Synchronisation of financial crises: six Asian countries, 1970–2002

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Abstract

This paper develops concordance indices for studying the simultaneous occurrence of financial crises across markets and/or countries. The typically low incidence of financial crises necessitates a change in the definition of concordance from those recently developed for the business cycle literature (Harding and Pagan 2002, 2003). We propose to confine attention to non-tranquil periods to develop a revised bivariate index, and its multivariate analog, and study their properties, including tests of independence between the component series. An application to East Asian countries reveals the extent of concordance in crises by both asset market and country.

Keywords: financial crisis, contagion, synchronisation, concordance indexes, exact homogeneity test
JEL-code: F31, F47

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1 Introduction

Financial crises can have a huge impact on economies, but fortunately do not occur very often. The probability of a country experiencing a financial crisis - currency, banking or twin - is by most calculations very low; for example Eichengreen and Bordo (2002) produce a figure of 12 percent for 56 countries over the sample 1973-1997.

Nevertheless there is substantial policy and academic interest in whether crises do occur together, either across nations or across different asset markets within a particular country (or countries). The preconditions for a crisis in one market are often related to financial fragility in other markets, see Goldstein, Kaminsky and Reinhart (2000) for discussion. In recent times policy interest in spillovers of crises between countries heightened with the East Asian crisis of 1997-1998 and the spread of the Russian bond default to other emerging market bond spreads, and subsequently to developed markets through the near collapse of the US hedge fund Long Term Capital Management. Much of this interest focused on the often poorly defined concept of contagion, broadly defined as the spread of crises between countries and markets after controlling for the usual linkages due to trade and fundamentals; see Dornbusch, Park and Claessens (2000) and Pericoli and Sbracia (2003) for a review of this literature. Because of the relatively low probability of independent crises in individual countries and markets, this is often taken as *prima facie* evidence of transmission of crises, either by the usual linkages or contagions; see Lowell, Neu and Tong (1998).

The concern with the transmission of crises between countries and markets is such that we find it worth considering appropriate measurement of the true extent of independence or otherwise of the observed crisis data. Some existing literature considers the extent to which crises occur simultaneously by counting the number of co-occurrences, see Kaminsky and Reinhart (1999) for example. Here we propose to formalise this drawing on recent business cycle literature looking at the synchronisation of business cycles. We draw on work by Harding and Pagan (2002, 2003) who develop a concordance index for the common phases and turning points of business cycles, and adapt this

to deal with financial crises. Our adaptations consist of confining attention to turbulent periods, excluding the long tranquil periods from the analysis. We show the properties of both the Harding and Pagan indices, our suggested Turbulent Periods concordance index and an intermediate concordance index. Additionally we extend each of these indices from the bivariate to multivariate framework, and show how to test the hypothesis that the crises are independent in each case.

To illustrate the techniques we apply the concordance index to six Asian economies for the period January 1970 to December 2002. The results suggest that when two or more crises occur concurrently they are unlikely to be coincidental. In the bivariate indices we find that the Asian sample can be characterised as having spread across markets over geographic borders rather than between markets within countries. The multivariate indices and tests reinforce this view. This type of crisis has quite different policy implications than those which spread primarily within countries, and has influenced the discussion of links formed by international financial architecture; see for example Eichengreen (2002) and Eichengreen, Kletzer and Mody (2003) for a review of proposals to reform this sector.

The paper proceeds as follows. Section 2 defines what is meant by synchronisation of crises, and gives some definitions which are closely related to the business cycle literature. Section 3 outlines the Harding and Pagan bivariate concordance index and develops the turbulent period concordance index which is more appropriate to the current situation of relatively rarely occurring events. Multivariate extensions of each concordance index and their properties are outlined. Appropriate tests for whether independent crisis events are truly being observed are explained in Section 4. The concordance index and tests are then applied to Asian data in Section 5. Section 6 concludes.

2 Defining synchronisation

Let a financial crisis be represented by the binary variable S_{it}, where $i = nm$, which takes the value one if a crisis occurs in country n and market m in period t and zero otherwise. Following Harding and Pagan (2003), *strong perfect positive synchronisation* (SPSS) occurs when two of these random indicator variables are identical, that is $S_{xt} = S_{yt}$. Necessary and sufficient conditions for SPSS are

$$\begin{aligned} \Pr(S_{yt} = 1, S_{xt} = 0) &= 0 \quad (1) \\ \Pr(S_{yt} = 0, S_{xt} = 1) &= 0 \quad (2) \end{aligned}$$

The binary character of the variables means that the probabilities in Equations (1) and (2) can be expressed as expectations. The following conditions are necessary under the null of SPSS

$$\begin{aligned} E(S_{yt}(1 - S_{xt})) &= E(S_{yt}) - E(S_{yt}S_{xt}) \quad (3) \\ E(1 - S_{yt}S_{xt}) &= E(S_{xt}) - E(S_{yt}S_{xt}) \quad (4) \end{aligned}$$

or

$$\begin{aligned} E(S_{yt}) - E(S_{xt}) &= 0 \quad (5) \\ E(S_{xt}) - E(S_{yt}S_{xt}) &= 0. \quad (6) \end{aligned}$$

A useful way of expressing Equation (6) is as

$$\mu_{S_x} - \sigma_{S_y}\sigma_{S_x}\rho_S - \mu_{S_y}\mu_{S_x} = 0, \quad (7)$$

where $\mu_{S_y} = E(S_y)$, $\mu_{S_x} = E(S_x)$, σ_{S_y} and σ_{S_x} are the standard deviations of S_x and S_y, and ρ_S is the correlation coefficient between S_x and S_y. When the first condition of SPSS holds, then $E(S_{yt}) = E(S_{xt}) = \mu_S$ and $\sigma^2_{S_y} = E(S_{yt})(1 - E(S_{yt})) = \sigma^2_{S_x}$, so Equation (7) becomes

$$(1 - \rho_S)\mu_S(1 - \mu_S) = 0. \quad (8)$$

If we exclude the uninteresting cases of only crises , $\mu_S = 1$, or no crises, $\mu_S = 0$, from the analysis then equation (8) implies that $\rho_s = 1$, logically that the two series are perfectly correlated. Hence, Harding and Pagan conclude that test statistics for SPSS can be based on the estimated means and correlation

$$\begin{aligned} \text{SPSS(i):} \quad & \hat{\mu}_{S_y} - \hat{\mu}_{S_x} \\ \text{SPSS(ii):} \quad & \hat{\rho}_S - 1. \end{aligned}$$

We now consider cases of measuring imperfect synchronisation.

