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Article

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CONTAGION PATTERN IDENTIFICATION THROUGH MINIMUM SPANNING TREES DURING THE ASIAN FINANCIAL CRISIS

Vasile-George Marica, PhD Candidate*

Abstract

Complexity in financial markets is slowly overwhelming canonical statistical modelling. With global crises which stemming from contagion effects becoming more frequent, new tools for financial distress transmission capture are needed. Graph theory, with its branch on minimum spanning trees can help researchers better represent the numerous multivariate and asynchronous interactions that suddenly manifest during moments of market panic. Under the current research, a novel graphical methodology is employed for the description of the 1997 Asian financial crisis. It is shown that market sentiment can have an interpretable image through the use of correlation based minimum spanning trees, a useful tool for policy makers and risk managers alike.

Keywords: correlation matrix, graph theory, minimum spanning tree

JEL Classification: C10, C18, C14, C38, C88

1. Introduction

Systemic risk can be expressed as the probability that a financial market suffers a catastrophic collapse due to a chain of events that arise locally and propagate globally in an interlinked system (De Bandt & Hartmann, 2000). Government finance is nowadays exposed to international debt markets and through this medium, public liabilities are traded between global financial institutions. With liabilities comes the risk of default and when this risk manifests itself, financial stress spreads through world markets in chain reaction. The current paper tries to address the problem of representing and understanding the propagation patterns of contagion through the use of minimum

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spanning trees. Its use case pertains to the Asian financial crisis of 1997-1998 due to the global reach that systemic risk gained at that specific time. By first engulfing the eastern and south-eastern parts of Asia and the spreading across the world to Russia and the American continent, the currency crisis that took place will always be a vivid reminder of the dangers of panic in an asymmetric informational environment.

Throughout this research multiple points about the Asian financial crisis will be discussed like its historical timeline, the economic and behavioral causes that lead to the crisis. As a technical tool for investigation, the minimum spanning tree was chosen. It represents a geometrical construction emerging from graph theory with custom applicability to the understanding of interconnected complex systems. Stepping into the temporal dimension of the study, three periods were chosen with respect to the crisis (ante, intra, post), in order to present the topology of market interactions on Asian currency markets.

2. Origins and context of the crisis

Tracing the path of what lead to the Asian crisis requires us to move backwards into history, to the decades of the 80's and 90's when South-East Asia experienced a period of rapid growth sustained by large capital inflows. During this period, the economies neighboring the Indonesian Archipelagoes and the South China Sea managed to lift a large part of their population from poverty and become important producers of manufactured goods. Nonetheless, these swiftly attained benefits came with hidden costs, typical of a "fast-track capitalism" (Weisskopf, 1992) implemented in countries that moved towards market economy status without an appropriate institutional infrastructure.

At the start of the 1980's, the US monetary and fiscal policies were marked by a fundamental change of direction, with Paul Volker at the head of the Federal Reserve. Targeting inflation and trying to avoid stagflation, the FED steadily raised key interest rates from 11% to 17.6% (Walsh, 2004). On the fiscal front, the Reagan administration tried to encourage growth and private initiative by reducing government spending along with tax and regulation cuts and by managing the quantity of money in the economy (Blanchard, 1987). Cumulatively, all of these measures gradually lead to an appreciation in interest rates, followed by an inflow of capital into the US and an investment

speculative bubble (Bergsten, 1984). But as any economy inevitably reverts to equilibrium, the balance was struck by the overvaluation of the US dollar with reference to the currencies of the major G7 countries and also to Asian and Latin America countries. Facing losses in commercial competitiveness, the US was slowly sliding towards a position where it would have to manage both a budget deficit and a current account deficit, a situation termed as “twin deficits” (Abell, 1990). In an effort to restore macroeconomic equilibrium, the US engaged in a coordinated international effort to devalue the dollar. Consequently, in September 1985, the Plaza Accord was signed by the five richest countries in the world, the US, Japan, Germany, France and Great Britain. It was then agreed that coordinated action would be taken to devalue the dollar with respect to the Japanese yen and the deutsche mark. As planned, the dollar lost approximately 50% of its value to the yen by 1987 followed by gains in the trade balance of the US by 1991 (Frankel, 2015). In Europe, the European Rate Mechanism was adopted to protect against currency market volatility with no effect on intra-union trade (Belongia, 1988), whilst Japan faced export competitiveness deterioration due to a doubling in the yen’s real value. Faced with the prospect of recession, the Bank of Japan came up with a fiscal stimulus package that restarted the economy but also spurred real-estate speculation and sub-optimal credit allocation.

Moving into the 1990’s two bubbles, a real-estate and stock market one, burst in Japan. Because of the reorientation of banks away from corporations a towards real-estate loans, the traditional Japanese business environment was altered. Constrained by the US, Japan deregulated its financial sector, opening it to outside competitors and investors. Fundamental shifts were also done to the monetary policy by renouncing the objective of growth and focusing towards an unnecessary inflation targeting. History shows that the Japanese government overreacted to the Plaza Accord risks by sustaining a budget surplus at the expense of corporate profits. As a side effect the stock market collapsed, infecting the real-estate sector (Pigeon, 2000) and starting a period of prolonged stagflation, also known as the “lost decade” (Hayashi, 2002). This was when Japanese and “newly industrialized countries” (Schmiegelow, 1992) corporations relocated important production capacities to the emerging economies of South-East Asia.

