoid a loss of competitiveness.

A third hypothesis relates to the *existence of common shocks* (for instance: rise in interest rates, increase in price of oil) although in this cases there is not systematic effect so to speak, the crisis exhibit a strong correlation. Finally the fourth hypothesis is the *change in expectations*. Investors realize the lack of solidity of certain types of economies or the unwillingness of the IMF to help restructure the debt.

In general, explanation theories of contagion have been divided in two groups by [22] and [23]: crises-contingent and non-crises-contingent theories. In crises-contingent models it is assume that the transmission mechanisms change after a shock or, to put it another way, the behaviour of investors is different after a crises and therefore cross-market linkages increases after a shock among countries. This can occur due to changes in investors' sentiment or herding behaviour. In non-crises-contingent models it is assume that any increase in cross-market correlations after a shock is a continuation of previous and stable links among countries and, so, the transmission mechanism is the same during both crises and non-crises periods. These linkages are commercial, financial and/or institutional liaisons among countries.

Related to this division, there is an ongoing empirical debate around crises and non-crises contingent explanations of contagion. The stress of debate is focused then on the difference between interdependence (non-crises-contingent models) and contagion, or pure contagion, (crises-contingent models). Many other works have tried to make progress on the debate by using new methodologies; some of them have found evidence of contagion, for instance [27] 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. [26] find evidence of contagion in developed countries and find evidence of interdependence in Latin American countries. [17] 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. [18] find some contagion effects and some interdependence effects on the Hong Kong stock market crisis of October 1997 as a case study. [16] find no evidence of contagion in Mexican and Asian crises but long term interdependence among involved countries.

3 Minimal Spanning Tree and Hierarchical Tree construction

Methodology proposed by Mantegna [34] uses Pearson correlation coefficient as fundamental input which quantifies the degree of similarity between the synchronous time evolution of a pair of variables

$$\rho_{ij} = \frac{\langle Y_i Y_j \rangle - \langle Y_i \rangle \langle Y_j \rangle}{\sqrt{\left(\langle Y_i^2 \rangle - \langle Y_i \rangle^2 \right) \left(\langle Y_j^2 \rangle - \langle Y_j \rangle^2 \right)}} \tag{1}$$

where Y_i and Y_j are the real exchange rate of countries i and j. This coefficient is a temporal average performed on all the trading days of the investigated time period. By definition ρ_{ij} can vary from -1 (completely anti-correlation) to 1 (completely correlation). Taking all possible combination of countries it is possible to form the correlation matrix. This is clearly a symmetric matrix with a diagonal of 1 ($\rho_{ii} = 1$). To construct an appropriate taxonomy of currency countries we need a metric distance; i.e., a function d defined for each pair of countries that takes values in $\mathbb{R}$ such that:

1. $d(i,j) \geq 0 \; \forall i,j$
2. $d(i,j) = 0$ if and only if $i = j$;
3. $d(i,j) = d(j,i) \; \forall i,j$
4. $d(i,j) \leq d(i,k) + d(k,j)$

As it is well known, function (1) does not verifies all these properties. As in [25], distances between countries can be constructed using the correlation coefficient.

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

This distance is used to determine the Minimal Spanning Tree (MST) connecting the n countries. The MST is progressively constructed by linking all the countries together in a graph characterized by a minimal distance between time series, starting with the shortest distance. This method is the Kruskal's algorithm and consists of the following steps: In the first step we choose a pair of countries with the nearest distance and connect with a line proportional to the distance. In the second step we also connect a pair with the 2nd nearest distance. In the third step we also connect the nearest pair that is not connected by the same tree. We repeat the third step until all the given countries are connected in a unique tree. The attractive thing of MST is that provides an arrangement of currencies which selects the most relevant connections of each element of the set.