3 Measuring synchronisation

3.1 Bivariate crises

An alternate way of viewing the concordance between series is simply to 'count' the number of times the variables S_{xt} and S_{yt} are in various combinations of states. In a bivariate setting the total observations in the sample (T) consist of the number of simultaneous crises periods ($\#(1,1)$), the number of periods with a single crisis ($\#(1)$) and the number of tranquil periods ($\#(0)$), or

$$T \equiv \#(1,1) + \#(1) + \#(0).$$

Harding and Pagan (2003) advocate measuring the degree of synchronisation in cycles in terms of the fraction of time the cycles are in the same phase. Their *concordance index* has the form

$$\hat{I}_t = \frac{\#(1,1) + \#(0)}{T} \left(= 1 - \frac{\#(1)}{T} \right). \tag{9}$$

The relevance of the expression between brackets will become clear in our discussion of multivariate synchronisation below. The index can be rewritten as

$$\hat{I} = \frac{1}{T} \left\{ \sum_{t=1}^{T} S_{xt} S_{yt} + \sum_{t=1}^{T} (1 - S_{xt})(1 - S_{yt}) \right\}.$$

Equivalently the index can be expressed in terms of the estimated means $\hat{\mu}_{S_x}$, $\hat{\mu}_{S_y}$ and the estimated correlation coefficient $\hat{\rho}_S$ between S_{xt} and S_{yt}

$$\hat{I} = 1 + 2\hat{\rho}_s(\hat{\mu}_{S_x}(1-\hat{\mu}_{S_x}))^{1/2}(\hat{\mu}_{S_y}(1-\hat{\mu}_{S_y}))^{1/2} + 2\hat{\mu}_{S_x}\hat{\mu}_{S_y} - \hat{\mu}_{S_x} - \hat{\mu}_{S_x}. \quad (10)$$

Figure 1 shows the values of this concordance index for feasible combinations of estimated means $\hat{\mu}_{S_x}$ and correlations $\hat{\rho}_S$ between perfect positive correlation (+1) and perfect negative correlation (-1). For purpose of illustration assume that the incidences of the crises we are looking at are the same, *i.e.,* the estimated means $\hat{\mu}_{S_x}$ and $\hat{\mu}_{S_y}$ are equal, as this is usually the case of interest.[1] The figure shows that high concordance can be achieved with $|\hat{\rho}_s| = 1$, that is at either end of the x axis, regardless of the mean value. For our purposes a focus on perfect offsets, $\hat{\rho}_s = -1$, is of less interest. That is we are not particularly interested in the case where country A is always in a crisis when country B is not, and vice versa.

A typical feature of financial crises is their low incidence, or a large number of tranquil periods in the sample. The Harding-Pagan concordance measure is clearly not designed with this as it is dominated by a large number of zero observations in the sample. Focusing on crises periods in the whole sample gives the *crisis-only concordance index*

$$\hat{I}^{co} = \frac{\#(1,1)}{T}\left(= 1 - \frac{\#(1)+\#(0)}{T}\right), \quad (11)$$

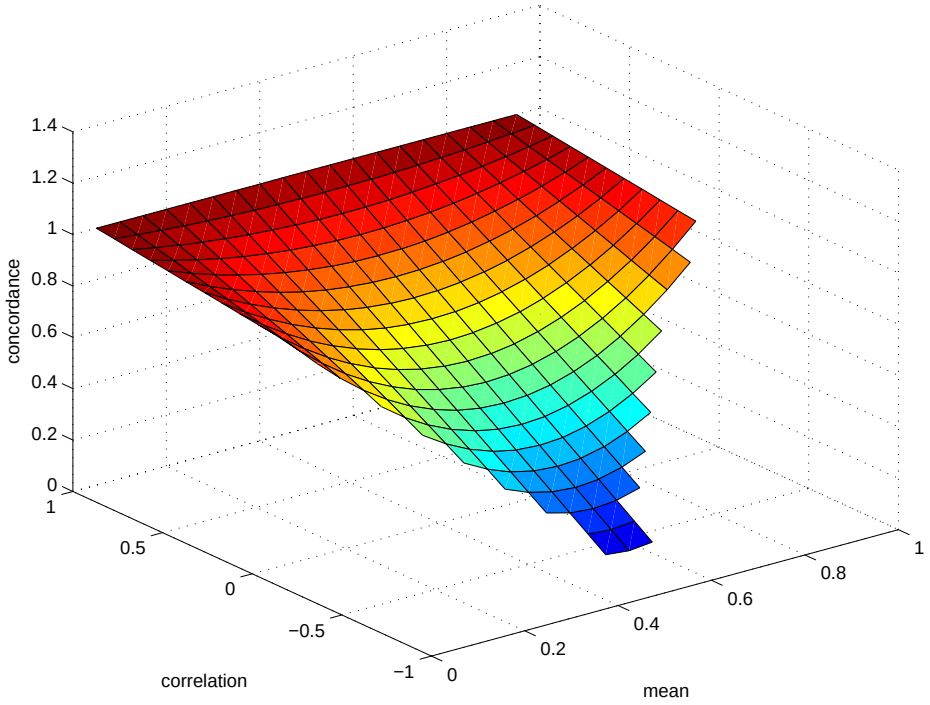
which in rewritten form becomes

$$\hat{I}^{co} = \hat{\rho}_s(\hat{\mu}_{S_x}(1-\hat{\mu}_{S_x}))^{1/2}(\hat{\mu}_{S_y}(1-\hat{\mu}_{S_y}))^{1/2} + \hat{\mu}_{S_x}\hat{\mu}_{S_y}. \quad (12)$$

The corresponding surface plot, using the same assumption on the estimated means, is shown in Figure 2. The figure illustrates that concordance can be low despite high correlation between the binary crisis variables, because of the low incidence of crises. Another disadvantage of this index is that it depends on the number of tranquil periods included in the sample. If we

[1]It is simple to observe the means of the zero-one indexes, and if they are not very close then clearly the potential for the series to be closely related is uninterestingly low.

Figure 1: Harding-Pagan Concordance Index



add a non-turbulent year of observations, the crisis-only concordance index becomes smaller.

It seems natural then to confine attention to the concordance of crises in turbulent periods and introduce the *turbulent-periods concordance index*

$$\hat{I}^{tp} = \frac{\#(1,1)}{T - \#(0)} \left(= 1 - \frac{\#(1)}{T - \#(0)} \right), \tag{13}$$

where we assume that there is at least one crisis in our sample, *i.e.*,$T - \#(0) \neq 0$. Equation (13) gives the number of times in which the two markets are both in crisis as a proportion of the number of times there are any crises in the sample. Hence, the influence of the dominant non-crisis periods is removed.