In the wake of the Plaza Accord, Japanese corporations understood that it will be long before the yen depreciates. Unable to

maintain market share through sacrificing profits alone, entire production branches had to be reorganized and transferred abroad. For example, Japanese yearly foreign direct investment in South-East Asia grew from one billion USD in the first half of the 80's, to a sustained six billion in the 90s (Ishida, 1998). Profiting from a young population with an insured secondary education level and a constant flow of engineers (Felipe, 2006), Asian industrialized countries were able to maintain their international share in export markets. So successful was this regional expansion that Japan's trade balance shifted from deficit to surplus in less than a decade. Discussing about the opportunity of creating a regional free trade zone with the yen at its core, (Kwan, 1994) measured that the export of heavy machinery and components to ASEAN countries tilted the Japanese current account from a 9.4 billion USD deficit in 1985 up to a 0.1 billion USD surplus. Other economies joined this trend, like those of Taiwan and Hong Kong. Nonetheless, working conditions worsened in Japan where there were less permanent jobs and salary purchasing power decreased¹.

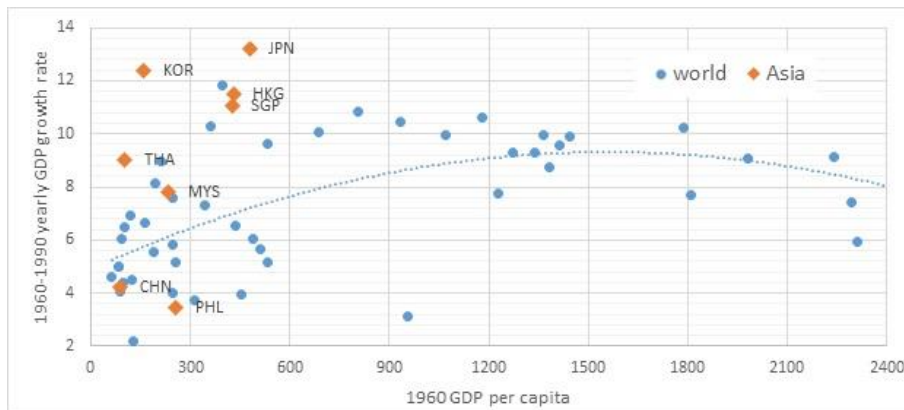
3. “Fast-track capitalism” and its hidden cost

Traditionally, emerging East Asia sustained a business model characterized by low wages, an underdeveloped finance sector and significant state intervention. The advent of large capital inflows opened the spectrum of better financing options and real growth. But, as any coin has a flipside, the ease of access to capital triggered an expansion in monetary mass, a deterioration of the current account, inflation and the overvaluation of the national currency. In a detailed report investigating the link between public policy and economic growth, the World Bank (WB) coined the term “Asian miracle” as the ability of the emerging economies in the region to lift large portions of the population out of poverty (Birdsall, et al., 1993). Looking at the period between the 1960 and 1990, the WB identifies twelve Asian nations with GNI higher than the emerging world's average. Of these, five were called “Asian tigers”, Hong Kong, South Korea, Singapore, Taiwan and China, alongside the “newly industrialized economies”(NIE) like Indonesia, Malaysia and Thailand. The report mentions that absolute poverty in the NIE decreased three times while life expectancy increased considerably as a result of accelerated but equally distributed growth.

¹ <https://www.economist.com/finance-and-economics/2013/03/09/waging-a-new-war>

Figure 1

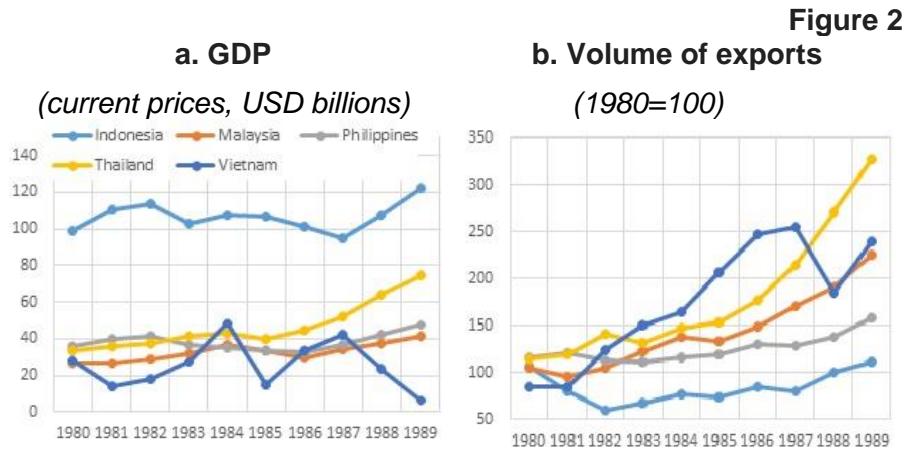
Yearly GDP growth against 1960 GDP per capita



Source: World Bank

Sustained by yearly GDP growth rates of impressive magnitude for three decades, the technocrats of Asian economies had institutionalized a development pattern based on massive inflows of foreign capital. Once on board the “globalization bandwagon” South-East Asia became subject to the ups and downs “fast-track capitalism”, where growth rates 7% to 10% year on year were based not on internal savings but on investments from outside the country (Bello, 1999).

Aside from the external factors, elements of own public policy encouraged the substitution of imports by internal manufacturing and later on developed into a commercial strategy. Policy makers marched full on towards encouraging exports through different measures like: protection of internal markets, export loans, tax exemptions for all imports used by exporting companies, tax cuts, and devaluation of the national currency. Together, these actions produced results that increased real exports more than 800% between 1970 and 1997 in the South-East Asia region (Redding, 2003).



