On the Measurement of the International Propagation of Shocks:

Is the Transmission Stable?\(^1\)

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September 30, 2002

\(^1\)This paper was previously titled: “On the Measurement of Contagion.” I am grateful to Raman Uppal for first introducing me to these problems. I thank Roberto Benelli, Irineu Carvalho, Bernard Dumas, Eduardo Fernandez Arias, Han Goldfajn, Bob Pindyck, Mark Showalter, Tom Stoker, Ernesto Taivi, Carlos Vegh, Mark Watson, and one anonymous referee for very useful conversations and suggestions. I also thank the participants of seminars at Harvard, NYU, Yale, MIT, Princeton, the NBER Summer Institute, 1999 and the Winter Camp in Cartagena in January 1999 for their comments. All remain errors are mine. Comments are welcomed to 50 Memorial Drive, Room E52-431, Cambridge, MA 02142. email: rigobon@mit.edu. home page: http://web.mit.edu/rigobon/www.
Abstract

The empirical literature on “contagion” focuses mainly on two questions: (1) what are the channels through which shocks are transmitted across countries, trade, macro similarities, financial weaknesses, or investor behavior? (2) Is there a shift in the transmission of shocks during crises? Are crises spread with higher intensity? If so, why? This paper concentrates on the econometric problems that arise in dealing with the second question.

The data where most of these issues are raised are plagued with problems of simultaneous equations, omitted variables, and heteroskedasticity. The standard methodologies used in the literature are inappropriate if all three are present. This paper applies a new procedure that allows one to test for parameter stability, taking into account all three predicaments. The paper tests for the stability of the transmission mechanisms among 36 stock markets during the last three major international financial crises (Mexico 1994, Asia 1997, and Russia 1998).

JEL Classification Numbers: F30, C32, G15.

Keywords: Contagion, stock market crises, international financial markets, measuring the transmission mechanism.
1 Introduction

It has been widely documented that stock markets around the world are highly correlated, specially during crises. Table 1 shows simple correlations of daily stock market returns from 1994 to 2001 for several Latin American, South East Asian, and developed countries. As can be seen, if Colombia and Chile are excluded from the Latin American sample, the average correlation is 56.6 percent between Latin American countries - it is 60.8 percent on average, with a median of 66.5 percent for the South East Asian countries - and, it is 41.8 percent, with a median of 60.7 percent for the developed economies. By any standard, these correlations show a very strong co-movement. Furthermore, the correlation coefficients are even higher during crises.

The Mexican, Asian, and Russian crashes were followed by a sequence of stock market and exchange rate crises in other markets. These collapses, and the processes that generated them, have driven the literature to ask exactly how these shocks were transmitted internationally and why with such intensity. Was it because, as some believe, the linkages between countries grew stronger during these crises, or as others have proposed, was it because they were already strong before the crises took place?

[Table 1 here]

This debate starts with the seminal contribution by King and Wadhwani [1990], where they define contagion as a significant change in the correlation coefficient. Still today, this is the most frequently asked questions in the contagion literature. However, no satisfactory procedure has been developed to been able to answer it.

The main econometric problem arises because the data on world stock markets suffers from problems of heteroskedasticity, simultaneous equations and omitted variables; as a result, traditional econometric techniques for testing for structural changes are inappropriate. Heteroskedasticity changes the biases introduced by the simultaneous equations and omitted variable problems. Therefore, the null hypothesis of parameter stability might be rejected due to of a change in the bias rather than to a shift in the underlying coefficients.

Ronn [1998] showed that tests of parameter stability based on correlation coefficients are biased when the data suffers from heteroskedasticity. Boyer, et. al [1999], Lorentan and English [2000], and Forbes and
Rigobon [2002] extend Ronn’s contribution to the case of contagion and concluded that most of the findings in the earlier literature are reversed when the heteroskedasticity is taken into consideration. However, the adjustment in the correlation coefficient requires very strong assumptions. As is indicated in Forbes and Rigobon’s appendix, the adjustments in the correlations are biased if the data suffers from simultaneous equations or omitted variable problems - both of which are likely to be present. Furthermore, this problem cannot be solved by using micro or firm level data because the aggregate issues will continue to be present and the OLS estimates from the microdata will be as inconsistent as those from aggregate regressions.