Rewriting gives a slightly more complicated expression

$$\hat{I}^{tp} = \frac{\hat{\rho}_s(\hat{\mu}_{S_x}(1-\hat{\mu}_{S_x}))^{1/2}(\hat{\mu}_{S_y}(1-\hat{\mu}_{S_y}))^{1/2} + \hat{\mu}_{S_x}\hat{\mu}_{S_y}}{-\left(\hat{\rho}_s(\hat{\mu}_{S_x}(1-\hat{\mu}_{S_x}))^{1/2}(\hat{\mu}_{S_y}(1-\hat{\mu}_{S_y}))^{1/2} + \hat{\mu}_{S_x}\hat{\mu}_{S_y}\right) + \hat{\mu}_{S_x} + \hat{\mu}_{S_x}}, \tag{14}$$

which is plotted in Figure 3.

Figure 2: Crisis-Only Concordance Index

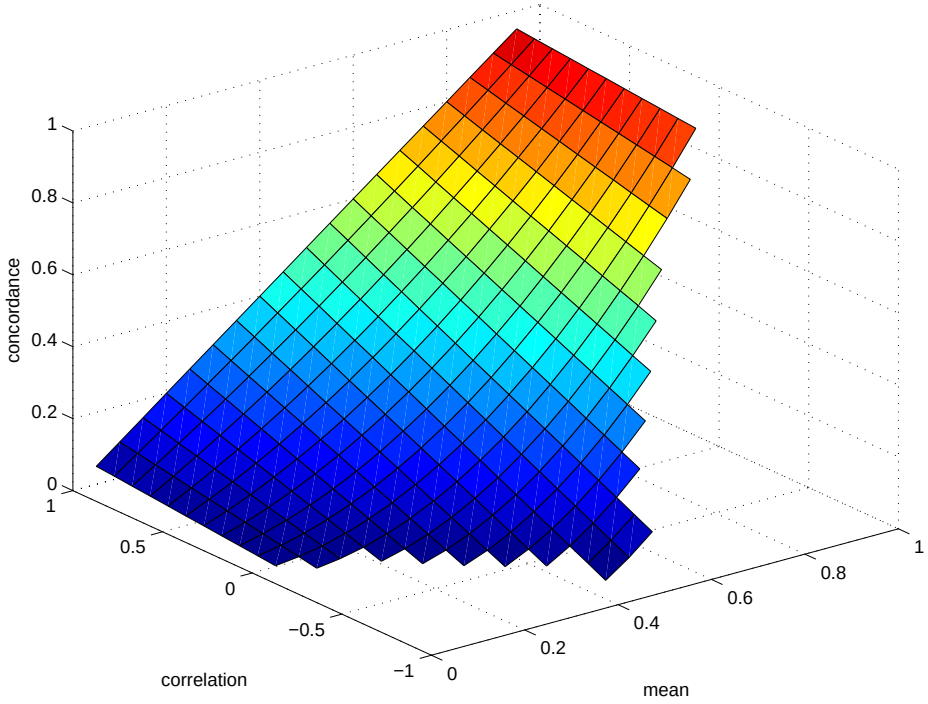


Figure 3: Turbulent Periods Concordance Index

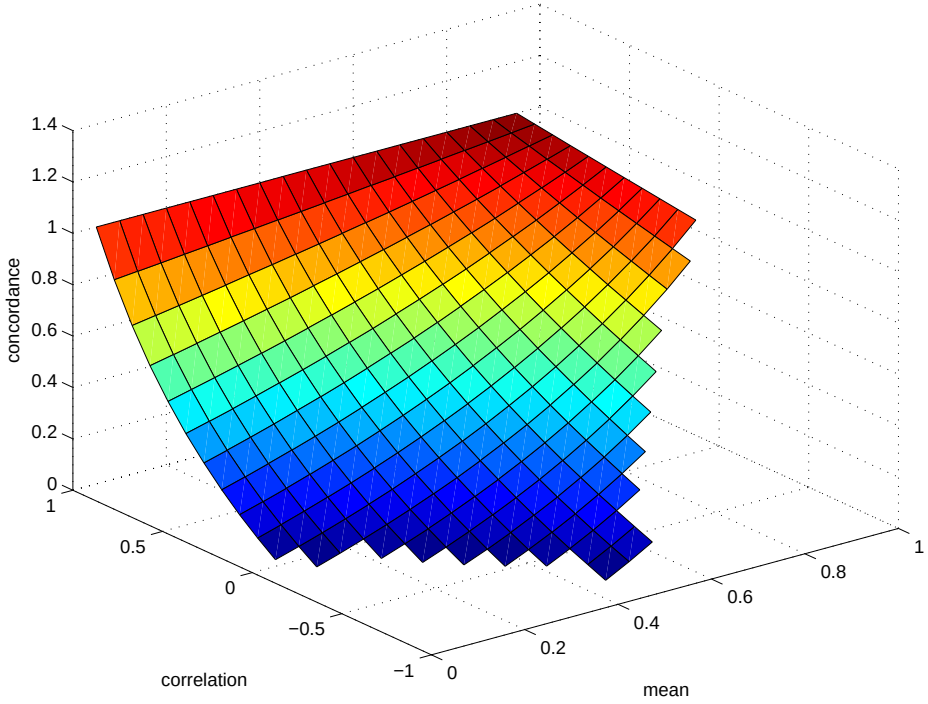


Figure 3 shows that high concordance is achieved when correlation is high, $\hat{\rho}_s = 1$, or means are high $\hat{\mu}_{S_x} = \hat{\mu}_{S_y} = \hat{\mu}_S = 1$, or a combination of these two characteristics. As either of $\hat{\rho}_s$ or $\hat{\mu}_S$ approach one the value of the concordance index increases. This makes intuitive sense because as the number of crisis observations in the sample increases the possibility of overlap also increases, even in the extreme case of independence of crises (a topic to which we return below).

3.2 Multivariate synchronisation

Consider the case of concordance in the context of multiple financial crises across m financial markets and n countries, giving a total of nm potential crises indices. We may be interested in testing for concordance in a number of ways here. It may be that we are interested in any instances of concordance across the indices, so that we are interested in the joint occurrence of 2 or more 1s in the index. Denote this as $(\#1 > 2)$. More generally we may be interested in instances where Z or more indices have the value of 1. Denote this as $(\#1 > Z)$.

