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Synchronisation of financial crises

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Abstract

This paper develops concordance indices for studying the simultaneous occurrence of financial crises. The indices are designed to cope with these typically low incidence events. This leads us to confine attention to non-tranquil periods to develop a bivariate index and its multivariate analog for potentially serially correlated categorical data. An application to the Bordo et al. (2001) data set reveals the extent of concordance in banking and currency crises across countries. The internationalisation of financial crises in the 20th century is shown to have increased for currency crises and decreased for banking crises.

Keywords: financial crises, synchronisation, concordance indices, independence tests, historical analysis

JEL-code: F31, F47, N20

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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 (2003) 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, particularly across international borders, and indeed as to whether there are differences between financial crises at the beginning and end of the 20th century; see Eichengreen and Bordo (2003) and Bordo et al (2001). 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 the relationships between the observed crisis data. To do this we develop both a bivariate and multivariate concordance index which provides information on the extent of international interdependence in financial crises based on the probability of observing independent crises. This index can be applied at a point in time, but also produces a time series with which to assess changes in the internationalisation of financial crises. The approach formalises the counting of co-occurrences of financial crises across borders; see Kaminsky and Reinhart (1999). Our adaptations consist of accounting for the low incidence of crisis events in categorical data, giving a turbulent period concordance index which ranges between zero, when there are no occurrences of simultaneous crises, and one, where all crisis occur

in synchronisation with other crises.[1] The great advantage of concordance indices compared to correlation coefficients is the possibility of addressing synchronisation among more than two crises.

We also show how to conduct tests with the index to determine whether observed contemporaneous financial crises are statistically independent, and account for potential serial correlation in the series. The tests can be used to calculate critical values of bivariate concordance indices (and correlaton coefficients) and multivariate concordance indices. The turmoil periods concordance index is applied to the data set of Bordo, Eichengreen, Klingebiel and Martinez-Peria (2001) covering banking and currency crises from 1883 to 1998 for 21 countries. The results show that any observation of 5 (4) contemporaneous currency (banking) crises rejects the null of independence in the occurrence of these events.

A significant advantage of our turbulent period concordance index is in analysing the characteristics of global financial turmoil. The proposed concordance index is ordinal, with the properties that it retains a constant value in periods of tranquility, declines when independent, country specific financial crises occur and increases during periods of internationally linked financial turmoil. This helps to distinguish whether a particular crisis period is likely to be associated with country-specific factors (christened here independent financial turmoil) or with international turmoil. Using the data set of Bordo et al. (2001), Eichengreen and Bordo (2003) and Bordo et al (2001) previously concluded that financial crises have not evidently grown more severe over the 20th century but are more prevalent. Our analysis augments this outcome

[1]The extension to relationships between non-contemporaneous crises is straightforward.

by showing that while both currency and banking crises have become more prevalent, currency crises are more likely to be associated with international turmoil at the end of the 20th century than the beginning, while banking crises are more likely to be independently occurring at the end of the 20th century compared with international banking crises at the beginning of the century. The degree to which financial crises are international has changed over the 20th century, and differently for the two types of crisis considered.

The analysis also allows a number of augmentations of existing results of Bordo et al (2001) and Kaminsky and Reinhart (1999). First, the prevalence of currency crises has increased regardless of whether countries are classified as developing. Second, while looser capital controls may be associated with more banking crises, these banking crises are also more likely to be associated with independent turmoil as opposed to international financial turmoil. Third, the results support the assertion that banking crises may have led currency crises in the 1970s, but without evidence as to whether they were reinforcing in the opposite direction. Finally, we discuss how the concordance indices may be used to make conditional statements on the international or domestic nature of observed financial crises thus contributing to the discussion on whether financial crises should be addressed with international or domestic policy solutions, see for example Karolyi (2003).

The paper proceeds as follows. Section 2 defines what is meant by concordance indices of crises, and why this is a useful concept for examining crisis synchronisation. The turbulent period concordance index appropriate to the current situation of relatively rarely occurring events is developed. A multivariate extension and its properties are outlined. The process for

obtaining critical values of the concordance index is described in Section 3. The concordance index and tests are then applied to the Bordo et al data in Section 4, and its usefulness is further illustrated in Section 5. Section 6 concludes.

2 Synchronisation and Concordance Indices

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.[2] When these two series are identical, that is $S_{xt} = S_{yt}$ for all t, the series are perfectly synchronised.

When two series exhibit strong synchronisation, and we omit the uninteresting cases where the series are either continually in crisis, or continually not ($S_{xt} = 1$ or $S_{xt} = 0$ for all t) two measures are of interest in describing how synchronised the series are. These are the means of the two series, and the correlation between them. In the case of perfect synchronisation $\mu_{Sx} = \mu_{Sy}$ and $\rho_{Sxy} = 1$. The statistics μ_{S_x} and ρ_{Sxy} describe the synchronisation between the series, but it is perfectly possible to observe series S_{xt}, S_{yt} and S_{zt} where $\mu_{Sx} = \mu_{Sy} = \mu_{Sz}$ but $\rho_{Sxy} \neq \rho_{Sxz}$, that is the series have the same means but different correlation coefficients, or that the correlation coefficients are the same, but the means differ. In this case the synchronisation between the series will differ.

[2]Note that we confine attention to categorical data on financial crises here. If the underlying data generating process is known, one could apply for example copulas as done by Rodriguez (2003).

Concordance indices provide a means of incorporating information on both the mean and correlation of the series in an ordinal (although not cardinal) manner. Such indices can also be simply extended to the multivariate environment, an attractive feature for assessing crises across numerous countries and markets.