Source: World Bank

This is not to say that ASEAN countries were traditionally isolated. On the contrary, in 1983, East-Asian intratrade represented 10% of world trade and 67% of the Pacific region trade (Petri, 1993). Due to the later expansion of world trade these percentages dropped to 7% and 40% respectively in 1990. Trade links had positive externalities into the investment flow towards the regional emerging economies, with NIE and Japan encouraging local business owners to join their global strategies. As such, the corporate industrial net spread amongst numerous production location in the region focusing on subcomponent manufacturing and assembly with imports of equipment and machinery, coming mostly from Japan. As side effects of this accelerated integration through expansion, inflationary pressures on salaries and real estate appeared, putting a strain on the existing physical infrastructure (Athukorala, 2006).

With easy access to external financing, the newly liberalized economies accumulated debt both on public and private sector balance sheets, through the intermediation of the financial sector. For example, sovereign debt in the Asia-pacific region grew from 204 billion USD in 1987 to 411 billion in 1994 (Tang, 1995), equivalent to an annual rate of growth of 7.5%.

Among other causes for the crisis it is worth mentioning the institutional and legal model adopted by Asian societies. Unlike western societies where business is done through arm-length transactions, subject to international law, Asian systems of relationships were based on prestige, personal connections. This type

of interaction created opaque monopolies, closed to outside competition. In a review about the legal bindings in business transactions in Asia, (RAJAN & ZINGALES, 1998) points out that foreign investors did not have guarantees that their money was allocated efficiently. Under such circumstances, many opted for frequently renewed, short term commitments, ready to retire their investments in case of financial distress. Of course, that moment finally came and when it did, the regional relationship-based networks absorbed the shock in its entirety.

In an analysis about the role of government institutions in contributing to the crisis, Joseph Stiglitz highlights three types of stimuli that encouraged short term debt in foreign currency (Stiglitz, 1998):

1) Pegging the national currency to the US dollar: though adverted as a means to control inflation, the adoption of fixed exchange rates in some Asian countries was meant to reassure investors that their assets would not lose values if they decided to pull out. Stock markets benefited from this regime as cross market migration could be done without exposure to currency risk.

2) Sterilization of capital inflows: a common response against national currency overvaluation following large inflows of foreign currency lies in the accumulation of reserves. By buying the excess foreign currency, the quantity of money in the economy grows, thus spurring inflation. Sterilization of these interventions can be achieved by raising the key interest rate. But, by making access to credit inside the country more difficult, central banks determined companies to look outside for financing.

3) Liberalization of capital accounts: less opened countries, with a lack of transparency of the financial sector, were less affected by the Asian crisis

We cannot say with certainty if the accumulation of debt in Asia was part of a broader strategy for industrial expansion. What is certain is that multiple disequilibria accumulated in the real economy like: the over expansion of the banking sector, highly leveraged investment in real-estate, an increase in government deposit guarantees (McKinnon, 1996). With such an accumulation of speculative investment, the sudden withdrawal of foreign capital can hurt internal savings and generate widespread bankruptcies. Therefore, there is a risk that local banks and credit networks might be dismantled, rendering human capital irrelevant (Calvo, 1998).

In the period preceding the crisis, the macroeconomic situation worsened in most Asian economies. In Thailand, the current account deficit rose from 5.7% in 1993 to 8.5% in 1996 due to overwhelming debt for private companies that had done bad investments in the real-estate sector (Corsetti, 1999). Foreseeing a potential crisis, Indonesia progressively raised interest rates up to 5% in 1997 and was in theory well suited to face the fore coming financial turmoil reserves of 20 billion USD and a current account surplus of 900 million USD. Despite this a large number of national corporations had borrowed in USD and the Bank of Indonesia was reluctant to raise interest rates further for fear of rupiah overvaluation. Moving on to South Korea one could observe that the family corporations (chaebol), composing the backbone of the countries industry, were engulfed in borrowing spree with the purpose of gaining international market share. Due to the close cooperation between the government and private corporations, financial controls and regulations were relaxed which, with time, resulted in a debt to equity ratio of almost 500% for the largest 30 corporations in South Korea in 1997 (Koo, 2001).

4. Chronology of the crisis

1997	January	Hanbo Steel corporation goes bankrupt, defaulting on its debt obligations, the first South-Korean chaebol to collapse in a decade
1997	February	Somprasong, a large real-estate developer in Thailand is forced into bankruptcy by its creditors
1997	March	A second South-Korean conglomerate, Sani Steel, defaults on its debt repayments
1997	May	Japan hints at possibly raising interest rates to prevent a yen devaluation. This announcement changed the perspective of international investors which decided it was a good moment to pull out of the region. All regional currencies are dumped, forcing the Thailand, the Philippines and Malaysian government to intervene through interest rate hikes, bailout packages for banks or restrictions on real-estate loans.
1997	June	Licenses are revoked for 16 major financial institutions in Thailand.
1997	July	Realizing it cannot support the currency peg, Thailand allows the baht to float, which immediately loses 20% of its value. A similar drop is incurred by the Malaysian ringgit after the government adopts a managed float regime for its currency
1997	August	Indonesia becomes the last economy to renounce its currency peg. The IMF intervenes for the first time in the crisis by granting a 3.9 billion dollars load to Thailand
1997	September	National banks in the region sterilize their open market operations in an effort to segregate their internal money markets from external ones.
1997	October	Contagion spills over from the currency markets to the capital markets of Hong Kong, Taiwan and US. The Dow Jones index registers its biggest historical drop of 544 points.