The MST permits to obtain the subdominant ultrametric distance matrix $D^{<}$. This matrix (see [34]) can be constructed from the ultrametric distance $d^{<}(i,j)$. The subdominant ultrametric distance $d^{<}(i,j)$ between i and j is the maximum value of any Euclidean distance $d(k;l)$ detected by moving in single steps from i to j through the shortest path connecting i and j in the MST. Note that

$$d^{<}(i,j) \leq \max\{d(i,l), d(l,j)\} \quad (3)$$

From these trees we can obtain both geometrical (throughout the MST) and taxonomic (throughout the hierarchical tree) information of the correlation present between the elements of the set. Note that the MST (and then the HT) is constructed using the Pearson Correlation coefficient as an input of a measure of distance between the time series. This methodology has demonstrated useful insights on the global structure, taxonomy[2] and hierarchy in the dynamics of the financial data, specially on the stock markets, but also in the exchange markets. (see [40], [34], [30], [38], [6], [8]) This is the point that we will modify in our paper. We will introduce different types of distances that will generate respective MST and HT. In particular, we introduce distances between time series that can be constructed using the tools of Symbolic Time Series Analysis (STSA). Combination of these two methods permit us to characterize the dynamics of the structure and hierarchy of exchange rate dynamics in different regime states and, in so doing, we present a new and visual method for testing contagion in currency crises episodes. In the next section we describe the symbolic methods and we introduce our data set.

4 Symbolic Time Series Analysis

The distinctive element of STSA is the introduction of a discrete partition into the state space. In our case, the state space consists of all the possible values that the returns from real exchange rate may adopt. We start with a given set of measurements $\{x_1, x_2, \ldots, x_t, \ldots, x_T\}$ that are transformed into symbolic form. This transformation is based on partitioning the state space D into a finite number of regions $D_1, D_2, \ldots D_N$. Original measurement x_t is transformed into the symbol $s \in \{1, 2, \ldots N\}$ if and only if x_t belongs to the region (D_s) labeled by s. This process of transformation of data into a symbolic sequence is called *symbolization* in the STSA literature and can be done in several ways. Clearly, the detailed features of the resulting symbol series will depend on the specific choice of the partition. See [43], [28], [19], [33] and [4] for a discussion of symbolization methods and the relevance of selecting a good partition. In [28] and [47] some methods to approximate generating partitions from data are presented. In this paper we use the simplest possible partition involving a division of the data range into two parts (a binary partition) determined by a threshold value τ: we transform the sequence of data $\{x_1, x_2, \ldots, x_t, \ldots, x_T\}$ into the sequence of symbols $s_1 s_2 \ldots s_t \ldots s_T$, where $s_t = 1$ if and only if x_t is above the threshold value τ and $s_t = 0$ if and only if x_t is below τ.

In our case we will progressively move the threshold τ testing whether certain structures and dynamics remain.

[2] Originally term taxonomy referred to science of classifying living organisms. Mathematically, a hierarchical taxonomy is a tree structure of classification for a given set of objects.

Let now introduce the data set that will be used in our empirical exercise and the corresponding data symbolization.

4.1 Data

Returns from real exchange rate (RER) are obtained for 28 countries calculated as follows:

$$rRER_i = \frac{RER_i(k+1) - RER_i(k)}{RER_i(k)} \tag{4}$$

where $RER_i(k)$ is the monthly real exchange rate from country i, at month k, and $rRER_i(k)$ the corresponding return.

Data is obtained from International Financial Statistics in the IMF database available on-line (http://ifs.apdi.net/imf/logon.aspx) and coincides with the monthly data from 1990 to 2002 as in [40]. This will help us to do comparative analysis of both methodologies to construct the MST and the HT. RER is computed as the ratio of domestic consumer price to foreign price proxied by USA consumer price, and the result is multiplied by the nominal exchange rate of the domestic currency with US dollar.

4.2 Data symbolization

As described in [29], when studying currency crisis one of the main variables is the deviation from the trend of real exchange rates. Let μ_i be the threshold separating two regimes. At first μ_i will be the statistical mean of the $rRER$ of country i. This represents the trend of real exchange rates. From this remark, we can divide our state space into two sets: the values that are above and below the trend. With this space state partition we will be able to represent the co-movements of pair of countries around the trend of their exchange rate dynamics.