2.1 Bivariate concordance indices

Concordance indices can be simply constructed by 'counting' the number of times the variables S_{xt} and S_{yt} are in various combinations of states (with analogs expressed in terms of means and correlation coefficients). 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 (2005) advocate measuring the degree of synchronisation in business cycles in terms of the fraction of time the cycles are in the same phase. Their *concordance index* has the form

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

The relevance of the expression between brackets will become clear in our discussion of multivariate synchronisation below. The index can also be expressed in terms of the estimated means $\hat{\mu}_{S_x}$, $\hat{\mu}_{S_y}$ and the estimated cor-

relation coefficient $\hat{\rho}_S$ between S_{xt} and S_{yt}

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

High concordance can be achieved with $|\hat{\rho}_S| = 1$, 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.

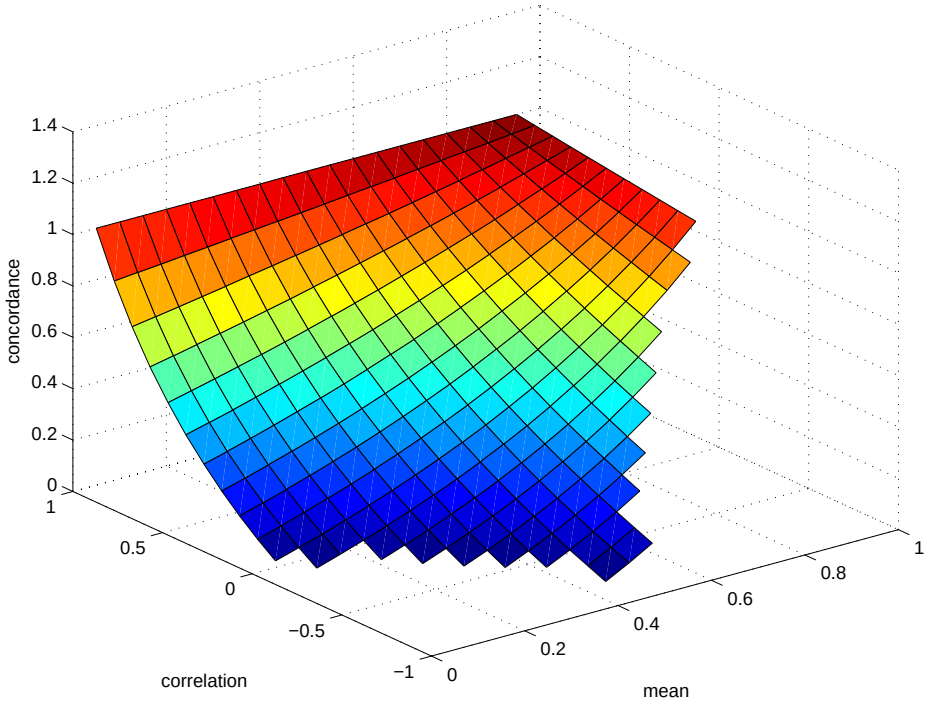
A typical feature of financial crises is their low incidence, or a large number of tranquil periods in the sample. It seems natural then to confine attention to the concordance of crises in turbulent periods and introduce the *turbulent-periods concordance index*

$$\hat{I}^{tp} = \frac{\#(1,1)}{T - \#(0)} \left(= 1 - \frac{\#(1)}{T - \#(0)} \right), \quad (3)$$

where we assume that there is at least one crisis in our sample, *i.e.,* $T - \#(0) \neq 0$. Equation (3) 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.[3]

[3]In an earlier version we also describe the *crisis-only concordance index*, which has the same numerator as the turbulent-periods concordance index, but takes T as its denominator. This was found to be less useful as it did not necessarily produce high values of the concordance index in the case of high correlation of the crisis indicators, due to the prevalence of non-crisis observations.

Figure 1: Turbulent Periods Concordance Index



Rewriting gives a slightly more complicated expression

$$\hat{I}^{tp} = \frac{\hat{\rho}_s(\hat{\mu}_{S_x}(1-\hat{\mu}_{S_x}))^{1/2}(\hat{\mu}_{S_y}(1-\hat{\mu}_{S_y}))^{1/2} + \hat{\mu}_{S_x}\hat{\mu}_{S_y}}{-\left(\hat{\rho}_s(\hat{\mu}_{S_x}(1-\hat{\mu}_{S_x}))^{1/2}(\hat{\mu}_{S_y}(1-\hat{\mu}_{S_y}))^{1/2} + \hat{\mu}_{S_x}\hat{\mu}_{S_y}\right) + \hat{\mu}_{S_x} + \hat{\mu}_{S_x}}, \quad (4)$$

which is plotted in Figure 1.

Figure 1 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). The turbulent-periods concordance index

is the focus of the remainder of the paper, and as such is simply referred to as the concordance index.

2.2 Multivariate concordance indices

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 $(\#1 > Z)$. The number of times this may occur in any given nm crises is given by nm multichoose Z, so in the case of $nm = 6$, $Z = 3$ gives 12 possible combinations.[4]