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1997	November	New loan arrangements are offered by the IMF to Indonesia and South Korea, with the condition that countries adopt structural adjustment policies. Though reassured for a short period, financial markets anticipate the fore coming tax raises and continue to attack the regional currencies.
1997	December	The Korean Won and Indonesian ringgit maintain their downward trend.
1998	January	Structural reforms announced by South Korea, Thailand, and Indonesia target non-performing banks, opening them to foreign investors. Government spending is severely cut. Markets start to regain confidence.
1998	April	The IMF secures a third loan arrangement with Indonesia in exchange for the phase out of food and fuel subsidies
1998	August	Fiscal policy across the Asian region becomes stricter, with tax and interest rate hikes discouraging speculation.
1998	December	American banks are asked by the FED to restructure the sort term loans offered to Asian banks

Source: Bloomberg, Financial Times and other media outlets of the time

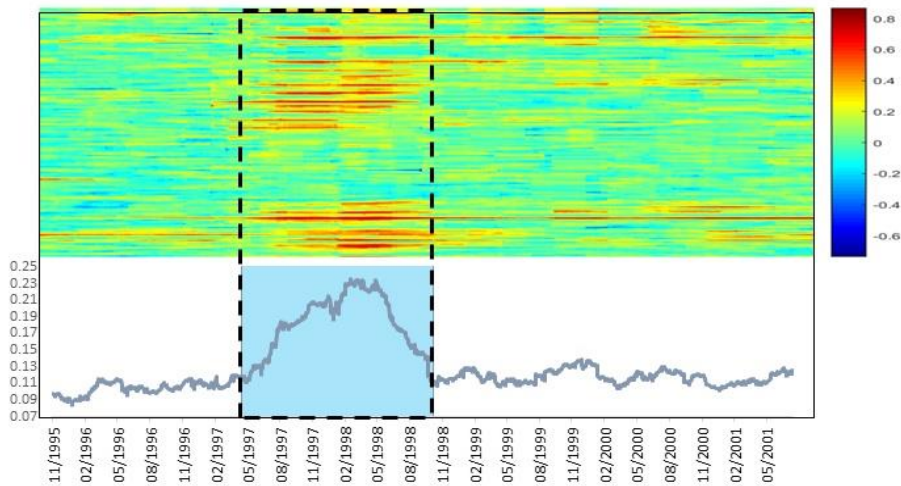
5. Graphs as a tool for navigating complex financial networks

Complexity emerges from the interaction of numerous entities abiding by local rules and yet, producing a higher order behavior. One tool for visualizing and understanding complex systems is the graph, an abstract mathematical construct defined by nodes connected by edges, describing the direction and intensity of interactions in the system.

5.1. Data set

As dataset, daily forex returns were chosen, for 17 USD currency pairs involved in the Asian crisis, with a time frame spanning from November 1995 to December 2001. The currency symbols are: JPY, AUD, CNY, HKD, INR, IDR, MYR, NZD, PHP, RUB, SGD, ZAR, KRW, CHF, TWD, THB, TRY. For the correlation coefficients, daily logarithmic returns were used. By calculation rolling 100 day rolling window correlations, a color map representation can highlight periods of sustained global interactions. For example, figure 3 depicts the correlation indices evolution for all currency bivariate combinations. Most of the correlations do not exceed on average an absolute value of 0.1, except for the crisis period when they start growing in May 1997, reaching a climax in March 1998 and then returning to normal levels by the end of the year. Taking into account the chronology of the crisis, it looks like statistical correlations emulate well the historical description of the events and their corresponding market actions.

Figure 3
Absolute correlations for bivariate currency combinations



Source: IMF

5.2. Distance measures for graph construction

A graph is a dynamic map of interactions and like any map, it relies on the accurate measurement of distances. Economics deals with causality measures or, in the absence of causality with statistical correlations. As such, the correlation matrix is often the preferred choice for describing the hierarchical structure of multivariate systems. Aggregating and analyzing bivariate correlations between financial time series can lead to the discovery of stable interdependency connections or to the side lining of those sporadic interactions determined by false signals.

If the Pearson correlation index is to be used as a distance measure, it would need to respect a set of axiomatic rules that derive from the concept of topological distance. Given two points in space X and Y , $d(X, Y)$ represents the distance between the point if:

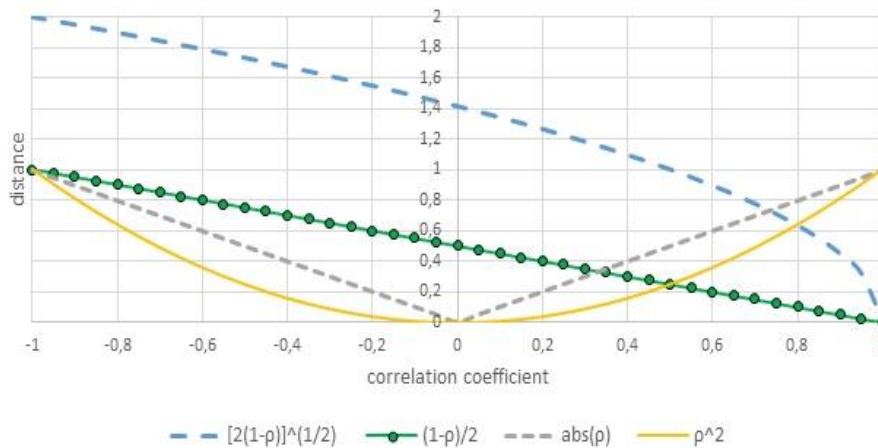
1. $d(X, Y) \geq 0$ distance cannot be negative
2. $d(X, Y) = 0 \approx X = Y$ distance is zero for overlapping points
3. $d(X, Y) = d(Y, X)$ distance is symmetric
4. $d(X, Z) \leq d(X, Y) + d(Y, Z)$ distance is additive

In light of the above restrictions, (Mantegna, 1999) proposes a distance measure for financial returns, derived from the Pearson correlation coefficient $\rho_{XY} = cov(X, Y) / \sigma_X \sigma_Y$ under the form $d = \sqrt{2(1 - \rho_{XY})}$. Other measures based on correlation coefficients can also be utilized. Figure 4 shows multiple distance shapes based on correlation coefficient transformation. Some measures are symmetric with respect to the correlation coefficient sign. Mategna's distance takes sign into account, exponentially converging to zero when correlation converges to 1.