After that we will take different thresholds in order to capture hierarchies and links structures among countries when their currencies are suffered more volatile times and crises episodes. In so doing, our thresholds will be based on the past standard deviation of the exchange rate dynamics. Therefore we will be able to detect if particular structures and dynamics prevail, deducing something about contagion. This determines a binary partition where μ_i is the threshold value and each piece of the partition can be viewed as having a particular qualitative dynamics that can be distinguished from the dynamics of the complementary piece. In other words, if we want to represent the dynamics of this phenomena, we have to use two (qualitatively) different models, one for each element of the partition. In this case the system generating the dynamics of the observed data is a multiregime system where we can observe a twofold dynamics, one *within* a given regime and one *across* regimes, running at the same time though with different clocks.[3] The former represents the behavior

[3] See [9], [10], [11], [12], [13], [14] and [15] for a detailed expositions about the notion of

within any specific regime, the latter captures and formalizes the concept of regime switch. Regime changing corresponds to a form of structural change since it is the very model of the system that is changing. To study structural changes in multiregime models, we can focus our attention on this dynamics across regimes (we call it *regime dynamics*). Regime dynamics is defined on the finite set of regimes and then we only need two symbols to describe its domain. In other words, regime dynamics can be represented in a natural way by resorting to the idea of coding. The coding procedure translates a classical trajectory in the state space into a trajectory in the space of regimes. This representation of the system dynamics is obtained by associating a symbol to a chosen regime and then coding observed dynamics by means of a string of two symbols. In this way, each trajectory of the model turns out to be a sequence of traverses of regimes. Consequently, we label each regime by a symbol and describe the evolution of the system in terms of regime changing with a symbolic sequence. The use of such a technique is the fundamental difference between our approach and the conventional one where state variables are real numbers.

Hence, we can construct a binary partition where μ_i is the threshold value that defines two regimes. Regime labelled by 0 is determined by the values of $rRER$ of country i that are less than μ_i. Let regime 1 be the portion of the state space formed by the values of the real exchange rate bigger than μ_i. It is reasonable to think that each regime has its own data patterns that characterize it. Then data is symbolized by:

$$\begin{cases} s_i = 0 & \text{if} \quad rRER_i < \mu_i \\ s_i = 1 & \text{if} \quad rRER_i > \mu_i \end{cases} \tag{5}$$

Note that, as is highlighted by Bergstrand [3], relative productivity levels, capital-labor ratios and tastes can explain as much as 90% of the variation across countries in real exchange rates. Hence each country has its own trend which depends on particular monetary targets, quantity of international reserves, level of competitiveness or ratio capital-labor.

4.3 Statistical tools

STSA addresses the issue of how to extract and describe time patterns of complex dynamic processes. Compared with more standard analytical approaches, the novelty is in that this set of methods does not rest upon any hypotheses as to the data generating (deterministic and/or stochastic) model. STSA accepts the *paradigm of irregularity*, where irregularity is the generic, and regularity the rare property of time series reflecting a dynamic process endowed with sufficient complexity. Under such paradigm, we have to look at most for near-regularities in the raw data sets, or at higher levels of dynamics of regime or coded dynamics.

The simplest statistical tool that can be introduced to compare symbolic sequences is the distance d_0 that counts the coincidences of symbols. In particular, given two binary symbolic sequences $a_1 a_2 \ldots a_t \ldots a_T$ and $b_1 b_2 \ldots b_t \ldots b_T$,

regime, examples of multiregime models and multiregime dynamics statistical and modelling tools.

let

$$f(a,b)=\begin{cases}1, & \text{if } a\neq b\\ 0, & \text{if } a=b\end{cases}$$

Then

$$d_0\left(a_1a_2\ldots a_t\ldots a_T, b_1b_2\ldots b_t\ldots b_T\right)=\sqrt{\sum_{t=1}^{t=T} f\left(a_t,b_t\right)} \tag{6}$$

measures the distance between two sequences. Note that

$$0\leq d_0\left(a_1a_2\ldots a_t\ldots a_T, b_1b_2\ldots b_t\ldots b_T\right)\leq\sqrt{T}.$$

Note that

$$d_0\left(a_1a_2\ldots a_t\ldots a_T, b_1b_2\ldots b_t\ldots b_T\right)=0$$

means that the two processes have traverses the same regimes at the same time and that

$$d_0\left(a_1a_2\ldots a_t\ldots a_T, b_1b_2\ldots b_t\ldots b_T\right)\leq\sqrt{T}$$

reflects the contrary situation; i.e., the two processes have traversed complementary regimes at each tick of the clock.