The objective of this paper is to extend the literature by presenting evidence on the stability of the international propagation of shocks using a new test that is robust to all three predicaments present in the data. The procedure is rooted in the assumption that if the heteroskedasticity in a sub-sample can be explained by a shift in the variance of only a sub-set of the shocks, then it is possible to test for the stability of the coefficients. The recent international crises, therefore, provide a natural framework which to conduct the test. The country (or countries) generating the increase in the variance is (are) usually known (for example, Mexico in 1994). And it is reasonable to assume that most of the rise in variance in other markets (for example, Argentina) shortly after the original shock is due to the Mexican crisis and not to idiosyncratic Argentinian news. One advantage of the test is that if the assumption about heteroskedasticity is violated, then the null hypothesis is rejected. Thus, the lack of rejection is informative regarding both parameter stability and the form of the heteroskedasticity.

Using daily data from a total of 36 stock market indices, I find that the transmission mechanism did not differ significantly between low-volatility and high-volatility periods surrounding the Mexican and the Russian crises. I did, however, find evidence of some change in the transmission mechanism after Thailand’s devaluation.

The paper is organized as follows: Section 2 describes the procedure. Section 3 applies the test to daily data of 36 stock markets from 1993 to 1998. Section 4 concludes and discusses extensions.
2 Measuring changes in the transmission mechanism

2.1 Setup

Assume that there are $N$ countries whose stock markets’s returns ($x_{it}$) in excess of the risk-free rate are described by the following latent factor model:

$$X_t'A' = X_t\phi(L) + z_t\Gamma' + \varepsilon_t,$$  \hspace{1cm} (1)

where $X_t$ is the $T \times N$ vector of endogenous variables (country indices) given by $X_t = (x_{1t} \ldots x_{Nt})$. $\phi(L)$ is the vector of lags, $A$ and $\Gamma$ are non-triangular matrices given by

$$A = \begin{pmatrix}
1 & a_{12} & \cdots & a_{1N} \\
a_{21} & 1 & \cdots & \\
\vdots & \ddots & \ddots & \\
a_{N1} & \cdots & 1
\end{pmatrix},$$ \hspace{1cm} (2)

$$\Gamma = \begin{pmatrix}
1 & \gamma_{21} & \cdots & \gamma_{2k} \\
\gamma_{12} & 1 & \cdots & \\
\vdots & \ddots & \ddots & \\
\gamma_{N1} & \cdots & \gamma_{Nk}
\end{pmatrix},$$ \hspace{1cm} (3)

$z_t$ is a $T \times K$ matrix representing $K$ unobservable common shocks (which, for simplicity, have been normalized: the first row of $\Gamma$ is all ones), and where $\varepsilon_t$ has dimensions $T \times N$ and summarizes the country specific shocks.

Assume that the common shocks have a mean of zero ($E[z_t] = 0$), are uncorrelated among them ($E[z_{it}z_{j,\tau}] = 0 \forall i \neq j \forall t \neq \tau$), and have covariance matrix at time $t$ given by $E[z_t'z_t] = \Omega^z_t$ (which is diagonal). The country specific shocks satisfy similar properties: They also have an expected value of zero, $E[\varepsilon_t] = 0$, are uncorrelated among them ($E[\varepsilon_{i,t}\varepsilon_{j,\tau}] = 0 \forall i \neq j \forall t \neq \tau$), are uncorrelated with the common shocks ($E[\varepsilon_tz_{\tau}] = 0 \forall t, \tau$) and have a diagonal covariance matrix at time $t$ given by $\Omega^\varepsilon_t$.

In this model, the simultaneous equations problem is summarized in the non-triangularity of $A$, the
problem of omitted variables is captured in \( \Gamma \) and \( z_t \), and the heteroskedasticity is modeled as changes across time in the variance of the structural and common shocks. Furthermore, throughout this paper it is assumed that the variance of \( X_t \) is finite; thus, \( A \) and \( \Gamma \) satisfy the proper conditions for this to be true. Without loss of generality, it is assumed that the returns have mean zero. The results discussed here are independent of this assumption.

It is important to mention that this setup is flexible enough to allow for relatively complex dynamics; for example, \( z_t \) can include lags of itself. In fact, the model is general enough to encompass a large set of the linear models used by the contagion literature.