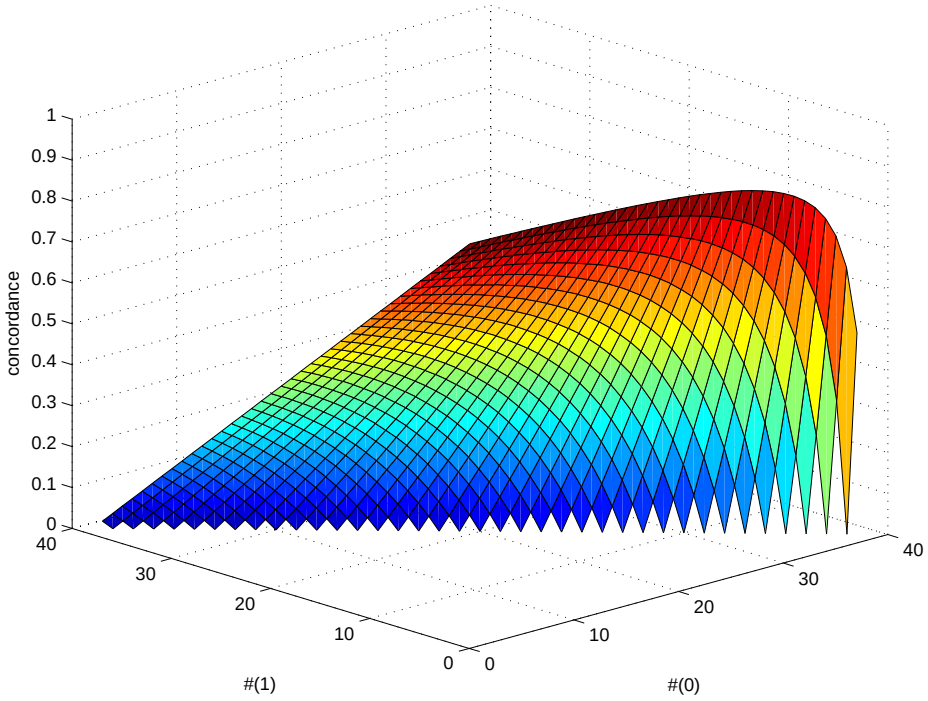
Then the multivariate forms of the turbulent periods concordance index is given by:

$$\hat{I}^{tp} = \frac{(\#1 \geqslant Z)}{T - \#(0)} = 1 - \frac{(\#1 < Z)}{T - \#(0)}, \tag{5}$$

Figure 2 show the multivariate versions of the index for $Z = 2$. The turbulent periods concordance index shows 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. A simple interpretation is that this index will rise whenever the number of simultaneous crises rises as a proportion of the total

[4]The formula for multichoose is nm multichoose $Z = (nm + Z)!/(n!m!)$.

Figure 2: Multivariate Turbulent Periods Concordance Index



number of periods in turmoil, and this may occur through either a rise in the number of simultaneous crises without a change in the number of periods of turmoil, or a fall in the number of periods of turmoil without a fall in the number of simultaneous crises. This provides a convenient short hand for comparing the coincidence of crises across different asset markets and countries.

3 Critical Values for Concordance Indices

Concordance indices for various crisis series can be calculated as outlined in the previous section. However, we are also interested as to whether an observed concordance index exceeds a critical value indicating that the two

or multiple crises are no longer occurring coincidentally. This section outlines how those critical values can be calculated.[5]

Tests of independence in a contingency table can be applied to obtain critical values for concordance indices. For a introduction to testing independence in two-way contingency tables see Agresti (2002, Chapter 3). Consider the following contingency table

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

Below we apply Fisher's exact test in most cases, which proceeds as follows. The probability of observing the outcomes in the table when all marginal frequencies, i.e., column and row sums, are fixed is equal to

$$\begin{aligned} P_1 &= P\{n_{ij}|n, n_{1.}, n_{n.1}\} = \frac{P\{n_{ij}|n, n_{1.}\}}{P\{n_{.1}|n\}} \\ &= \frac{n_{1.}!n_{.1}!n_{2.}!n_{.2}!}{n!n_{11}!n_{12}!n_{21}!n_{22}!}. \end{aligned} \tag{6}$$

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

[5]In a companion paper we plan to address methodological issues more extensively.

frequency of simultaneous crises observations required to obtain a rejection of the null hypothesis of independence.

Corresponding critical values for the concordance indices and correlation coefficients 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 (1) and (3). 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.

The vital precondition for the application of the Fisher exact test is that the individual crisis series, S_{xt}, are independent and identically distributed, *iid*. In particular, we are concerned that they may exhibit serial correlation. To establish whether the individual series exhibit first order serial correlation we use the Fisher exact test for the null of independence against a first order Markov chain by operating on the transition matrix of the series itself (Anderson and Goodman, 1957). To make this clearer, consider a series S_{xt}, which can take on state values 1 and 0 at time t. In its move to the next period it can also take on either of these values, so that the transition matrix between period t and period $t+1$ is represented by a two by two matrix with elements $(1,1),(1,0),(0,1),(0,0)$ in the same form as the Fisher test shown above. The null hypothesis of independence against a first order Markov process can be tested by

$$H_0 : \frac{n_{11}}{n_{1.}} = \frac{n_{21}}{n_{2.}}. \tag{7}$$

If the series for which a particular concordance index is calculated are serially correlated we apply corrections to Pearson chi-squared statistics as proposed by Tavaré (1983) and Tavaré and Altham (1983). The Pearson X^2 statistic for testing the null hypothesis of independence in an $I \times J$ contingency table is defined

$$X^2 = \sum_i \sum_j \frac{(n_{ij} - \hat{\mu}_{ij})^2}{\hat{\mu}_{ij}},$$

where $\hat{\mu}_{ij} = \frac{n_{i.} n_{.j}}{n}$. The Pearson X^2 statistic is asymptotically chi-squared with $(I-1)(J-1)$ degrees of freedom, which is equal to one in 2×2 contingency table. Let S_A and S_B be independent stationary two-state Markov chains with transition matrices P_{S_A}, P_{S_B} and let λ and μ be the non-unit eigenvalues of P_{S_A} and P_{S_B}. Then $[(1-\mu\lambda)/(1+\mu\lambda)]\, X^2$ is asymptotically chi-squared with one degree of freedom. This result can be extended to testing independence of the r-state process $\mathcal{A}$ and the c-state process $\mathcal{B}$, provided each of $\mathcal{A}$ and $\mathcal{B}$ is reversible, a condition which is met in our application. The corresponding correction factor becomes

$$\sum_{i=1}^{r-1} \sum_{j=1}^{c-1} \left(\frac{1 - \lambda_i \mu_j}{1 + \lambda_i \mu_j} \right),$$

where λ_i, μ_j are the non-unit eigenvalues of the transition matrices $\mathcal{A}$ and $\mathcal{B}$, respectively.