The first step in identification of temporal patterns is the extraction of *short symbol sequences* of chosen length, from the overall sequence of symbols $s_1s_2\ldots s_t\ldots s_T$ coding the whole history of a system in terms of regimes, and we do this by grouping symbols together while preserving their temporal order. Such ordered subsequences are called *words* in the symbolic dynamics literature. They stand to us for *paths (*to adhere to dynamic terminology) or *patterns* to emphasize their qualitative significance looking at them from the regime point of view. To extract information encoded in the strings so constructed, we introduce the *symbolic tree.* This is a graphical representation of the symbol statistics in a given coded history as a function of the length of patterns in what has been called the *available dynamic menu.* We compute the relative frequency of occurrence of all symbol sequences of length k in a system's symbolic history and, varying the length $k\geq 1$, represent them as a tree, one branch for each value of length k. Hence, the first level shows the probabilities of occurrence of the individual symbols or regimes (as patterns of unitary length), the second the probabilities of occurrence of paths with two (different *or* equal) symbols, and so on so forth. The symbol tree is a compact information summary of the regime dynamics under observation.

Given two measurements with the corresponding coded sequences, we can evaluate how different they are by means of some measure of their distance. The most commonly used of such measures is, of course, the Euclidean distance from the k-th levels of their trees ($k\geq 1$) or in other words, for k-long episodes, here re-defined as

$$d_k\left(A,B\right)=\sqrt{\sum_i\left(A_i-B_i\right)^2} \tag{7}$$

where A_i and B_i are the probabilities for the possible sequence code or *episode* i in the distinct k-levels A and B of the corresponding symbolic trees. Descriptions of other measures of distances are given by [31] and [19] and in references

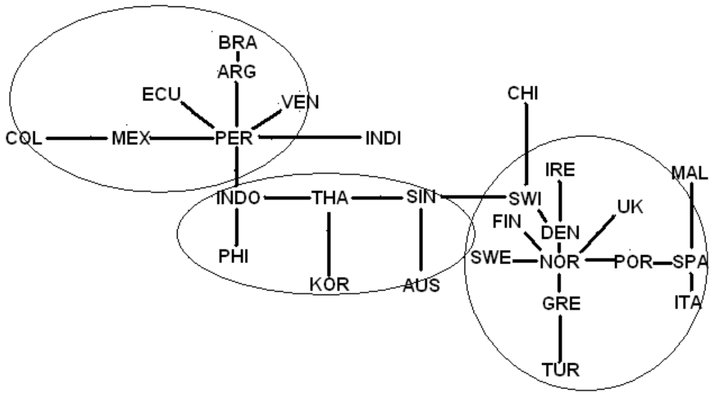

Figure 1: MST determined by d_0.using mean as partition.

included in these papers. The Euclidean distance works like a metric in the space of all possible sequences providing a measure of the distance between different k-histograms in terms of the probability of exhibiting like episodes: a greater distance implies that the dynamics in the two data set is very different.

5 Minimal Spanning Tree: the case of d_0.

In this section we construct the MST and the HT for our set of countries when the metric is defined by d_0 and the threshold is the mean as explained above. Note that in this case the distance reflects the (regime) dynamics of the sequences at the same moment in each country. In this case, being, similar to the Pearson correlation coefficient, d_0 is useful to compare our results with [40]. To construct the Minimal Spanning Tree (MST) we compare the distances between pairs of countries. The methodology is simple, once we have computed all the possible distances between two countries of the sample, we first connect the closest countries. For instance, in our case when considering the mean as partition $d_0(ARG, BRA) = d_0(DEN, SWI) = 4.1231$ is the minimum distance of the sample implying that we have to link ARG and BRA in a group and DEN and SWI in a different group. Then, being that the second distance is $d_0(DEN, NOR) = 4.899$, we link NOR to DEN which was connected to SWI. One proceeds by linking the remaining countries with their closeness to the previously connected countries. See [34], [35], [5], [7] and [40] for a detailed description of the previous construction. If the number of countries is n, then the MST is a graph with $n-1$ links (27 in our exercise) which selects the most relevant connections of each country of the sample. In Fig. 1 we show the MST determined by the distance d_0. Figure 2 shows the distances between connected countries.