Finally, equation (1) should be interpreted as more than a statistical description of the data. First, a similar equation is the outcome of a general equilibrium endowment economy with \( n \) countries and \( n \) assets, where the idiosyncratic shocks are country-specific productivity shocks (or shocks to their dividend process), where \( A \) summarizes the output linkages across countries (trade is the linkage used in most general equilibrium setups, though other linkages could be present), \( z_t \) summarizes common shocks, such as changes in risk aversion, or world endowments, etc., and \( \Gamma \) summarizes how those shocks affect each particular country (in most of the models, the elements of \( \Gamma \) are the same across countries, but this is mainly a simplification to obtain close form solutions). An international version of CCAPM (or a multifactor latent model) reproduces equation (1) because the market portfolio, or other factors, are a linear combination of the underlying structural stocks. A log linearization of the Euler equation generates a linear model like the one used above. Second, a large literature on “contagion” has used linear specifications as a way to test either the channels of transmission, or their stability. For example, papers that measure the international propagation of shocks using principal components\(^4\), or correlations\(^5\), or linear regressions\(^6\) implicitly assume a setup similar to the one used here. Other papers deal with non-linear relationships.\(^7\) The non-linearity in those papers is mainly due to the inclusion of interaction terms between shocks in other stock markets and macro variables or country characteristics. An important extension of the current methodology is to allow for those non-linear specifications.
2.2 Parameter stability

It is well known that equation (1) cannot be estimated without further information. Moreover, tests on parameter stability cannot be performed either: the biases introduced by simultaneous equations and omitted variables are a function of the underlying variances. Under the assumption of heteroskedasticity, then, this implies that the null hypothesis of stability could be rejected even though the coefficients might be stable. Moreover, the adjustment in the correlation coefficient proposed by Ronn [1998], Boyer, et. al [1999], English and Loretan [1999], and Forbes and Rigobon [2002] is wrong in this framework; hence, it should not be used.

The properties of the test developed here are the same whether or not lag dependent variables are present. Thus, to simplify the exposition I assume that lags are not present, even though they are in the empirical implementation. The reduced form implied by equation (1) is

\[ X_t = z_t \Gamma A^{-1}\gamma + \varepsilon_t A^{-1/2} \]  

where the variance covariance matrix of \( X_t \) at time \( t \) is:

\[ \Omega_t = A^{-1}\Gamma \Omega_z \Gamma^\prime A^{-1} + A^{-1} \Omega_{\varepsilon} \Gamma^\prime A^{-1}, \]  

where, as before, \( \Omega_z \) is the covariance matrix of the common shocks at time \( t \), and \( \Omega_{\varepsilon} \) is the covariance matrix of the idiosyncratic shocks at time \( t \).

Proposition 1 (DCC test) Let \( X_t \) be described by a latent factor model given by equations (1), (2), and (3). If the parameters are stable, and if in a sub-sample the heteroskedasticity is explained by a subset of either the structural or the common shocks, then the determinant of the change in the covariance matrix is zero.

The properties of the test are thoroughly explored in Rigobon [2000]. Here I discuss mainly its general characteristics.

To clarify the intuition of how the test works, assume that between times \( t \) and \( t+1 \) the heteroskedasticity observed in the stock market returns is the result of heteroskedasticity of a subset of the idiosyncratic
(\varepsilon_t) shocks. Without loss of generality assume the first $i < N$ country shocks are heteroskedastic. The first implication of this assumption is that the change in the covariance of the common shocks from $t$ to $t+1$ is zero: $\Delta \Omega^\varepsilon_t = 0$. The second implication is that the change in the covariance matrix of the structural shocks has zeros everywhere, except in the first $i$ elements of its diagonal:

$$
\Delta \Omega^\varepsilon_t = \\
\begin{pmatrix}
\Delta \sigma^2_{\varepsilon_1} & \cdots & 0 & 0 & \cdots & 0 \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
0 & \cdots & \Delta \sigma^2_{\varepsilon_i} & 0 & \cdots & 0 \\
0 & \cdots & 0 & 0 & \cdots & 0 \\
\vdots & \ddots & \vdots & \ddots & \ddots & \vdots \\
0 & \cdots & 0 & 0 & \cdots & 0 \\
\end{pmatrix}.
$$