To find critical values for multivariate concordance indices we use simulation techniques. In each replication we build a new matrix of observations on crises dummies with the same properties as the originally observed data set.

For *iid* series in the data set the crises means give the exact number of draws from a uniform (0,1) distribution; these are converted into period numbers for the 1s in the crisis dummies. In the case of serially correlated series, the transition probabilities observed in the data are used to produce series with the same serial correlation properties and the same number of crisis observations as the original data. 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 critical values. Converting these critical values for the totals into critical values for the multivariate concordance indices is again straightforward from Equation (5).

4 Application

4.1 Measuring and dating financial crises

Identifying and observing the occurrence of financial crises is non-trivial and the focus of much international research. The application here takes dates for currency and banking crises for 21 countries over the period 1883 to 1998 from Bordo et al (2001). This data takes the form of annual 1- 0 indices as compiled by Bordo et al, taking a 1 in years when a crisis occurs. We use their longer data set, covering 1883 to 1998, including Argentina, Australia, Belgium, Brazil, Canada, Chile, Denmark, Finland, France, Germany, Greece, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the UK and the US.

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 (2005). In the Bordo et al. paper currency crises occur in association with either a forced change in parity, a realignment or as indicated by an exchange market pressure index exceeding a threshold value.[6] Banking crises are dated as periods of continuous financial distress leading to substantial erosion of banking capital, as per Caprio and Klingebiel (1996). Table 2 shows the occurrences of the crises in the dataset.

We can identify a number of simultaneous crisis periods in the data. In 1907 a banking crisis occurred in 7 of the 21 countries in the sample—see Bordo and Eichengreen (2000) and Goodhart and Delargy (1998). Both banking and currency crises were widespread in 1931, associated with the Great Depression, with 8 countries experiencing both banking and currency crises (twin crises), a further 5 countries a banking crisis alone, and a further 6 countries a currency crisis alone. The next major period of disruption in the sample is the currency crises associated with the breakdown of Bretton Woods in 1971 when 12 countries observed currency crises (but not banking crises). The third major set of currency crises in the dataset occurs in the 1992 ERM crisis, when the UK and Italy exited the system, and 7 of the European countries report a crisis observation (Denmark, France, Italy, the Netherlands, Spain, Sweden and the UK).

[6]The exchange market pressure index is constructed as a weighted sum of exchange rates, interest rate differentials and changes in reserves as per Eichengreen, Rose and Wyplosz (1995,1996), and hence has an underlying data generating process unlike the banking data.

Table 2: Distribution of financial crises: 1893-1998 numbers

	Currency crises	Banking crises	Twin crises
Argentina	19	8	4
Australia	7	2	0
Belgium	5	5	0
Brazil	13	9	3
Canada	10	1	0
Chile	10	5	1
Denmark	8	6	2
Finland	7	5	3
France	9	6	0
Germany	5	3	1
Greece	7	1	1
Italy	8	8	1
Japan	7	4	0
Netherlands	6	3	1
Norway	4	5	1
Portugal	6	5	2
Spain	8	5	1
Sweden	5	5	2
Switzerland	4	2	0
UK	11	1	0
US	7	9	2
All countries	166	51	25

Table 2 shows the results of tests of independence against a first order Markov process on the transition matrices as described in the previous section for each of the 21 data series in both currency and banking crises. As is quickly observed, almost all series display independence. The exceptions are in Denmark for currency crises, and France, Norway and the US for banking crises.

Table 3: Univariate tests of independence versus first order Markov process: p-values

	Currency crises	Banking crises
Argentina	0.2647	0.3527
Australia	0.3057	0.9654
Belgium	0.7975	0.1881
Brazil	0.2694	0.1248
Canada	0.3870	0.9913
Chile	0.3870	0.7975
Denmark	**0.0101**	0.2491
Finland	0.6364	0.7975
France	0.3860	**0.0297**
Germany	0.7975	0.9231
Greece	0.3057	0.9913
Italy	0.3527	0.3527
Japan	0.3057	0.8663
Netherlands	0.7197	0.9231
Norway	0.8663	**0.0141**
Portugal	0.7197	0.1881
Spain	0.5511	0.1881
Sweden	0.1881	0.1881
Switzerland	0.8663	0.9654
UK	0.0597	0.9913
US	0.3057	**0.0018**

Note: bold indicates rejection of null hypothesis of no serial correlation

4.2 Bivariate concordance outcomes

Table 4 shows bivariate turbulent period concordance indices for currency crises, and corresponding 95% critical values derived from Fisher exact test, again shown in the upper and lower triangles of the table respectively. Bivariate independence tests involving any of the serially correlated series are based on corrected Pearson chi-squared statistics, while for combinations not including a serially correlated series the Fisher exact test method is appropriate. The effects of ignoring serial correlation are best illustrated for bivariate concordance indices involving Denmark. On the basis of the Fisher exact test critical values listed in the lower triangle in the table the null hypothesis is independence between currency crisis in Denmark and the other countries in the sample is rejected for many countries (Finland, Greece, Japan, the Netherlands, Norway, Portugal, Spain, Switzerland and the United Kingdom). However, independence is not rejected once we allow for serial correlation (as seen in Table 4).