Then the multivariate forms of the three indices are given by:

- the multivariate Harding and Pagan concordance index is symmetric in considering both occurrences of non-crisis and crisis periods, in the case of $Z = 2$, for $nm > 2$,[2]

$$\hat{I} = \frac{(\#0) + (\#1 \geqslant Z)}{T}, \tag{15}$$

- the multivariate crisis-only concordance index

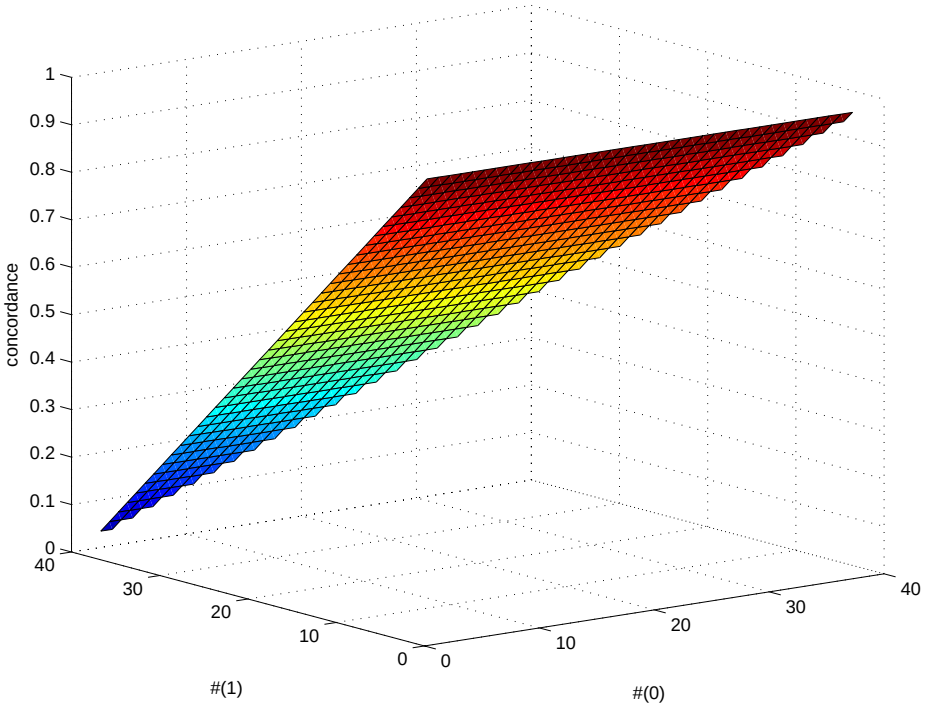
$$\hat{I}^{co} = \frac{(\#1 \geqslant Z)}{T} = 1 - \frac{(\#1 < Z) + \#(0)}{T}, \tag{16}$$

[2]The case given in the text is one alternative. Another form may be that one is interested in the cases in which there are both occurrences of zeros (non-crisis periods) $\geqslant Z$ as well as ones $\geqslant Z$ in which case the concordance index would be calculated as

$$\hat{I} = \frac{(\#0 \geqslant Z) + (\#1 \geqslant Z)}{T}.$$

This would give a slightly different profile for the Figure shown.

Figure 4: Multivariate Harding-Pagan Concordance Index



- the multivariate turbulent-periods concordance index

$$\hat{I}^{tp} = \frac{(\#1 \geqslant Z)}{T - \#(0)} = 1 - \frac{(\#1 < Z)}{T - \#(0)}, \tag{17}$$

Figures 4–6 show the multivariate versions of the index for $Z = 2$. The linear nature of both the Harding-Pagan multivariate index and the crisis-only index are clearly visible in the figures. In the case of the turbulent periods concordance index there is a trade-off in the value of the index between the number of crises observed as a proportion of the number of non-crisis periods.

Figure 5: Multivariate Crisis-Only Concordance Index

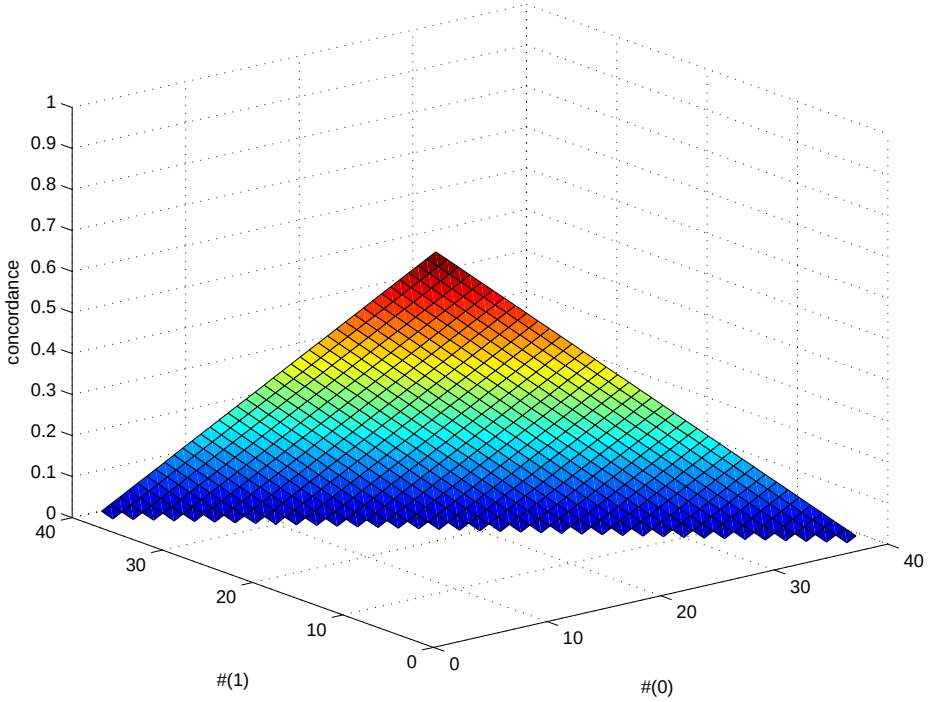
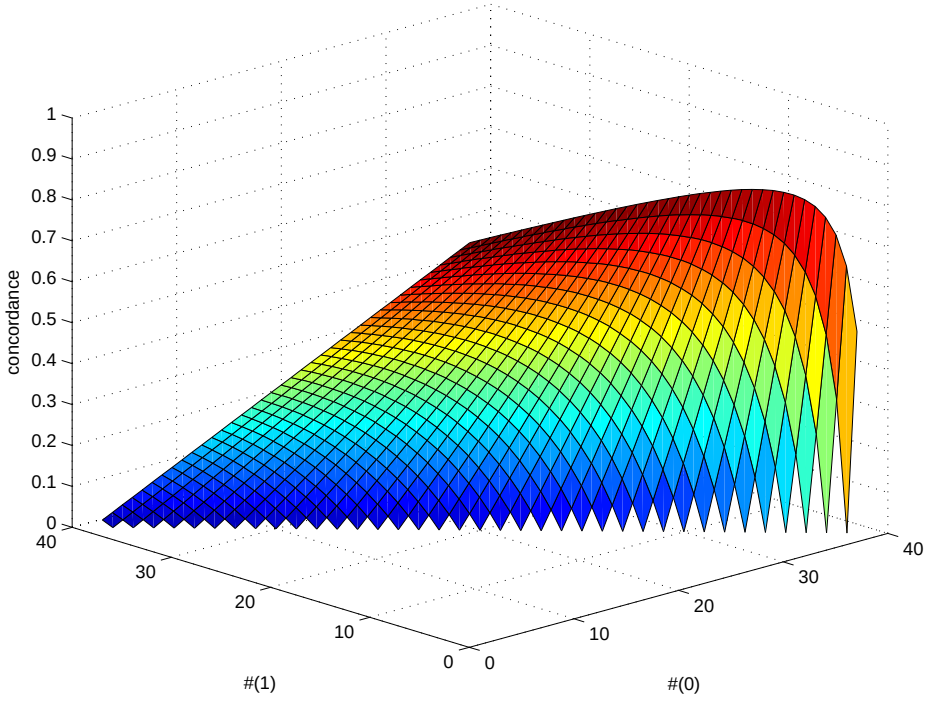