If the parameters are stable, the change in the covariance matrix of the reduced form is

$$
\Delta \Omega_t = A^{-1} \Gamma \Delta \Omega^\varepsilon_t \Gamma' A'^{-1} + A^{-1} \Delta \Omega^\varepsilon_t A'^{-1}.
$$

Given the previous assumptions that $\Delta \Omega^\varepsilon_t = 0$ and that $\Delta \Omega^\varepsilon_t$ is less than full rank, the determinant of $\Delta \Omega_t$ is equal to zero.

$$
\det \Delta \Omega_t = \det A^{-1} \det \Delta \Omega^\varepsilon_t \det A'^{-1} = 0.
$$

This is the Determinant of the Change in the Covariance matrix test (from now on the DCC test). The same property is true if the heteroskedasticity of the observed variables is explained by a subset of the common shocks.

Notice that the determinant is different from zero in two circumstances: (i) if the coefficients change; (ii) if all the shocks exhibit heteroskedasticity. Therefore, it is crucial that at least some shocks are assumed to be homoskedastic if the rejections are to be interpreted as parameter instability.
3 Empirical Evidence

The financial crises in Mexico, Asia, and Russia, reverberated around the world; Several stock markets plunged, some countries devalued, and almost all financial markets saw their volatilities increase. This section studies the parameter stability across stock markets during these events.

This application represents a natural setup where the assumptions underlying the test developed in the previous section can be justified. The financial crises involved massive changes in the second moments, that were relatively short lived, and clearly the result of problems in a subset of the countries in the sample. For example, it is difficult to argue that the increase in the world variance during the Asian crises was due to increases in the volatility of all idiosyncratic shocks around the world at the same time.

The data was collected from Datastream, and it consists of daily stock market returns in dollars for 36 countries, covering the period from January 1993 to December 1998. The countries studied are: Argentina, Australia, Austria, Brazil, Canada, Chile, Columbia, Denmark, Finland, France, Germany, Greece, Hong Kong, India, Indonesia, Italy, Japan, Malaysia, Mexico, Netherlands, Norway, Peru, Philippines, Portugal, Russia, Singapore, Korea, South Africa, Spain, Sweden, Swiss, Taiwan, Thailand, UK, USA, and Venezuela. Short term interest rates and exchange rates covering the same period and frequency were also collected.

3.1 Definition of the windows.

The test compares the covariance matrix of a set of random variables at two different sub-samples. Hence, I use the crises in Mexico, Asia, and Russia as the dividing events, considering a low-volatility (trough) period prior to the crises, and a high-volatility period immediately after it.

The test first estimates the covariance matrix in the tranquil and the crises periods, and then computes the determinant of the difference: if the determinant is different from zero, then the stability of the parameters is rejected. In implementing the test, there is an important trade off. On the one hand, the windows should be defined as narrowly as possible. The longer the windows are, the higher the likelihood that most of the shocks are heteroskedastic, which increases the chance that the test is rejected because all shocks are heteroskedastic and not because the parameters are unstable. On the other hand, narrower windows undermine the estimation of the covariance matrices. If the covariance matrices are too noisy, then the test is never rejected. Therefore, there is a tension between the quality of the estimation of the
covariance matrices and the likelihood of satisfying the heteroskedasticity assumption. Going even further, this also implies that the number of countries tested at a single time cannot be too large.\textsuperscript{9} Hence, instead of testing all the countries together, four sets of countries are analyzed separately: 7 Latin American countries, 8 Asian countries, 18 OECD countries (not including Mexico and Korea), and the 3 remaining countries in the sample.

Splitting the sample by regions seems to be a natural choice. In the literature there is strong evidence that regional variables are an important source of contagion.\textsuperscript{10} In the robustness section, I study the sensitivity of the results to changes in the countries included in the regression.\textsuperscript{11}

The next step is to define the windows for which the covariance matrices are estimated. From 1994 to 1998, international markets faced three major crises. In Table 2, the low-volatility and high-volatility windows are shown for each crisis.

\begin{table}[h]
\centering
\caption{Table 2 here}
\end{table}

**Tequila effect:** For the Mexican crisis, the tranquil window is defined as the period from June to December of 1994 right before the devaluation of the Peso. This short period is relatively stable. The beginning of 1994 is not considered tranquil because two political events in Mexico increased the volatility: the uprising in Chiapas and the assassination of Collosio.