For the current study, a custom distance measure was derived by the formula $(1-p)/2$. The shape of the distance is fully linear with respect to the correlation coefficient, fluctuating between 1 and 0 for correlations of -1 and 1 respectively.

Figure 4

Correlation coefficient derived distance measures



Source: Author's calculations

5.3. Minimum spanning trees

Representing the matrix of correlation in graph form is in itself not very informative. Every time series is more or less correlated to all others and so the graph becomes just a visual representation of a correlation table. By constructing the minimum spanning tree(MST) from the graph, a structural system of dependencies is revealed, which still guards a global view on the data set but is in turn more informationally efficient. A minimum spanning tree is defined as the set

of edges in an undirected graph that connects all the nodes, with no cycles and a minimum sum of edge weight. Applied for correlation-based distances, the MST shows what chained path causality might borrow to, propagate a shock, from one variable to another. Employing the word “causality” is not done in the statistical model based sense of (GRANGER, 1969) causality, but more in the context of contagion spreading through a network of dependencies.

In the research literature, MST's have been previously used to explain complexity in financial networks. (Bonanno G. e., 2003) proves in a comparative study of MST extracted from stock market and synthetically generated data, that market models are not able to capture the hierarchical structures inherent to real market data. In a later development of this observation, (Bonanno G. e., 2004) proposes that MSTs be used for assessing the informational relevance of factor models, beyond their averaging statistical properties. On a more practical side (Tabak, 2010) looks at the emerging hierarchies on the Brazilian stock exchange, noticing clustering effects in the MST based on industry and economic sector criteria. Incorporating the temporal dimension into analysis, (Coelho, 2007) challenges the modern portfolio allocation approach of (Markowitz, 1952), after showing that correlation based MSTs vary in shape and structure with time. MSTs have also been called upon in the understanding of the Asian financial crisis, when (Jang, 2011) used correlation matrices to highlight a spatial dispersion in dependencies between countries in the period preceding the crisis. Also, in the sphere of time varying MSTs, (Onnela, 2003) does a link survivability study on stock market data for NYSE, between 1980 and 1990. He shows that in general the topology of MSTs is constant, with contraction around the 19th of October stock market crash, also known as Black Monday.

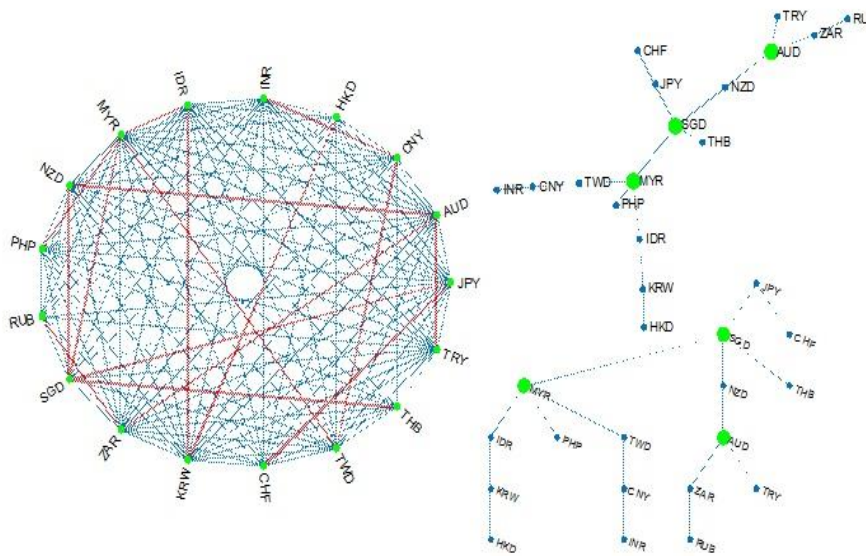
5.4. Minimum spanning tree representation

One of the problems with graphs produced from correlation matrices is the high number of edges. For n variables there are $n(n-1)/2$ possible connection, a quadratically increasing quantity. For example, under the current paper dataset, for 17 currency pairs there are 136 unique combinations of two. Faced with such a high number of relationships to analyze, we ask ourselves which are the most relevant for the systems behavior. We also know that on currency markets, some pairs are deemed “majors”, due to their high trading

volume. Do these pairs matter more in the market landscape? Or do crisis episodes reveal regional clusters with higher influence?

Figure 5 is a representation of a pairwise distance matrix derived from correlation coefficients between 17 currency pairs. The full connected graph representation is overwhelmed with edges that can confuse any human observer. By highlighting the MST, complexity is reduced and relevant connections emerge. Taking only the MST and representing through force directed placement (FRUCHTERMAN & REINGOLD, 1991) or through layered levels (BARTH, JÜNGER, & MUTZEL, 2004), one is able to understand the hierarchical dependencies in the data. Under the present example the Singapore dollar, the Australian dollar and the Malaysian ringgit are influence intermediaries. Possible explanations are that the first two currency pairs are highly traded in the region and worldwide, whilst the third one suffered severe devaluation during the crisis and was at the origin of contagion.