From the MST we can identify three clusters where South America appears

Link	C	C2	d_0	Link	C	C2	d_0	Link	C	C2	d_0
1	ARG	BRA	4.1231	10	DEN	IRE	6.245	19	SIN	SWI	7.0711
2	DEN	SWI	4.1231	11	PER	VEN	6.3246	20	SIN	THA	7.0711
3	DEN	NOR	4.899	12	INDO	PER	6.4807	21	MEX	PER	7.1414
4	ITA	SPA	5.099	13	ARG	PER	6.6332	22	MAL	SPA	7.2801
5	POR	SPA	5.2915	14	INDO	THA	6.6332	23	AUS	SIN	7.4162
6	NOR	SWE	5.3852	15	NOR	UK	6.7823	24	KOR	THA	7.4833
7	GRE	NOR	5.6569	16	INDO	PHI	6.8557	25	COL	MEX	7.746
8	FIN	NOR	5.7446	17	ECU	PER	6.9282	26	CHI	SWI	7.8102
9	NOR	POR	6	18	GRE	TUR	6.9282	27	INDI	PER	7.9373

Figure 2: In this table we show the 27 distances representing the MST links when mean is the partition.

connected to Europe by Asia. MST results are quite similar to those presented by [40], with three groups clearly defined in regional terms: European countries, Asian countries and Latin American group. We find "strange" connections such as Malaysia and Spain or Peru and India, for instance. In general, these results are showing that exchange rate has followed dynamics based on economic regional liaisons and that co-movements in these groups are, in some sense, structural and are due to strong commercial and financial links among them. Interesting enough, Denmark and Thailand (and Norway) are the most linked countries in EU and Asian groups respectively and they were the countries where currency crises begun in the European storm and the Asian crises. So, by using the simplest threshold we are able with this methodology to detect regional hierarchy consistent with commercial and financial links among countries and to detect the most linked countries which have suffered the first currency crises in their groups. Of course, because of the simple threshold used we find mistaken connections.

Now, to construct the respective HT we use the ultrametric distance $d^<$ as introduced in [34] and [35]. One method to obtain $d^<(i,j)$ directly from the distance matrix $d_0(i,j)$ is through the MST method as described in [44]. From the MST, the distance $d^<(i,j)$ between two countries i and j is given by

$$d^<(i,j) = Max\,\{d_0(w_i;w_{i+1}); 1 \leq i \leq n-1 = 27\}$$

where $\{(w_1;w_2);(w_2;w_3);\ldots;(w_{n-1},w_n)\}$ denotes the unique path in the MST connecting i and j, where $w_1 = i$ and $w_n = j$. Then we compute $d^<(i,j)$ for each pair of countries Then to construct the HT we proceed as in the following example. Note that SWI is connected with NOR by DEN, the distance between SWI and NOR is the maximum among $d_0(SWI,DEN) = 4.1231$ and $d_0(DEN,NOR) = 4.899$. Then $d^<(SWI,NOR) = 4.899$, even though the computed distance $d_0(SWI,NOR)$ was 5.3852. This is the procedure to compute the distances between two countries. Note that the most distant country will have the same distance with all country (in our case is $INDI$, where

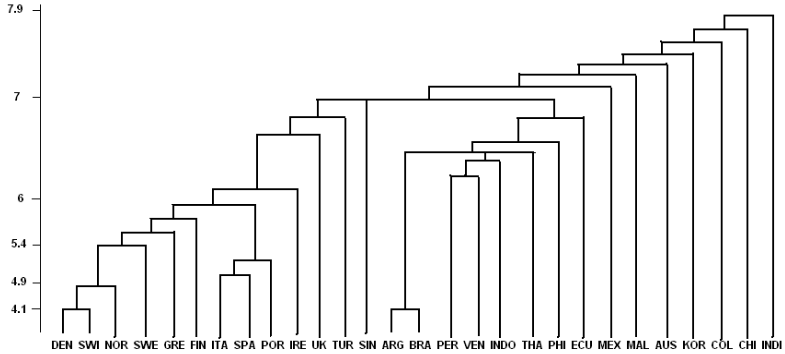

Figure 3: Hierarchical tree for the 28 countries when mean is the partition.