Figure 6: Multivariate Turbulent Periods Concordance Index



4 Testing synchronisation

Basically we are interested whether the probability of simultaneous occurrence of crises is statistically different from the product of the probability of independent single crises. Rather than base the test on estimated means and correlations as explained in Section 2, we calculate the p-values directly from the following contingency table using Fisher's exact homogeneity test (Kendall and Stuart, 1967, Chapter 33).

Table 1: Bivariate crises: contingency table

	Crisis A	No crisis A	Row sums
Crisis B	$n_{11} = \#(1,1)$	$n_{12} = \#(1,0)$	$n_{1.} = T\mu_{S_B}$
No crisis B	$n_{21} = \#(0,1)$	$n_{22} = \#(0,0)$	$n_{2.} = T(1-\mu_{S_B})$
Column sums	$n_{.1} = T\mu_{S_A}$	$n_{.2} = T(1-\mu_{S_A})$	T

The hypothesis of independence can be written as

$$H_0 : \frac{n_{11}}{n_{1.}} = \frac{n_{21}}{n_{2.}}. \tag{18}$$

The probability of observing the outcomes in the table when all marginal frequencies, i.e., column and row sums, are fixed is equal to

$$\begin{aligned} P_1 &= P\{n_{ij}|n, n_{1.}, n_{n.1}\} = \frac{P\{n_{ij}|n, n_{1.}\}}{P\{n_{.1}|n\}} \\ &= \frac{\begin{pmatrix} n_{1.} \\ n_{11} \end{pmatrix}\begin{pmatrix} n_{2.} \\ n_{21} \end{pmatrix}}{\begin{pmatrix} n \\ n_{.1} \end{pmatrix}} \\ &= \frac{n_{1.}!n_{.1}!n_{2.}!n_{.2}!}{n!n_{11}!n_{12}!n_{21}!n_{22}!}. \end{aligned} \tag{19}$$

Since the row and column sums are fixed, only one of the n_{ij} may vary independently. Without loss of generality, we take this to be n_{11}. We can use this expression to construct an exact test by calculating the probabilities

of any given configuration of frequencies and summing these over the tail of the distribution of n_{11}. Alternately the test can be used to calculate the frequency of simultaneous crises observations required to obtain a rejection of the null hypothesis of independence, which is how the results are presented in the next section.

Corresponding critical values for the three types of concordance indices and the correlation can be calculated directly from the critical value of the simultaneous crises n_{11}, the incidences of the crises and the number of observations. For the concordance indices this follows directly from Equations (9), (11), and (13). The critical value of the correlation coefficient of two binary crisis series can be calculated by putting simultaneous 1s at the beginning of both series, followed by the additional 1s for the first series and zeros for the other, and the additional 1s for the second series and zeros for the first, completed by zeros for the remainder of the observations.

We have not yet constructed an equivalent exact independence test for the multivariate case. Instead we report bootstrapped critical values for the number of observations with Z or more joint occurrence of crises, where $Z = 2, \ldots Z^*(\equiv \max Z)$. In our illustration below Z^* equals $(6 \times 3 =)18$. In each replication we build a new matrix of observations on crises dummies with the same properties as the originally observed data set. The crises means give the exact number of draws from a uniform (0,1) distribution; these are converted into numbers for the 1s in the crisis dummies. The numbers in this matrix are summed: we calculate the number of tranquil periods, single crisis periods, periods with two or more simultaneous crises, three or more, etc. We use 10,000 replications to generate the distribution of these totals and 95% critical values. Converting these critical values for the totals into critical values for the multivariate concordance indices is again straightforward from Equations (2)–(17).[3]

[3]Note this test is somewhat crude and uninformative if the number of crises becomes very large. Therefore we report not only the multivariate test outcomes for all types of crises but also outcomes for interesting subsets of crises.

5 Illustration

5.1 Measuring and dating financial crises

At least three types of financial crises are distinguished in existing literature; currency crises, banking crises and foreign debt crises. Identifying and observing the occurrence of these crises is non trivial and the focus of much international research. A number of methods, including statistical criteria and event studies, have been suggested to classify, measure and date financial crises see for example the overview in Jacobs, Kuper and Lestano (2004).

Currency crises are often dated on the basis of events, such as a devaluation or float of a currency as in a number of studies of the Asian financial crisis dated from the float of the Thai baht, or by using some form of threshold in an exchange market pressure index, as originated by Eichengreen, Rose and Wyplosz (1995, 1996), or more recently determined endogenously in Abiad (2003) using Markov switching. These dating schemes are all sample dependent.

In this paper, we identify currency crises in East Asia using the exchange market pressure approach of Kaminsky, Lizondo and Reinhart (1998) and Kaminsky and Reinhart (1999, 2000). They define the exchange market pressure index as:

$$EMPI_{i,t} = \frac{\Delta e_{i,t}}{e_{i,t}} - \frac{\sigma_e}{\sigma_r}\frac{\Delta r_{i,t}}{r_{i,t}} \tag{20}$$

where $EMPI_{i,t}$ is the exchange rate market pressure index for country i in period t, $e_{i,t}$ the units of country i's currency per US dollars in period t, σ_e the standard deviation of the relative change in the exchange rate $(\Delta e_{i,t}/e_{i,t})$, $r_{i,t}$ gross foreign reserves of country i in period t and σ_r the standard deviation of the relative change in the reserves $(\Delta r_{i,t}/r_{i,t})$.