Table 4: Currency crisis bivariate tests

	Ar	Au	Be	Br	Ca	Ch	De	Fi	Fr	Ge	Gr	It	Ja	Ne	No	Po	Sp	Sw	Sz	UK	US
Ar		0.04	0	0.19*	0.21*	0.21*	0.08	0.08	0	0.04	0.18*	0.08	0.13*	0	0.05	0.04	0.17*	0.09	0	0.11	0.04
Au	0.11		0.20*	0	0	0	0.25*	0.17	0	0.09	0.40*	0.07	0.08	0.18*	0.22*	0.30*	0.15	0.33*	0.1	0.13	0.27*
Be	0.20	0.20		0	0	0	0.08	0.20*	0	0.11	0.09	0.08	0	0.38*	0.29*	0.1	0.08	0.25*	0.13	0.07	0.09
Br	0.19	0.18	0.20		0.1	0.15	0.05	0.05	0.05	0.13	0.05	0	0.05	0.06	0.06	0.05	0.06	0	0.09	0	
Ca	0.16	0.21	0.25	0.21		0.11	0.13	0.21*	0	0.15	0.13	0.06	0.21*	0.07	0.17*	0.14	0.06	0.07	0	0.05	0.13
Ch	0.16	0.21	0.25	0.21	0.18		0.06	0.06	0.06	0.07	0.06	0	0.06	0	0.08	0.07	0.13	0.07	0.08	0.11	0
De	0.17	0.25	0.18	0.17	0.20	0.20		0.36	0.06	0.08	0.25	0.14	0.25	0.27	0.20	0.27	0.33	0.44	0.09	0.19	0.07
Fi	0.11	0.27	0.20	0.18	0.21	0.21	0.25		0	0.20*	0.17	0	0.17	0.30*	0.57*	0.18*	0.15	0.33*	0.1	0.13	0.08
Fr	0.17	0.23	0.17	0.22	0.19	0.19	0.21	0.23		0	0	0.13	0	0.15	0	0	0.06	0.08	0.08	0.05	0
Ge	0.20	0.20	0.25	0.21	0.25	0.25	0.20	0.20	0.17		0.09	0	0.09	0.10	0.29*	0.10	0.08	0.25*	0	0.14	0.09
Gr	0.11	0.27	0.20	0.18	0.21	0.21	0.25	0.27	0.23	0.20		0	0.17	0.08	0.22*	0.30*	0.15	0.33*	0.10	0.06	0.17
It	0.17	0.25	0.18	0.17	0.20	0.20	0.23	0.25	0.21	0.18	0.25		0.07	0.17	0	0.08	0.23*	0.08	0.09	0.19*	0
Ja	0.11	0.27	0.20	0.18	0.21	0.21	0.25	0.27	0.23	0.20	0.27	0.25		0.08	0.10	0.08*	0.07	0.20*	0	0.06	0
Ne	0.14	0.18	0.22	0.19	0.23	0.23	0.18	0.18	0.25	0.22	0.18	0.18	0.18		0.25*	0.09	0.17	0.38*	0.11	0.13	0.08
No	0.15	0.22	0.29	0.21	0.17	0.20	0.22	0.18	0.29	0.22	0.20	0.20	0.22	0.25		0.25*	0.20*	0.50*	0.14	0.15*	0.10
Po	0.14	0.18	0.22	0.19	0.23	0.23	0.18	0.18	0.25	0.22	0.18	0.18	0.18	0.20	0.25		0.27*	0.22*	0.11	0.13	0.18*
Sp	0.17	0.25	0.18	0.17	0.20	0.20	0.23	0.25	0.21	0.18	0.25	0.23	0.25	0.27	0.20	0.27		0.30*	0.09	0.36*	0.07
Sw	0.20	0.20	0.25	0.21	0.25	0.25	0.20	0.20	0.17	0.25	0.20	0.20	0.20	0.22	0.29	0.22	0.20		0.13	0.23*	0.09
Sz	0.14	0.18	0.29	0.21	0.17	0.17	0.2	0.18	0.18	0.29	0.18	0.20	0.18	0.25	0.33	0.25	0.20	0.29		0	0.10
UK	0.20	0.20	0.20	0.20	0.17	0.17	0.19	0.20	0.18	0.20	0.20	0.19	0.20	0.21	0.15	0.21	0.19	0.20	0.15		0
US	0.11	0.27	0.20	0.18	0.21	0.21	0.25	0.27	0.23	0.20	0.27	0.25	0.27	0.18	0.22	0.18	0.25	0.20	0.22	0.20	

Note: Upper triangle gives the bivariate concordance indices for each category, lower triangle gives the critical values of the concordance index 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; independence test outcomes involving Denmark are based on corrected Pearson chi-squared statistics, not on the Fisher exact test outcomes listed in the lower triangle of the table.

The country pairs for which currency crises reject the null of independence predominantly involve Argentina, Australia, Brazil, Norway or Sweden as one of the pair considered. Sweden particularly rejects independence with the majority of its potential European partners in the Table. Belgium and the Netherlands also reject independence with a substantial number of other European nations. Argentina rejects independence with the other Latin American countries in the sample (in addition to a number of others). These results lend further credence to the concern over regional interdependence in financial crises; for example Kaminsky and Reinhart (2002), Glick and Rose (1999), and Dungey and Martin (2005).

Table 5 lists bivariate turbulent period concordance indices and corresponding 95% critical values derived from Fisher exact test for banking crises. In contrast with the currency crises, once serial correlation has been taken into account for France, Norway and the US, very few of the country pairs reject independence for banking crises. The exceptions are Belgium with each of Finland and Spain, Poland with both Spain and Switzerland and Switzerland with Finland. This set of five countries consistently rejects independence between their banking crises, but not for all possible combinations within the five (for example, Polish and Finnish crises are independent, while Polish and Swiss and Finish and Swiss crises are not).