Figure 5
Multiple topological representations of the MST (circle, force, layered)

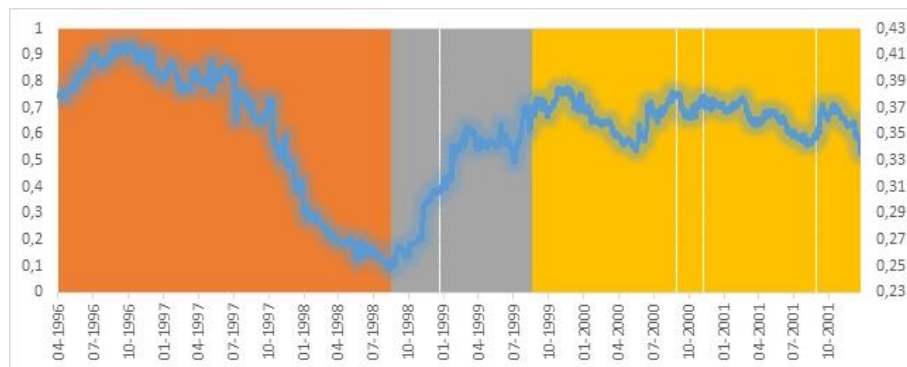


Source: Author's calculations

6. Minimum spanning tree analysis of the Asian financial crisis

In order to observe the evolution of the MST in the vicinity of the crisis events, 100 day rolling window correlations were computed for all combinations of currency pairs. By taking the correlations and transforming them into distances by the formula $(1-\rho)/2$, MST are obtained for each observational 100 day window. Even though the MST is constructed from a different distance matrix each period, as the correlation coefficient remain relatively stable from day to day, it is acceptable to locally compare the total edge weight sum as a measure for total tree dispersion. As such, the plot of these consecutive edge distances offers hints about market cohesion in time

Figure 6
Total edge weight sun in the MST for consecutive periods



Source: Author's calculations

Figure 6 shows that total distance in the MST drops starting with the year 1997, when the crisis occurred. As correlations across the region become more significant, economies come closer together in the view of market participants. Three distinct periods are isolated, according to the total MST cohesion measure:

1) Build-up of distress and collapse (April 1996-August 1998) – the MST structure becomes denser due to a generalized increase in correlations

2) Economic recovery (August 1998-September 1999) – increase in MST dispersion following a regain of market confidence in the Asian region

3) Post crisis calm (September 1999 – December 2001) – cross-country correlations might vary, but on average the region is stable

Selection of the three time frames was done visually by taking the minimum and maximum values of the total edge sum in the MST.

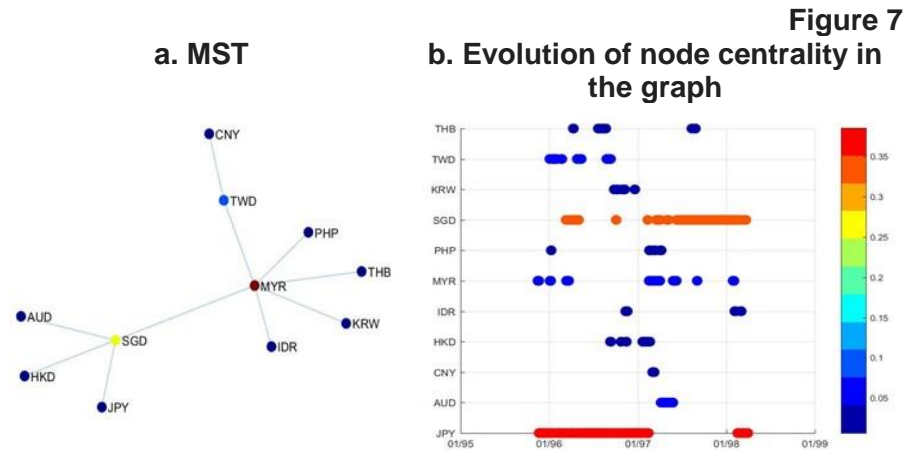
6.1. Estimation results

a) Build-up of distress and collapse (April 1996-August 1998)

Considering the correlations for the complete period 1996-1998, the topological analysis (fig.7a) suggests the existence of two distant sets of currency pairs at a distance sufficient to allow their discrimination. The first set consists of AUD (Australian Dollar), HKD (Hong Kong Dollar) and JPY (Japanese Yen), centered around SGD (Singapore Dollar). It should be noted that the Singapore Dollar was pegged to the GBP (British pound) till 1970 and after it was under a managed float based on a US dollar-dominated currency basket. So we can consider SGD as a regional approximation of the US dollar. The second set consists of CNY (Chinese Yuan), TWD (New Taiwan Dollar), PHP (Philippines peso), THB (Thai Baht), KRW (Korean won), IDR (Indonesian rupee) concentrated around MYR (Malaysian ringgit). The centrality measure that designates the Singapore dollar and the Malaysian ringgit as central currencies should not be interpreted as an absolute indication of their domination, but rather as the measure of maximum similarity with the currencies of their own group, an average of the evolutions of the other variables.

Moving from the topological analysis to the interpretive synthesis, we understand that the graph managed to classify the currencies depending on the degree of industrial development and the opening to trade of the represented economies, despite the fact that these characteristics were not incorporated into the algorithm. Here is an indication of the usefulness of modern methods of viewing and interpreting large data sets. The MST method produced useful informative content without the researcher issuing a subjective initial hypothesis and then testing it quantitatively.

Focusing on the node hierarchy (Figure 7b), it is observed that for the 100-day correlation, the SGD and MYR dominance is equal to JPY and TWB respectively. The topology of node relations remains relatively constant, but at different times, the central nodes are interchangeable in a group (a core) of similar currencies.