$d^{<}(INDI, PER) = 7.9373$); this is showed in Figure 3, representing the Hierarchical tree for the 28 countries. The hierarchical tree shows that the EU countries present the smallest distances among them. After that no other homogeneous group is detected but Argentine with Brasil and Peru with Venezuela in the HT. We observe some Asian countries (Thailand, Philippines and Indonesia) together in the middle of the HT. As in [40] using mean as partition of the space state yields interesting regional groups implying similar exchange rate dynamics, unless we obtained strange results from the economic liaisons point of view.

As expected, EU countries have shown the shortest distances in our sample range due to common relative real exchange movements inside the European Monetary System until January 1, 1999 when EU countries decided to give up their own currencies and adopted the Euro currency with fix exchange rates among them. (See, for instance, [1] and [2]) In this group we have found two different subgroups of countries: one composed by Denmark, Norway, Finland, Sweden plus Greece and Switzerland and the second composed by Italy, Spain and Portugal. Three EU countries are within the group but outside both subgroups: United Kingdom, Ireland and Turkey. Note that Denmark is the most linked country in the EU group implying that currency variations in this country produce effects on the rest of the countries in the group. Finally, Finland is the less connected country in this group. This group makes sense when remembering the exchange market turmoil in 1992-1993 where speculative attack which led to the floating of the Finnish markka on 8th September 1992 appears to trigger speculative against the Swedish krona. According to [24] after the floating of the Finnish exchange rate the probability of a devaluation during the coming three months increased by 12% in Sweden and 5% in Norway. Abandonment of the Swedish krona's ECU parity on 18th November 1992 caused substantial pressure on the parity of the Norwegian krone. Then Spanish peseta and the Portuguese escudo were devaluated. Again, in this case the hypothesis introduced in [24] is verified: according to a speculative attack which leads to a devaluation by one country may threaten the competitiveness of trading partner. In fact this was the argument invoked for Portugal in 1993 after Spanish peseta depreciation, again in 1995 the realignment of the Portuguese escudo was blamed on exchange market difficulties finishing in realignment in neighboring Spain.

6 Changing the partition 1 and 3 standard deviations of the statistical mean

As it was mentioned, we also changed the partition in order to detect if particular structures and dynamics related to crises events or volatile periods remain in the MST and HT and so we could offer some insights on the contagion-interdependence debate by using this methodology. In the currency crises empirical literature, one of the most usual definition of crises is that currency crises is an unusual or sudden variation of the exchange rate. In many works, standard deviation has been used to represent this sudden variation of real exchange rate (see [42] for a survey on the statistical definitions of currency crises used in the literature). To detect hierarchical structures in our group of countries in crises periods, we have used two partitions of the state making regime 1 a progressively riskier regime. Specifically, we have move our threshold to 1 and 3 standard deviations of the 36 past months above the mean of, again, the 36 past months of each country. Different MSTs show that the three clusters prevail when changing the threshold highlighting a strong structure in the regional hierarchies. We find that our three regions remain very connected and form a group independently the threshold we use. European Union, Asian group and Latin American countries seem to have very similar co-movements both in what we can call tranquil times (when threshold used is the mean) and in more volatile times and crises events (standard deviations thresholds). Besides, countries originating crises in Europe and Asia (Denmark and Thailand) are the most linked in their groups showing that currency problems can extend very fast to nearest countries. In figure 6 we can observe this interesting result, when exchange rate dynamics are in crises event, Thailand and Denmark became the centre of their groups where almost all connections converge. In Latin America is interesting to note that Chile is now the very centre of the region suggesting that a currency crisis in this country could spread to others[4].