Table 5: Banking crisis bivariate tests

	Ar	Au	Be	Br	Ca	Ch	De	Fi	Fr	Ge	Gr	It	Ja	Ne	No	Po	Sp	Sw	Sz	UK	US
Ar		0.11	0.18	0.06	0.00	0.00	0.08	0.08	0.08	0.10	0.13	0.14	0.00	0.00	0.08	0.18	0.08	0.08	0.11	0.13	0.13
Au	0.25		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Be	0.18	0.40		0.00	0.00	0.11	0.10	0.25∗	0.10	0.14	0.20	0.08	0.00	0.14	0.11	0.11	0.25∗	0.11	0.17	0.00	0.17
Br	0.21	0.22	0.17		0.11	0.00	0.00	0.08	0.15	0.09	0.00	0.06	0.08	0.09	0.08	0.08	0.00	0.08	0.00	0.11	0.00
Ca	–	0.50	0.20	–		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.00
Ch	0.18	0.40	0.17	0.17	0.20		0.10	0.00	0.10	0.00	0.00	0.08	0.13	0.00	0.00	0.00	0.11	0.11	0.00	0.00	0.08
De	0.27	0.33	0.22	0.25	–	0.22		0.22	0.20	0.13	0.17	0.27	0.11	0.13	0.38	0.10	0.10	0.22	0.14	0.00	0.15
Fi	0.18	0.40	0.17	0.17	0.20	0.17	0.22		0.10	0.14	0.20	0.18	0.00	0.33	0.25	0.11	0.11	0.25∗	0.17	0.00	0.08
Fr	0.27	0.33	0.22	0.25	–	0.22	0.20	0.22		0.13	0.17	0.27	0.11	0.00	0.10	0.22	0.10	0.38	0.14	0.00	0.36
Ge	0.22	0.50	0.33	0.20	0.33	0.33	0.29	0.33	0.29		0.33	0.10	0.17	0.00	0.14	0.14	0.33	0.14	0.25	0.00	0.09
Gr	–	0.50	0.20	–	–	0.20	–	0.20	–	0.33		0.13	0.00	0.00	0.20	0.20	0.20	0.20	0.50	0.00	0.11
It	0.23	0.25	0.18	0.21	–	0.18	0.27	0.18	0.27	0.22	–		0.09	0.10	0.18	0.18	0.08	0.18	0.11	0.00	0.31
Ja	0.20	0.50	0.29	0.18	0.25	0.29	0.25	0.29	0.25	0.40	0.25	0.20		0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.08
Ne	0.22	0.50	0.33	0.20	0.33	0.33	0.29	0.33	0.29	0.50	0.33	0.22	0.40		0.14	0.00	0.00	0.14	0.00	0.00	0.00
No	0.18	0.40	0.17	0.17	0.20	0.17	0.22	0.17	0.22	0.33	0.20	0.18	0.29	0.33		0.25	0.11	0.11	0.17	0.00	0.08
Po	0.18	0.40	0.17	0.17	0.20	0.17	0.22	0.17	0.22	0.33	0.20	0.18	0.29	0.33	0.17		0.25∗	0.25∗	0.17	0.00	0.17
Sp	0.18	0.40	0.17	0.17	0.20	0.17	0.22	0.17	0.22	0.33	0.20	0.18	0.29	0.33	0.17	0.17		0.11	0.17	0.00	0.08
Sw	0.18	0.40	0.17	0.17	0.20	0.17	0.22	0.17	0.22	0.33	0.20	0.18	0.29	0.33	0.17	0.17	0.17		0.17	0.00	0.27
Sz	0.25	0.33	0.25	0.22	0.50	0.25	0.33	0.25	0.33	0.67	0.50	0.25	0.50	0.67	0.25	0.25	0.25	0.25		0.00	0.22
UK	–	0.50	0.20	–	–	0.20	–	0.20	–	0.33	–	–	0.25	0.33	0.20	0.20	0.20	0.20	0.50		0.00
US	0.21	0.22	0.17	0.20	–	0.17	0.25	0.17	0.25	0.20	–	0.21	0.18	0.20	0.17	0.17	0.17	0.17	0.22	–	

Note: Upper triangle gives the bivariate concordance indices for each category, lower triangle gives the critical values of the concordance index 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; independence test outcomes involving France, Norway and the US are based on corrected Pearson chi-squared statistics, not on the Fisher exact test outcomes listed in the lower triangle of the table.

Other combinations of bivariate tests are also easily constructed. 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. These are very low incidence crises, as recorded in Table 2 above. However, 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, and Eichengreen and Bordo (2003) claim this type of crisis is more frequent in recent history.[7] This suggests that the concordance of twin crises is an interesting avenue for future work.

Given the relationships revealed by the bivariate indices we now consider the construction and testing of the multivariate concordance indices.

4.3 Multivariate concordance indices

Table 6 reports the multivariate concordance indices for the group of crises which involves both 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 currency crises across the 21 economies sampled. A total of 39 time periods are identified which fulfill that criteria, giving a turbulent periods index of 0.58.

The final column of Table 6 reports the 95% critical value for the concordance indices in each case expressed as the minimum number of times that

[7]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.

one would observe that many crises and be able to reject the null of independence. That is for the row of at least two simultaneous currency crises, one can observe up to 19 occurrences of two simultaneous crises without having to reject independence. In the sample there are 39 occurrences of at least two simultaneous currency crises, clearly rejecting independence. The results in Table 6 show that the sample rejects independence between simultaneous crises in all instances. The table shows that a single occurrence of five simultaneous currency crises (four simultaneous banking crises) is sufficient to reject independence in the data. This implies there is some underlying mechanism connecting the observed occurrence of simultaneous crises.