To avoid the problem that currency crises are associated with high inflation, the sample is split into periods with hyperinflation and low inflation; separate indices are constructed for each subsample. A period of currency

crisis is identified when the index exceeds some upper bound:

$$Crisis = \begin{cases} 1 & \text{if } EMPI_{i,t} > \beta\sigma_{EMPI} + \mu_{EMPI} \\ 0 & \text{otherwise,} \end{cases}$$

where σ_{EMPI} equals the sample standard deviation of *EMPI* and μ_{EMPI} is the sample mean of *EMPI*. The threshold to define a currency crisis is set to three standard deviations above the mean.[4]

Banking crises are even more difficult to define than currency crises. Here we use the definition and dates provided by Kaminsky and Reinhart (1999).[5] In their chronology bank crises begin with events which point to either bank runs that lead to closure, merger or take overs by the public sector of one or more financial institutions or large scale government bailouts. The end of crises is marked by the cessation of government assistance. In addition to the Kaminsky and Reinhart (1999) data we augment the sample period and countries covered to include Singapore and South Korea. Our additions to their dating rely on correspondence with central banks, IMF country reports and various financial publications as documented in Lestano, Jacobs and Kuper (2003).

The literature on debt crises is extensive and also incorporates a number of potential definitions with which to identify an observed debt crisis. Typically, the incidence of a debt crisis is interpreted as a debt rescheduling agreement or negotiation, arrears (amounts past due and unpaid) on principal repayments or interest payments and an upper-tranche IMF agreement.[6] Here we constructed the debt crisis index based on debt rescheduling events, where debt default occurs when a country pursues commercial bank rescheduling with commercial borrowers as defined by the IMF and the World

[4]This method is not the only one used in the existing literature for dating crises; other possibilities include ad hoc dates, Forbes and Rigobon (2002), Dungey and Martin (2004), thresholds on volatility, Frankel and Rose (1996), identification with outliers, Favero and Giavazzi (2002), or tails of distributions, Bae, Karolyi and Stulz (2003).

[5]Other literature which dates banking crises includes Caprio and Klingebiel (1996), Lindgren, Garcia and Saal (1996) and Dermirgüç-Kunt and Detragiache (1997).

[6]For example Berg and Sachs (1988), Lee (1991), Balkan (1992), Lanoie and Lemarbre (1996) and Marchesi (2003) define a debt crisis as debt rescheduling. McFadden *et al.* (1985) and Hajivassiliou (1989,1994) incorporate a wider range of the elements listed.

Bank. Commercial borrowers are defined as those developing countries for which at least one third of foreign borrowing is from private sector creditors. We also include debt problems that led to rescheduling of the official debt in the Paris Club,[7] debt equity swap and voluntary buybacks and use the list of debt rescheduling events recorded by the World Bank, Global Development Finance and World Debt Table in various issues.

Each of these three crisis indicators has in common that they provide zero-one indices of the form explored in the first section of this paper. Table 2 summarizes the distribution of the financial crises over the countries in our sample of six Asian countries. Currency crises are distributed more or less evenly over the six countries. Banking crises are relative rare for Singapore, a country with a more advanced banking system. Debt crises occur most frequently in Philippines, followed by Indonesia.

Table 2: Distribution of financial crises: 1970-2002 numbers (proportion of total observations)

	Currency crises	Banking crises	Debt crises
Indonesia	9 (2.3%)	12 (3.0%)	5 (1.3%)
Malaysia	10 (2.5%)	7 (1.8%)	0 (0.0%)
Philippines	12 (3.0%)	8 (2.0%)	14 (3.5%)
South Korea	7 (1.8%)	12 (3.0%)	1 (0.3%)
Singapore	11 (2.8%)	2 (0.5%)	0 (0.0%)
Thailand	9 (2.3%)	10 (2.5%)	0 (0.0%)
All countries	58 (2.4%)	51 (2.2%)	20 (0.8%)

[7]The Paris Club is an informal group of official creditors (19 countries) whose role is to find co-ordinated and sustainable solutions to the payment difficulties experienced by debtor nations. Paris Club creditors agree to reschedule debts due to them. Rescheduling is a means of providing a country with debt relief through a postponement and, in the case of concessional rescheduling, a reduction in debt service obligations (see http://www.clubdeparis.org/en/).

5.2 Bivariate concordance outcomes

This section presents a selection of the bivariate concordance outcomes calculated for the data given above, along with tests based on the null of independence of the crises, *i.e.*, the crises are coincidental only.

Table 3: Harding-Pagan indicator

	Indonesia	Malaysia	Philippines	South Korea	Singapore	Thailand
Currency crises						
Indonesia		0.97	0.95	0.96	0.97	0.97
Malaysia	0.30		0.96	0.96	0.97	0.97
Philippines	0.07	0.25		0.96	0.95	0.96
South Korea	−0.02	0.10	0.09		0.96	0.97
Singapore	0.39	0.36	0.06	0.09		0.97
Thailand	0.32	0.41	0.17	0.37	0.49	
Banking crises						
Indonesia		0.95	0.96	0.96	0.97	0.95
Malaysia	−0.02		0.97	0.96	0.98	0.96
Philippines	0.18	0.12		0.96	0.97	0.95
South Korea	0.31	0.20	0.18		0.97	0.95
Singapore	0.20	−0.01	−0.01	0.40		0.97
Thailand	0.16	0.10	−0.02	0.16	0.22	
Debt crises						
Indonesia		0.99	0.95	0.98	0.99	0.99
Malaysia	–		0.96	1.00	1.00	1.00
Philippines	−0.02	–		0.96	0.96	0.96
South Korea	−0.01	–	−0.01		1.00	1.00
Singapore	–	–	–	–		1.00
Thailand	–	–	–	–	–	

Notes: Correlations below the diagonal and concordance indexes above the diagonal.

Table 3 shows the Harding-Pagan bivariate concordance indicators for currency, banking and debt crises respectively. The upper triangular portion of each panel gives the concordance indicator and the lower triangle the correlation matrix between the indicators. Each indicator is constructed across countries. Hence we read in Table 4 that the correlation between currency crises in Malaysia and Singapore is 0.36, but the concordance index is 0.97. The high values of the Harding Pagan bivariate concordance index reported in each table are consistent with the relatively low incidence of crises

in the sample, so that almost all countries report situations of no crisis at any time resulting in high concordance.

In contrast, Table 4 constructs the bivariate turbulent period concordance indices for the currency and banking crises case. There are no cases of positive correlation between debt crises in the East Asian sample so that the turbulent crisis index is zero in each case. In the case of Malaysia and Singapore the concordance index is 0.24, indicating the lower probability of both these countries' currency markets being in crisis at the same time. Unsurprisingly the concordance index is highest in these tables for pairs of countries involving Thailand, since Thailand is usually regarded as the source of the shock for the East Asian crisis of 1997-1998.