Three different crisis periods are studied: One starts with the devaluation on December 19, 1994 and ends before the announcement of no-rollover of the short term Mexican debt on January 9, 1995. The second runs from the no-rollover announcement until the end of March 1995. The third excludes the initial period of turmoil due to the no-rollover announcement and runs from February 1 1995 to the end of March, 1995.

The devaluation can be interpreted as a pure idiosyncratic shock if Mexico is included in the group of countries. If it is excluded, then the devaluation should be interpreted as an unobservable common shock. The January 9 no-rollover announcement of short-term debt had a large impact on bond markets around the world. Indeed, the EMBI+ dropped by almost 6 percent that day. This shock could be interpreted as a liquidity shock, and therefore, in this model it is a common shock. This is the case whether or not Mexico is included in the regression. Finally, the period from February until the end of March reflects mainly a
period of high uncertainty. During this period the rescue packages from the IMF and the Treasury were under discussion.

Separating these three events allows us to study which type of shock produced the shift in coefficients (if any): in other words, if there is a shift in the parameters, then it is possible to conclude whether the devaluation, the liquidity shock, or the uncertainty caused by the liquidity shock induced the change.

**Asian Flu:** The Asian crises started in June of 1997 with Thailand’s devaluation and ended in 1998 when the Korean crisis settled down. For these crises the low-volatility period is defined as the six months prior to Thailand’s devaluation. Even though some of the Asian stock markets were showing a downward trend during this period, the drop was not dramatic. In the robustness section, I discuss how this assumption was relaxed.

Five high-volatility periods are studied: First, the Thailand crisis started at the beginning of June 1997 and was followed by a sequence of devaluations in Malaysia and Indonesia. I treat all these crises as the same event. Second, the Hong Kong crisis began on October 27, 1997. This is the only crisis with a clear initial data, identified as the day on which short-term interest rates increased dramatically. This was a sharp and large shock that was felt worldwide, and therefore I analyze it separately. Third, the Korean crisis is also analyzed alone. It began around December 15, 1997 and ended in January 1998. The fourth period studies the Hong Kong and the Korean crises together. And the fifth window analyzes all the Asian crises together. Again, in the robustness section I study the sensitivity of the results to changes in the initial dates of these crises.

Note that including two or more crises in these windows should not violate the heteroskedasticity assumption. All the countries under analysis belong either to the regression or to the common shocks (depending on the group analyzed). This is an advantage of the DCC test over the correlation adjustment procedures.

**Russian Cold:** The third event studied is the Russian crisis and the LTCM collapse.

The tranquil period runs from March to July of 1998. This crisis starts two months after the end of the Korean crisis. The end of the tranquil period is two months before the bond market collapse in Russia. For the Russian case there is little room to define another tranquil window. The high uncertainty from the
Asian crises and the initial turmoil produced by the IMF’s rescue package in early July set the boundaries of what could be considered as the low-volatility regime.

Three high-volatility periods are studied: First, the pure Russian collapse, which started at the beginning of August and ended a couple of weeks afterwards. The start of this crisis is not entirely clear. In a span of two weeks, the bond market, then the stock market, and finally the exchange rate collapsed. The events are clearly separated, but cannot be considered as economically independent events. Thus, for this crisis I choose the first of these crashes as the starting point. The second crisis is LTCM’s collapse. LTCM issues appeared at the end of August and lasted until the end of September. Finally, in October there is a speculative attack to the Brazilian currency.

The advantage of separating the different economic events that shaped each of the crises is to increase the understanding of what causes the parameters to shift. This would give some direction to theoretical work explaining the international transmission of shocks. It is important to mention that the tests are independent if, under the null hypothesis, the windows do not overlap. I have tried to use the longer and non-overlapping periods to define the windows. Obviously, other splits are possible. Several sensitivity analyses were performed to evaluate the robustness of the results to changes in the definition of the windows. These results are discussed in Section 3.4.

3.2 Testing for Changes in the Transmission Mechanism

The model used is an extension of equation (1). I allow for trends, lags, and additional controls. Assume that returns are explained by the following latent factor model:

\[ AX_t = c + \phi(L)X_t + \Phi(L)Y_t + \Gamma z_t + \varepsilon_t, \]  

(6)

where \( Y_t \) are exogenous controls and \( X_t \) represent the stock market returns of a subset of the countries. Because markets are not open at the same time around the world, \( X_t \) is defined as the two-day return in dollars. In the specification, five lags are allowed.