In this sense, results of this new methodology are showing that most of the times, during nineties there were no contagion evidence in currency crises. Contrary, exchange rate liaisons among countries seem to be structural and clearly based on commercial and financial linkages, supporting the theory of non-crises-contingent models and so the spread of currency crises has been due to previous interdependence among countries.

[4] This result is suggesting that Chile could be a case of contagion in Latin America if a currency crisis occurs. As we can observe in figure 1 Chile is not connected to the Latin American group showing that links are intense in crises periods but not in tranquil times, what is the definition of crises-contingent models or contagion.

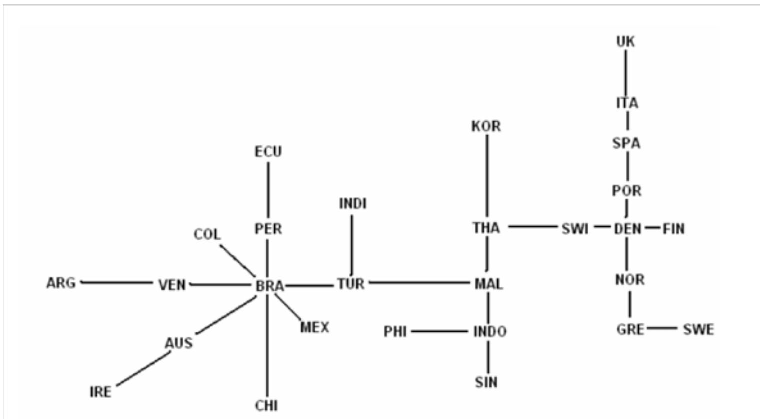

Figure 4: MST d_0 1 s.d. of the mean

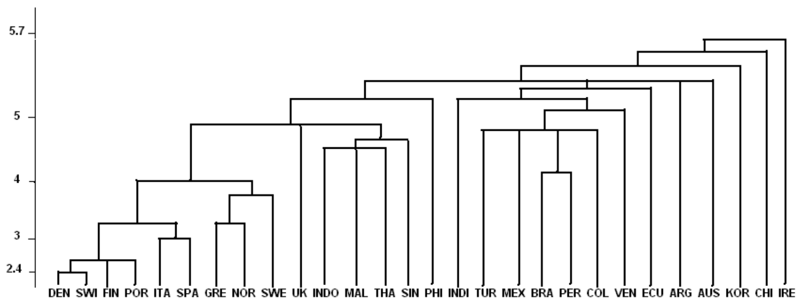

Figure 5: HT for 28 countries (1 s.d. of the mean)

The different HTs also show that EU is the region with the least distance among them showing a strong structure with remain in spite of changing the partition.

7 Dynamical Evolution: MST defined from d_k $(k \geq 1)$.

In this section we study the dynamical evolution of the MST looking at the tree structure across time $(1, 2, 3,$ etc. time lags). We know that the symbolic tree is a compact summary of the dynamics under observation. Then the dynamical evolution of the MST can be represented by the sequence of trees constructed from the distances d_k $(k \geq 1)$ introduced in the STSA section. Note that distance d_k takes into account the $k-$th level of the symbolic trees of the involved