Table 4: Turbulent periods indicator

	Indonesia	Malaysia	Philippines	South Korea	Singapore	Thailand
Currency crises						
Indonesia		0.19	0.05	0.00	0.25	0.20
Malaysia	0.30		0.16	0.06	0.24	0.27
Philippines	0.07	0.25		0.06	0.05	0.11
South Korea	−0.02	0.10	0.09		0.06	0.23
Singapore	0.39	0.36	0.06	0.09		0.33
Thailand	0.32	0.41	0.17	0.37	0.49	
Banking crises						
Indonesia		0.00	0.11	0.20	0.08	0.10
Malaysia	−0.02		0.07	0.12	0.00	0.06
Philippines	0.18	0.12		0.11	0.00	0.00
South Korea	0.31	0.20	0.18		0.17	0.10
Singapore	0.20	−0.01	−0.01	0.40		0.09
Thailand	0.16	0.10	−0.02	0.16	0.22	

Notes: Correlations below the diagonal and concordance indexes above the diagonal.

Other combinations of bivariate tests are also easily constructed.[8] For example we can construct concordance indices for the possibility of a banking crisis in one country being associated with a currency crisis in another. The results of such an exercise produce positive turbulent period concordance indices for the case of Indonesian banking crises and currency crises in

[8]These tables are available from the authors on request, but are omitted in the interest of saving space.

Table 5: Twin crisis concordance indexes

	Harding-Pagan	Turbulent periods
Indonesia	0.96	0.11
Malaysia	0.96	0.00
Philippines	0.95	0.00
South Korea	0.95	0.00
Singapore	0.97	0.00
Thailand	0.95	0.00

other countries, but otherwise generally a zero index (in contrast the Harding Pagan index produces very high values as can be imagined due to the high number of non-crisis periods).

The most interesting of these results is the incidence of so-called twin crises, that is concurrent banking and currency crises, which are more frequent in the modern age than previous ones according to Bordo and Eichengreen (2000). In addition, Bordo *et al.* (2001) calculate that twin crises are twice as costly as currency crises and four times more costly than banking crises in terms of output loss.[9] Table 5 shows the concordance indices for twin crises across the different countries. We observe that the index is high for the Harding Pagan index, again due to the low incidence of crises. The turbulent periods concordance indices for the countries considered for twin crises is low for all but Indonesia. It would be of considerable interest to apply this to the sample of countries considered in Bordo *et al.* (2001) to further assess both their results and the information in this index.

Table 6 reports the results for the tests of independence in the bivariate examples. The upper triangle of the table contains the observed number of incidences of each of the potential crisis combinations, for example the number of times that a banking and currency crisis occurred simultaneously

[9]Bordo *et al.* (2001) express some surprise at the relatively smaller size of the loss of banking crises compared with currency crises, but find this result over a number of sample periods. Their surprise stems from comparisons with alternative literature, such as canvassed in Goldstein, Kaminsky and Reinhart (2000) which rank the costs of banking crises as above currency crises.

Table 6: Bivariate tests

		Indonesia			Malaysia			Philippines			South Korea			Singapore			Thailand			Total single crisis
		CC	BC	DC	CC	BC	DC	CC	BC	DC	CC	BC	DC	CC	BC	DC	CC	BC	DC	
Indonesia	CC		2*	1	3*	1	-	1	1	0	0	1	1*	4*	0	-	3*	0	-	9
	BC	2		1	3*	0	-	2*	2*	0	2*	4*	0	3*	1	-	4*	2*	-	12
	DC	2	2		0	2*	-	0	0	0	0	0	0	0	0	-	0	0	-	5
Malaysia	CC	2	2	2		0	-	3*	0	0	1	2*	1*	4*	0	-	4*	0	-	10
	BC	2	2	2	2		-	0	1	0	0	2*	0	0	0	-	0	1	-	7
	DC	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	0
Philippines	CC	2	2	2	2	2	-		0	1	1	1	0	1	0	-	2*	0	-	12
	BC	2	2	2	2	2	-	2		0	0	2*	0	1	0	-	0	0	-	8
	DC	2	3	2	2	2	-	3	2		0	0	0	0	0	-	0	0	-	14
South Korea	CC	2	2	2	2	2	-	2	2	2		0	0	1	0	-	3*	0	-	7
	BC	2	2	2	2	2	-	2	2	3	2		0	1	2*	-	2*	2*	-	12
	DC	1	2	1	1	1	-	1	1	1	1	1		1	0	-	1*	0	-	1
Singapore	CC	2	2	2	2	2	-	2	2	3	2	2	1		0	-	5*	0	-	11
	BC	1	2	1	1	1	-	2	1	2	1	2	1	2		-	0	1*	-	2
	DC	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	0
Thailand	CC	2	2	2	2	2	-	2	2	2	2	2	1	2	1	-		0	-	9
	BC	2	2	2	2	2	-	2	2	2	2	2	1	2	1	-	2		-	10
	DC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		0

Note: Upper triangle gives the observed number of concurrent crises for each category, lower triangle gives the lowest number of simultaneous crises for which the null hypothesis of independence is rejected at the 5 percent level, * indicates a significant rejection of independence at the 5 percent level.

for Indonesia is 2 in this sample. The lower triangle records the minimum number of occurrences of the dual crises for each combination which would lead to a rejection of the null hypothesis of independence based on the Fisher exact test at the 5 percent significance level. The crisis combinations which reject independence are indicated with an * in the upper triangle. The results are extremely informative, and accord well with our intuition on the East Asian crises.

Combinations of the crises which reject the null of independence result in several findings. First, there is some support for the role of the Thai currency crisis as the 'trigger' event for the other currency crises in the region, with significant associations between the Thai currency crisis and that for each other country. Second, the Indonesian banking crisis is associated with both its own currency crisis and a broad range of banking and currency crises in other countries. Third, the South Korean banking crisis is associated with banking crises in each of the other countries. Finally the debt crises are generally less associated with other crises in this sample, the exception being the Indonesian debt crisis is associated with the Malaysian currency crisis. An interesting feature of the results is that they indicate that the financial crises in these countries in different markets are not driven by links within the country, that is the joint occurrences of any pair of currency, banking or debt crises within a country does not generally reject the null of independence. One exception to this, as may be expected is between banking and currency crises in Indonesia, but surprisingly not in Thailand and Malaysia. This reinforces our understanding that the crises in Asia have been primarily driven by international market linkages rather than individual countries (of course we have not included an equity market crisis here which may change this picture and would be a useful extension). To further investigate the linkages between the markets and countries we now consider the construction and testing of the multivariate concordance indices.