An important case is the inclusion of interest rates as control variables in equation (6). Including interest rates allows for a proxy for some of the omitted variable problems, but it could also lead to underestimating the propagation of shocks. On the one hand, interest rates account for common shocks,
such as monetary policy coordination across countries and shifts in risk preferences, that otherwise are unobservable at the frequencies where the study is performed. On the other hand, part of the propagation of shocks could be transmitted through the interest rate. In order to deal with this problem, the model is estimated with and without interest rates.

The reduced form of equation (6) is

\[ X_t = A^{-1}c + A^{-1}\phi(L)X_t + A^{-1}\Phi(L)Y_t + \nu_t \]  
\[ A\nu_t = \Gamma z_t + \varepsilon_t. \]  

Equation (7) can be estimated using a VAR. Observe that the residuals from the reduced form (\(\nu_t\)) satisfy equation (8) which is exactly the setup analyzed in equation (1).

The procedure is as follows: First, the VAR (equation (7)) is estimated and the residuals are recovered. Second, the residuals are split accordingly to the windows defined in Table 2. Third, for each regime the covariance matrix of the reduced form residuals is estimated and the DCC is computed. Finally, the distribution of the DCC is obtained by bootstrap. In other words, the DCC is performed on the reduced form residuals instead of on the original variables. At first glance, this procedure might suggest that only the stability of \(A\) and \(\Gamma\) is tested, but this methodology also tests the stability of \(\phi(L)\) (see Appendix B for a detailed discussion).

The distribution of the determinant of the change in the covariance matrices is estimated by bootstrapping and using the asymptotic distribution of the covariance matrices. The computation of the bootstrap is as follows: (i) after estimating the covariance in each of the windows, I generate several covariance matrices for each window using the asymptotic distribution of the covariance matrices; (ii) I compute the determinant of the change for each draw. The test is rejected if the determinant is different from zero. Hence, the procedure computes the mass of the draws that are above zero. If this mass is very small, or very large, then most of the distribution is on one of the sides and the test should be rejected. In other words, if 5 or 95 percent of the observations are above zero, then it is possible to say that the determinant is different from zero at 10 percent confidence. The bootstrap is implemented assuming that the covariance matrices are serially correlated across regimes. The procedure uses the point estimate of the covariance
matrix in the low-volatility regime and the change in the covariance matrix across regimes to generate random draws. It is important to mention that the procedure was also run assuming that the covariance matrices were independent across regimes. The test has less power in this case and the results are not presented. In fact, under this assumption not a single rejection was found.

3.3 Results

This section reports the results from running the DCC test. First, I show the size and importance in the changes in the covariance matrices. To do so, the change in the variance is computed per period and per group of countries, and the Euclidean norm \((L_2 \text{ induced norm})\) is computed. The increase between the high- and low-volatility regimes is reported in Table 3. This indicates how different the covariance matrices are in the sample.

[Table 3 here]

In order to provide an intuition of the importance of these numbers, a nine times proportional increase in all variances and covariances implies a change in this ratio equal to three. Thus, as can be seen, some of the crises implied very large increases in the standard deviations of the countries considered. An equivalent picture arises if, instead of computing the Euclidean norm on the matrix, only the country variances are used. Again, it is common to find country variances that increase by more than 12 times around the crises. Using the induced norm, however, takes into account changes in variances, as well as covariances, and that is why it was preferred.

The results are organized by groups of countries for all crises, and summarized in Tables 4 to 7. In all those tables the first column shows the value (point estimate) of the determinant. The second column indicates the standard deviation of the determinant obtained from the bootstrap. The third column is the quasi-z-statistic. Recall that the small sample distribution of the determinant is not normal. This column mainly indicates the precision of the estimates, but almost no conclusions are drawn from it. The fourth column reports the mass below zero. This is the column used for inference on the stability of parameters. Finally, I use "-" to denote instances when the data are insufficient to estimate a covariance matrix - which only occurs for the OECD group. All the tables have 12 rows. The first three rows coincide with the three
events studied during the Tequila effect. The next five rows are the crises during the Asian Flu; crises in Thailand, Hong Kong, Korean, and the two combinations of them. Finally, the last four rows are the events around the Russian collapse; the pure Russian crash and debt default, the LTCM collapse, both events together, and the Brazilian speculative attack in October 1998.