Table 6: Multivariate concordance indexes

	Turbulent periods	Observations	Critical value
Across countries–currency crises type			
At least 2 crises	0.58	39	19
At least 3 crises	0.30	20	8
At least 4 crises	0.15	10	3
At least 5 crises	0.10	7	1
At least 6 crises	0.09	6	1
At least 7 crises	0.06	4	1
At least 8 crises	0.04	3	1
At least 10 crises	0.03	2	1
At least 12 crises	0.03	2	1
At least 14 crises	0.01	1	1
Crises observations ($T - \#(0)$)		99	
Across countries–banking crises type			
At least 2 crises	0.59	24	6
At least 3 crises	0.34	14	2
At least 4 crises	0.12	5	1
At least 5 crises	0.07	3	1
At least 6 crises	0.05	2	1
At least 7 crises	0.05	2	1
At least 8 crises	0.02	1	1
At least 10 crises	0.02	1	1
At least 12 crises	0.02	1	1
At least 14 crises	0.02	1	1
Total crises ($T - \#(0)$)		57	

Note: 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.

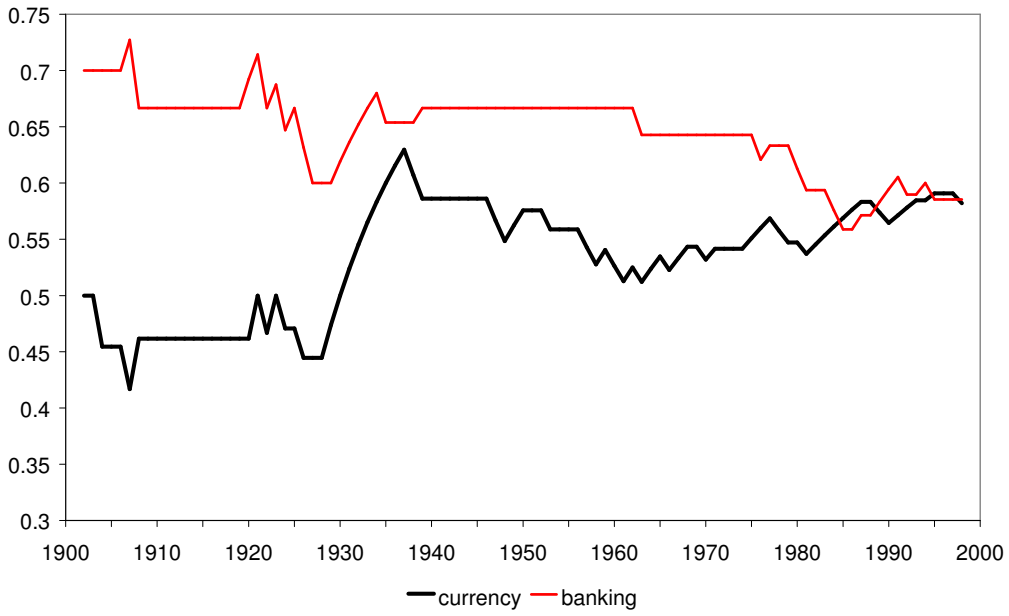
Policy makers are correct to be concerned about the occurrence of a crisis. However, knowing which crises are going to spread is as yet unresolved. Isolating the characteristics of what makes a particular crisis spread, or alternatively what makes other markets vulnerable to spread from other crises 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 concordance indices and their critical values.

5 Historical analysis

To illustrate the usefulness of the concordance indices, we analyse their patterns over time for the 20th Century. Figure 3 shows recursive calculations of the concordance indices using the initial 20 observations as the starting point and increasing the sample size by one observation at the time. Increases in the concordance index indicate an increase in international financial turmoil, and as shown before only a relatively small number of countries experiencing simultaneous financial crisis is sufficient to reject independence between them. A stable concordance index is associated with a period of tranquility.

A decrease in the concordance index is equally informative, as it signals an increase in isolated financial turmoil, that is turmoil confined to single or small groups of countries. Figure 3 is the recursive concordance index for the case of 2 or more simultaneous crises, so that a decline in this index is associated with the occurrence of isolated single crises. Similar indices can be constructed for greater values of simultaneous crisis, as discussed further below.

Figure 3: Recursive multivariate concordance indices, 1903–1998



We observe a constant value of the currency concordance index from 1908 to 1920, indicating periods of financial tranquility. The 1920s is characterised by periods of both international turmoil (increases in the index) and isolated turmoil (decreases in the index). The extended period of the 1929 crash and the following Depression results in an extended period of increase in the currency concordance index up to 1938, indicating a period of sustained

international turmoil. Immediately prior to World War II there is some evidence of isolated turmoil, and then a fixed regime prevails until 1946 associated with War time regulation. From 1946 to 1963 is a period of general decline in the currency concordance index, interpretable as a period of isolated turmoil. This corresponds to the first period of what Bordo et al (2001) characterise as the Bretton-Woods era from 1945 to 1971. Pressure on the international financial system began to emerge from 1963 onwards, evident in the increase in the currency concordance index. The collapse of Bretton-Woods is followed by a brief period of stability up to 1974 whereafter a number of countries suffer crises over the following years, and the index continues to climb over the periods of the first and second oil crises through to 1988. A small decrease in the index in 1989-1990 indicates some isolated turmoil. The currency concordance index then increases to the penultimate year in the sample, reflecting the general period of international financial turmoil of the 1990s.

The banking concordance index displays a similar pattern to the currency index up to and including the period of World War II. The effect of the Depression on the banking crisis concordance index is less pronounced than for the currency index. A very long stable period in the banking crisis concordance index prevails until 1963. Some isolated turmoil then reduces the index in 1964 which remains stable until 1976. The index then decreases up to 1986, and has its last prominent increase to 1991, associated with increased international turmoil. Thereafter the index is relatively stable, although not constant as in previous periods. Bordo et al (2001) find that the banking crises are more likely in periods of lower capital controls, in par-

ticular contrasting the Bretton Woods period with the current period. Our results suggest that post Bretton Woods banking crises occurred more frequently as independent events than they did previously - that is the banking crisis concordance index declines in the latter part of the sample, implying that the banking crises are more likely to be related to individual country specific conditions.