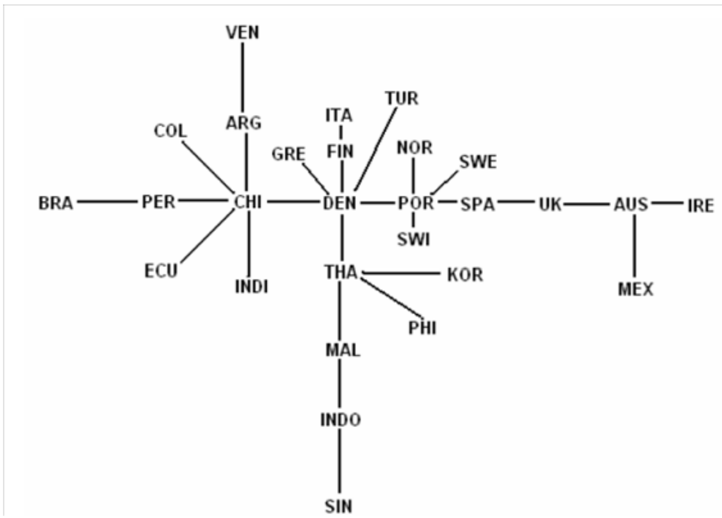

Figure 6: MST d_0 3 s.d of the mean

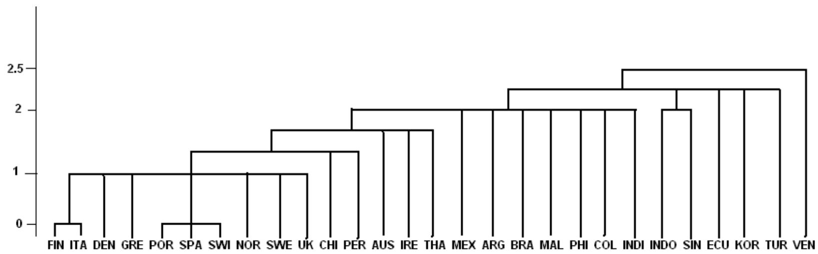

Figure 7: HT 28 countries (3 s.d. of the mean)

countries and then it can be interpreted as a representation of the dynamic process as a system with memory lenght k. Then, by repeating the construction of the MST as in the previous section but substituting d_0 with the distances d_k ($k \geq 1$), we can obtain a representation of the dynamic of the MSTs when time evolves. From the MSTs trees constructed from d_1, d_2, d_3 and d_4 the clusters defined in the previous section (EU, Asian and Latin American countries) can be detected for each of the MSTs. This fact reveals some kind of strong stability of the links between the geographical regions.

8 Conclusions

In the last years interest in studying currency crises, and in particular the effects of contagion has grown due to important crises in the nineties. Events such as occurred with the EMS in 1992, the "Tequila crisis" originated in Mexico and the Southern Asian crisis had a high impact in the international financial markets.

First-generation models based on Krugman (Krugman 1979) did not have success in explaining recent crises. Subsequent second-generation models focussing on the trade-off faced by the government did not explained completely the phenomenon. Even more some hypothesis appeared in order to explain the contagion effects, such as trade links among countries, the portfolio rebalance, existence of common shocks, and finally the change in expectations.

In this sense the present article tried to introduce a methodology based on the Symbolic Time Series Analysis with the nearest neighbor single linkage clustering algorithm. Using this method was possible to construct the MST and the associated HT. These trees seems to be useful as a theoretical description of the currency markets showing the most narrowly connected countries and those who seems to be more distant. Therefore, countries with strong links among them are subject to spread rapidly.

From the results three large regions or clusters of countries are obtained. They are related with their geographical and commercial closeness: Europe, Asia and Latin America. The European countries are the most connected among them, logically these countries have strong monetary and commercial links. In this group, Denmark is the most linked country. In second place appears a group of Asiatic countries where the least distance is taken by Thailand, this was precisely the country which started the Asian crisis in 1998 devaluing its currency. Finally there is a group of Latin American countries which are the most distant. We have shown that this regional hierarchical structure prevails in tranquil times and in more volatile and crises periods which we analyse by moving up our threshold. In this sense, this new methodology help to inquiry on the contagion-interdependence debate around currency and financial crises, supporting no evidence of contagion during currency crises in the nineties, but interdependence among exchange rate dynamics. Besides, we have observed some countries which could be generators of currency crises contagion in their regions because they became centre of all the regional links in crises periods (Chile and Brazil are clear examples). From this last result, we conclude that our methodology could be useful for countries to take into account for eventual exchange rate problems in this central countries.

A Countries

The 28 countries included in this work are as follows: 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 (UK), Sweden (SWE), Italy (ITA), Ireland (IRE), Finland (FIN), Chile (CHI), Greece (GRE), Portugal (POR), Switzerland (SWI), Denmark (DEN), Spain (SP), Norway (NOR), Australia (AUS)

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