Source: Author's calculations

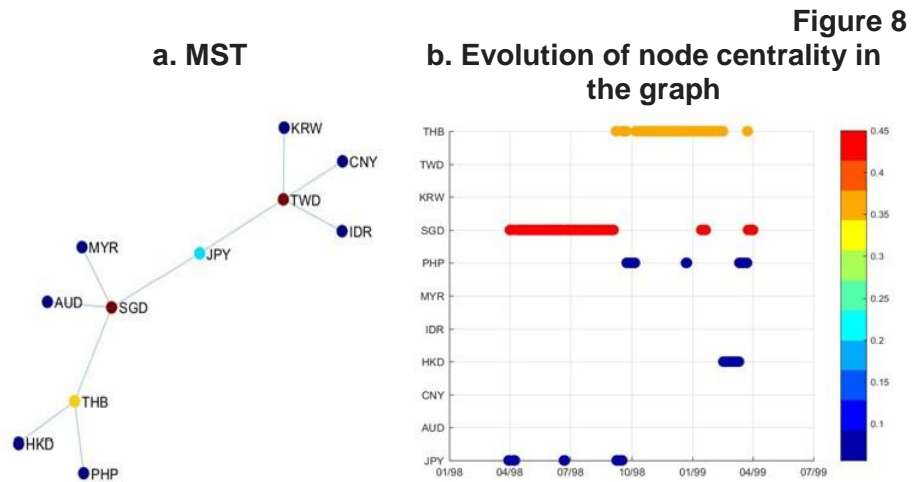
From a historical point of view, Japan resisted the crisis due to the world's largest currency reserves at that time. Australia had exported less to the region but at the same time the cost of imports had diminished, especially for raw materials whose production had increased, countries in difficulty trying to compensate their losses. In fact, liquid capital migrated from developing countries to economies in the region that have a tradition of banking and a consolidated rule of law.

Violent rebalancing in the forex markets was due to the currency management by central banks through controlled floatation or even fixation against the US dollar in the case of Thailand, Indonesia or Malaysia. But for these open economies, which liberalized their capital account, withdrawals and speculative attacks forced them to raise short-term interest rates, and when this mechanism no longer had effect, they let the currency fluctuate freely, triggering rapid devaluation.

b) Economic recovery (August 1998-September 1999)

In the second period, characterized by a sustained increase in intra-node spacing, currency pairs become more disparate, the role of central nodes being taken by THB, SGD, JPY and TWD for correlation over the entire period (Figure 8a). From the perspective of the mobile correlation window, the interconnected node role is preserved by THB and SGD (Figure 8b). The topological representation also takes into account the distances between the nodes. The largest distance is

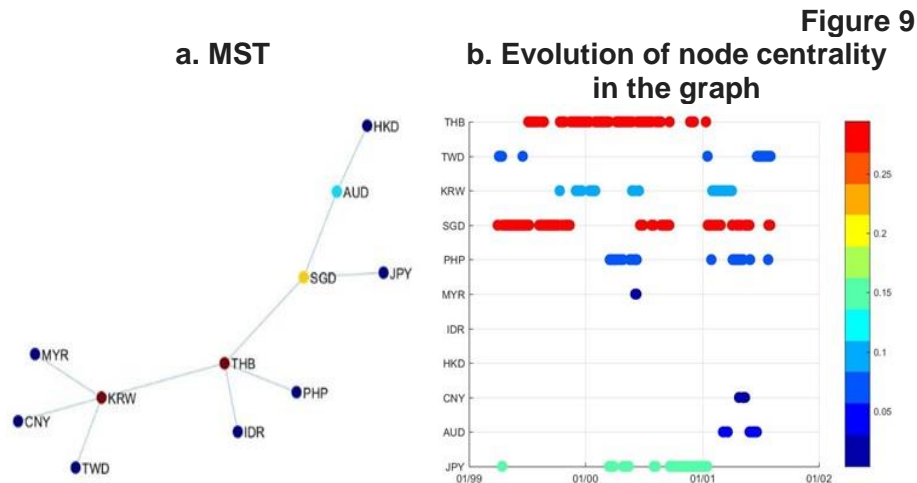
between the set of HKD and PHP and the set consisting of KRW, CNY and IDR.



Source: Author's calculations

In this case, pegged currencies that or who were heavily linked to the US economy, either through commerce or foreign investment, crowded into a distinct area of the graph, whilst those more dependent on the regional economy retained group cohesion. After the initial shock of the crisis, the IMF and the US intervened to support the Asian countries and save Russia from defaulting. In 1999, most economies stabilized their financial situation after their public debt exceeded 150% of GDP.

c) Post crisis calm (September 1999 – December 2001)



Source: Author's calculations

The Asian crisis also had beneficial effects for disciplining the affected economies, most of them developing rapidly after the end of the crisis. IMF aid packages, the restructuring of the economy, the liberalization of the exchange rate and the return of capital together with us prudential rules in the banking system, all these measures have contributed to nearly a decade of commercial recovery and an increase in average incomes in the region. The topological analysis is similar to the exit period of the crisis, demonstrating that the Asian region is differentiated according to the degree of integration into the global economy, but in times of crisis, this discrimination fades away and the capital withdraws to those savings reserves, HKD, JPY and AUD.

7. Discussion

Multivariate modelling of time series will always be prone to over parametrization and in the current international financial landscape complexity cannot be avoided. The present research brings forward graph theory as a helping tool for statisticians in choosing which type of modeling approach to take when dealing with high dimensional data. By looking at the Asian financial crisis from the perspective given by minimum spanning tree, one can understand that market sentiment is highly polarized in times of financial distress. Investor opinion tends to gravitate around a binary view of safe haven

currencies versus compromised currencies in times of crisis. The view reverts to a more geographical segregation mapping when no immediate threats are foreseen.

Minimum spanning trees can become a trustworthy tool for policy makers and risk managers in the analysis of complex financial systems. With characteristics that blend the dimensionality reduction of principal component analysis and shock analysis of impulse response functions, MSTs can prove highly informative. Through their capacity of efficiently extracting information from correlation matrices and plot causality paths between multiple variables, MSTs should be a first-choice option when dealing with shock propagation in financial networks.