An interesting aspect of Figure 3 is that although the number of banking and currency crises are quite different, the values of the concordance indices for banking and currency crises at the end of the sample period are quite similar. However, the historical pattern differs across the two indices. In general there have been more periods of international financial turmoil in currency crises, leading to an increase in the index over the 20th century, while banking crises have tended to be more internationally linked at the beginning of the century than the end. Banking crises have tended to have relatively more independent occurrences. The relative changes in the banking and currency crisis concordance indices in the 1970s support Kaminsky and Reinhart (1999) in finding little relationship between banking and currency crises in this decade. Both this and the claim that banking and currency crises are likely to be reinforcing could be more fully investigated with a twin crisis multivariate index.

There are a number of interesting hypotheses in the literature where the existing results can be augmented using these indices. First, although it may remain true that currency crises are more prevalent with emerging market data (Bordo et al, 2001), the currency crisis concordance index also reveals that there has been increasing incidence of internationally linked currency

crises in a set of countries dominated by developed nations. Second, countries without capital controls are more likely to experience banking crises (Bordo et al, 2001, Kaminsky and Reinhart, 1999). However, the banking crisis concordance indices show that the more recent liberalisations in banking systems in the 1980s onwards have been associated with instances of isolated crisis, rather than the more international banking crises seen in the early part of the 20th century. That is, the looser controls period is associated with more banking crises, but they are also less likely to be part of international banking turmoil. Third, in the 1980s banking and currency crises may be linked and reinforcing (Kaminsky and Reinhart, 1999). The concordance indices for these two crisis types move in opposite directions during the 1980s. If the two types of crisis are linked, then the impetus comes from independently occurring banking crises, which may then spread to international currency crises. Bordo et al (2001) claim that currency crisis frequency has increased relative to earlier periods, additionally, our analysis shows that currency crises are more internationally linked in the 1990s than in most earlier periods, with the exception of the last part of the 1930s. Historically, the prevalence of both banking and currency crises post 1973 is akin only to the turmoil in the 1920s and 1930s, Bordo et al (2001). However, our analysis shows that the internationalisation of crises in the 1970s is below that of the mid-1930s. In particular, for banking crises, the international interdependence of banking crises is less at the end of the century than the beginning. Our results support the finding of Bordo et al that the popular perception of a crisis prone 1990s is due to the prevalence of currency crises, and in our analysis particularly multiple contemporaneous currency crises.

Eichengreen and Bordo (2003) and Bordo et al (2001) conclude that financial crises have not evidently grown more severe over the 20th century but are more prevalent, to which our analysis adds that currency crises have become both more prevalent and more likely to be associated with international turmoil, while banking crises have become more prevalent but more likely to be independent and country specific events for this sample.[8]

The concordance indices can also be used to make conditional statements about the implications of a crisis in terms of its management and the international policy debate. Karolyi (2003) for example, has argued that more resources should be directed to domestic economic problems than to reforms of the international system. If the occurrence of a financial crisis in a country is associated with a fall in the concordance index, this supports the argument that domestic policy solutions are required. If, however, the concordance index rises this suggests that there is associated international turmoil, and there may be a case for considering international reforms; as we have formally tested, the probability of unconnected multiple contemporaneous financial crises across international borders is very low.

6 Conclusion

This paper developed a turmoil-periods concordance index for financial crises, with the property of being readily interpretable over time. The turmoil-periods concordance index was designed for use with the typically binary, low incidence, potentially serially correlated crisis events data and extended to

[8]Dungey, Jacobs and Lestano (2004) suggest that for the Asian crisis there is evidence of significant international cross border banking crises.

incorporate the concept of multivariate synchronisation between more than two countries simultaneously. The properties of the index were explored, including a simple means of constructing critical values for testing the independence of observed events. Moves in the multivariate turmoil-periods concordance index were used to consider the changing pattern of financial turmoil in world financial markets for the period 1883-1998. Stability in the index value indicated periods of stability. A decline in the index indicated the presence of independent crises, where an independent crisis occurred in a single or small group of countries and coincidental timing could not be dismissed. An increase in the index value indicated internationally linked financial turmoil - the financial crises involved did not occur independently.

Concordance indices for banking and currency crises for 21 countries currency and banking crises from 1883-1998 were constructed using data from Bordo et al (2001). Concurrent crises were unlikely to occur independently. In the data sample an observation of 5 (4) or more currency (banking) crises rejected independence between these events, that is they were not coincidental. Several significant periods of international financial turmoil were identified. In currency crises these were in the 1930s, from the mid-1960s to mid-1970s and throughout most of the 1990s. In banking crises the periods of international financial turmoil were identified in the 1930s and early 1990s. Periods of isolated turmoil were identified in the Bretton-Woods era for currencies and broadly from the mid-1960s to early 1990s for banking.

The degree of international financial turmoil in currency crises was shown to have broadly risen over the 20th century, associated with a rise in the currency crisis turbulent-periods concordance index. In contrast, the degree

of international financial turmoil in banking crises fell over the 20th century, shown as a fall in the banking crisis turbulent-periods concordance index.

None of these indices provide information about the underlying causes of the crises, although they strongly suggest there are relationships behind the simultaneous, or near-simultaneous, occurrence of crises. Clearly the tests for whether crises are related will be affected by definition, timing and measurement of when a crisis occurs.

Whether further analyses could be used to predict financial crises requires some benchmark against which to measure potential algorithms, in a means somewhat analogous to the methodology used in assessing business cycle dating as replicating the Business Cycle Dating Committee of the NBER dates for the US business cycle. Researchers and policy makers would similarly 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 immense assistance. An important step forward would be the institution of a Financial Crises Dating Committee.

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