5.3 Multivariate Concordance indices

Table 7 reports the multivariate concordance indices for the group of crises which involves all three types of crisis and all countries, that is the entire sample. Each row reports the concordance index for the stated number of common crises occurring across these categories shown in the first column. So the first row reports the concordance index for at least two concurrent crises in either of banking, debt or currency markets across the six economies sampled. A total of 25 time periods are identified which fulfill that criteria, giving a turbulent periods index of 0.31.

The final column of Table 7 reports the test of the null hypothesis of independence amongst the crises, here the null hypothesis is that all types of crisis are independent across all countries in the sample. Beginning with the higher number of concurrent samples in Table 7 the first panel records a critical frequency of zero for the categories of at least 5 and at least 6 crises. The appropriate interpretation is that there is no time at which the occurrence of 5 or 6 concurrent crises can be considered to be mere coincidence. These crises are related. As the number of concurrent crises recorded is reduced, the frequency with which this may occur is logically higher. For instance, the category of at least 3 crises can occur three times before the null hypothesis of independence is rejected. In the total sample, it occurs 11 times, and rejects the null. For the most encompassing of the concurrent crises, of at least 2 crises, the critical value indicates that up to 21 instances of concurrent crises may occur completely coincidentally, and the sample again rejects independence.

To further explore these results we consider the multivariate concordance indices, and tests of independence across banking and currency crises alone. We do not consider debt crises as they were of insufficient incidence to generate interesting results. The currency crisis results are given in the middle panel of Table 7 and the banking crisis results in the final panel of that Table. In each case, at all frequencies the null hypothesis of independence is rejected. That is, concurrent banking crises or concurrent currency crises across countries are not coincidental. This adds further to the evidence col-

Table 7: Multivariate concordance indexes

	Harding-Pagan	Crisis only	Turbulent periods	Observations	Critical value
Across countries–across crises type					
At least 2 crises	0.86	0.06	0.31	25	21
At least 3 crises	0.82	0.03	0.14	11	3
At least 4 crises	0.81	0.02	0.07	6	1
At least 5 crises	0.81	0.01	0.05	4	0
At least 6 crises	0.80	0.01	0.02	2	0
Crises observations ($T - \#(0)$)				81	
Across countries–currency crises type					
At least 2 crises	0.93	0.03	0.30	11	6
At least 3 crises	0.92	0.02	0.16	6	1
At least 4 crises	0.91	0.01	0.08	3	0
At least 5 crises	0.91	0.00	0.03	1	0
Crises observations ($T - \#(0)$)				37	
Across countries–banking crises type					
At least 2 crises	0.94	0.03	0.37	13	5
At least 3 crises	0.92	0.01	0.06	2	1
At least 4 crises	0.91	0.00	0.03	1	0
Total crises ($T - \#(0)$)				35	

Notes: the critical value gives the minimum number of observations for the case at hand that rejects the null hypothesis of multivariate independence at the 5 per cent level.
The occurrences of at least $Z, Z = 1, \ldots, 6$ crises in the top panel may differ from the sum of the corresponding numbers of currency crises in the middle panel and banking crises in the bottom panel, since for example a dual currency crises may occur simultaneously with a bank or a debt crisis.

lected from the bivariate results, suggesting that the East Asian crises spread primarily through the asset markets across countries, rather than within the countries themselves.

The results suggest that when two or more crises occur concurrently they are unlikely to be coincidental. In our sample, there were 129 crises, 57 percent of them were associated with concurrent crises in another market or country and 43 percent were isolated to a single market in a particular country. Pairing the crisis data in Table 6 provided 91 instances of dual crises, between currency, banking and debt markets across our sample countries, 71 of those pairs rejected the null hypothesis of independent occurrence of the events, suggesting that the majority of the crises were related. The multivariate tests reinforced this view, rejecting the null of independent crises when more than 2 occurred simultaneously across all the crisis types, and at a slightly higher frequency in each of the three crisis categories.[10]

Policy makers are correct to be concerned about the occurrence of a crisis. However, knowing which crises are going to spread is as yet unresolved. Isolating the characteristics of what makes a particular crisis spread, or alternatively what makes other markets vulnerable to spread from other crises remains an important issue, and is the focus of work on indicators of financial fragility such as associated with Goldstein, Kaminsky and Reinhart (2000). Unfortunately this literature has not been particularly successful to date, with the relatively poor performance of these indicators documented in Berg and Patillo (1999). The problem lies with the heterogeneity of the crises; it seems no two crises are ever the same. However, it is important we do know that crisis situations will tend to exacerbate other weaknesses in the economy and financial system, increasing the possibility of crises in other markets and countries, which is the aspect we see reflected in the rejection of the independence tests above.

[10]The differences between the bivariate and multivariate outcomes stress the need for an encompassing model incorporating different assets and country linkages; see for example Hartmann, Straetmans and de Vries (2004).

6 Conclusion

The concordance index of Harding and Pagan is designed for binary state variables and thus is applicable to other research topics, *e.g.*, the probability of crises. This paper demonstrated that the Harding-Pagan measure has to be adapted to deal with financial crises, essentially because of the large number of tranquil periods which have no real information for the question at hand. Our preferred measure, a turbulent period concordance index, has intuitive appeal and better properties for our purposes.

The fundamental question that comes to the fore here is whether we can treat a on-off binary variable such as a financial crisis in a similar way as an upturn-downturn business cycle dummy. We feel that the definition and measurement of financial crises itself should be scrutinized. Summarising the information into a binary crisis–no crisis dummy seems overly restricted, and clearly the tests for whether crises are related will be affected by timing and measurement of when a crisis occurs. The sensitivity of the proposed concordance measures to these definitions is obvious.

This paper developed a concordance inex for the case of low incidence events and extended the analysis to incorporate the concept of multivariate concordance. The properties of each index were explored, including a simple means of constructing critical values for testing the independence of observed events. East Asian data over the past 3 decades was used to illustrate the methods, and demonstrated that concurrent crises were unlikely to occur independently in this sample. The example demonstrated the richer story which emerged through the use of the new multivariate index.

Perhaps we can exploit the analogy to business cycle analyses once more, by translating the methodology the Business Cycle Dating Committee of the NBER uses to date the US cycle. Researchers and policy makers would greatly benefit from generally accepted chronologies of financial crises. An attempt has been made in this direction by the dating of equity and housing price cycles presented in the IMF's World Economic Outlook in April 2003, IMF (2003) and extension of this work to both other financial markets and a broader range of economies, including developing markets, would be of im-

mense assistance. Therefore we make a plea for the institution of a Financial Crises Dating Committee.

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