References

1. Abell, J. D. (1990). Twin deficits during the 1980s. An empirical investigation. *Journal of macroeconomics*.
2. Akhtar, M. H. (2010). Technical Efficiency and Productivity Growth of Saudi Banks: A Data Envelopment Analysis Approach. *Global Business Review*, 11(2), 119–133.
3. Athukorala, P.-c. a. (2006). Production fragmentation and trade integration: East Asia in a global context. *The North American Journal of Economics and Finance*.
4. Barth, W., Jünger, M., & Mutzel, P. (2004). Simple and Efficient Bilayer Cross Counting. *Journal of Graph Algorithms and Applications*.
5. Bello, W. (1999). The Asian financial crisis: Causes, dynamics, prospects. *Journal of the Asia Pacific Economy*.
6. Belongia, M. T. (1988). Prospects for international policy coordination: some lessons from the EMS. *Federal Reserve Bank of St. Louis Review*.
7. Benston, G. (1964). Economies of scale and marginal cost in banking operations. *National Banking Review*, 2, 507-549.
8. Bergsten, C. F. (1984). "The United States trade deficit and the dollar." Statement before the Senate Committee on Banking, Housing and Urban Affairs. Washington: Subcommittee on International Finance and Monetary Policy.

9. Birdsall, N. M., Campos, J. E., Kim, C.-S., Corden, W. M., MacDonald, L. J., Pack, H., . . . Stiglitz, J. E. (1993). *The East Asian miracle: economic growth and public policy*; A World Bank policy research report. New York: Oxford University Press.
10. Blanchard, O. J. (1987). Reaganomics. *Economic Policy*.
11. Bonanno, G. e. (2003). Topology of correlation-based minimal spanning trees in real and model markets. *Physical Review*.
12. Bonanno, G. e. (2004). Networks of equities in financial markets. *The European Physical Journal*.
13. Calvo, G. A. (1998). Capital flows and capital-market crises: the simple economics of sudden stops. *Journal of applied Economics*.
14. Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2, 429-444.
15. Coelho, R. e. (2007). The evolution of interdependence in world equity markets; Evidence from minimum spanning trees. *Physica A: Statistical Mechanics and its Applications*.
16. Corsetti, G. P. (1999). What caused the Asian currency and financial crisis? Japan and the world economy.
17. De Bandt, O., & Hartmann, P. (2000). Systemic risk: A survey. *European Central Bank Working Paper Series*.
18. Farrell, M. J. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society*, 120, 253-290.
19. Felipe, J. (2006). A decade of debate about the sources of growth in east Asia. *Estudios de economía aplicada*.
20. Frankel, J. (2015). *The Plaza Accord, 30 Years Later*. National Bureau of Economic Research.
21. Fruchterman, T. M., & Reingold, E. M. (1991). Graph Drawing by Force-directed Placement. *Software — Practice & Experience*.

22. Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica*.
23. Hayashi, F. a. (2002). The 1990s in Japan: A lost decade. *Review of Economic Dynamics*.
24. Ishida, K. (1998). Japan's Foreign Direct Investment in East Asia: Its Influence on Recipient Countries and Japan's Trade Structure. *East Asian Development*.
25. Isik, I., & Hassan, M. K. (2002). Technical, scale and allocative efficiencies of Turkish banking industry. *Journal of Banking & Finance*, 26, 719–766.
26. Jang, W. J. (2011). Currency crises and the evolution of foreign exchange market: Evidence from minimum spanning tree. *Physica A: Statistical Mechanics and its Applications*.
27. Koo, J. a. (2001). Recovery from a financial crisis: The case of South Korea. *Economic and Financial Review*.
28. Kwan, C.-H. (1994). Economic interdependence in the Asia-Pacific region: towards a yen bloc. *Psychology Press*.
29. Mantegna, R. N. (1999). Hierarchical structure in financial markets. *The European Physical Journal B-Condensed Matter and Complex Systems*, 193-197.
30. Markowitz, H. (1952). Portfolio selection. *The journal of finance*.
31. McKinnon, R. I. (1996). Credible Liberalizations and International Capital Flows: The "Overborrowing Syndrome". *Financial Deregulation and Integration in East Asia, NBER-EASE*.
32. Olson, D., & Zoubi, T. A. (2011). Efficiency and bank profitability in MENA countries. *Emerging Markets Review*, 12, 94-110.
33. Onnela, J.-P. e. (2003). Asset trees and asset graphs in financial markets. *Physica Scripta*.
34. Pearson, K. (1895). Notes on Regression and Inheritance in the Case of Two Parents.

35. Pearson, K. (1900). On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 157-175.
36. Petri, P. A. (1993). *The East Asian trading bloc: an analytical history. Regionalism and Rivalry: Japan and the United States in Pacific Asia.*
37. Pigeon, M.-A. (2000). *It's Happened, but Not Again: A Minskian Analysis of Japan's Lost Decade.* Jerome Levy Economics Institute Working Paper.
38. RAJAN, R. G., & ZINGALES, L. (1998). Which capitalism? Lessons from the East Asian crisis. *Journal of Applied Corporate Finance*.
39. Redding, S. a. (2003). South-East Asian export performance: external market access and internal supply capacity. *Journal of the Japanese and International Economies*.
40. Reisen, H. a. (2001). Which types of capital inflows foster developing-country growth? *International finance*.
41. Sandoval Jr, L. (2012). Pruning a minimum spanning tree. *Physica A: Statistical Mechanics and its Applications*.
42. Schmiegelow, M. (1992). The Asian newly industrialized economies: a universal model of action. *Civilisations. Revue internationale d'anthropologie et de sciences humaines*.
43. Sealey, C., & Lindley, J. T. (1977). Inputs, Outputs and a Theory of Production and Cost at Depository Financial Institutions. *Journal of Finance*, 32(4), 1251-1266.