Table 4 reports the results for the Latin American group: Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Venezuela. The first three rows show that the test of parameter stability is never rejected during the Mexican crisis. During the Asian crises, however, Thailand’s devaluation implied a change in the propagation of shocks among Latin American countries. There is a rejection during Thailand’s crisis alone and when it is considered together with the other crises. For the Latin American sample, turbulence in Thailand’s stock market (as well as in the stock markets of other countries in SEA) is a common shock ($z_t$). Note that considering the crises together should not violate the heteroskedasticity assumption, because SEA countries are a sub-set of the countries excluded from the regression.

During the Russian, crisis the LTCM collapse implied a shift in the propagation mechanism. However, this is not confirmed by the mass below zero when LTCM is analyzed together with the other events. So, the finding should be taken cautiously. Therefore, it could be said that the only rejections we found in the group of Latin American countries were during Thailand’s devaluation. Additionally, some suggestion of instability was found during the LTCM collapse.

Table 5 shows the results for the SEA countries: Hong Kong, Indonesia, Malaysia, Philippines, Singapore, Korea, Taiwan, and Thailand. In this case, there is no single rejection of the hypothesis that the coefficients are stable. During the Mexican crisis, the mass below zero of the distribution is close to 30 percent for all three events. During the Asian crises, the closest case to a rejection is Thailand’s crisis, though the mass below zero is 17.5 percent. Similarly, the events surrounding the Russian crisis imply very few rejections. Again, the closest rejection is during the Brazilian speculative attack, where the mass above zero is 12.5 percent. In summary, for the Asian countries, the stability of the parameters was not rejected.
Table 6 reports the results for the OECD group: Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK and USA. Note that in this case, the covariance matrix cannot be computed for the devaluation period during the Mexican crisis: there are more countries than days. For the OECD group of countries, all the possible tests indicate no rejection. It is important to highlight, though, the large size of this group may account for this result, in so far as it may have dimished the power of the test. A sensitivity analysis was run, in which only the big G7 countries were included in the estimation. The results were the same as those reported here. The distribution is almost centered around zero. Therefore, it is possible to conjecture that the lack of rejection in Table 6 is not a consequence of the large number of countries in the OECD group.

Table 7 shows the other three countries in the sample: India, Russia, and South Africa. During the Mexican crisis, the mass below zero is close to 90 percent. For Thailand’s crisis, there is a rejection on the stability of the coefficients. Notice that the rejection occurs for Thailand’s crisis alone, and for the other sample in which Thailand is included. Finally, during the Russian devaluation a rejection is close to being found, but not strong enough. The mass below zero is above 90 percent.

How should these results be interpreted? One could assume that they are “true” rejections of the parameter stability. In that case, the results point to a shift in the transmission mechanism during Thailand’s crisis - which is the only case where there are at least two groups with a rejection. Alternatively, one could assume the rejections are random. Only two rejections were found out of all the independent tests (8 for each group of countries), which is less than 7 percent of the independent samples, and is smaller than the size of the test. I leave the interpretation of these results to the reader. However, it should be pointed out that Thailand’s devaluation consistently rejected the hypothesis of stability in several of the sensitivity tests performed below - i.e. debilitating the claim in favor of random rejections.

Nevertheless, even if the rejection during Thailand’s devaluation is accepted, it is still the case that the proportion of rejections in the data is small. This is different in other data sets. For example, in data on sovereign debt, the DCC is always strongly rejected during the no-rollover announcement of the Mexican
crisis and the LTCM crisis after Russia.\textsuperscript{15} For the stock market cases, however, the rejections are quite limited and weak.

These results contrast with the “correlation adjustment” literature where almost no rejections are found. It is important to mention, however, that the adjustment of the correlation will excessively adjust the coefficients when common shocks are present. This point is raised in the appendix of Forbes and Rigobon [2002] and the results here suggest that adjustment of the correlation should not be used.

Finally, some words about the power of the test are in order. The DCC is an overidentification test so there is a continuum of alternative hypotheses. The fact that some rejections were found indicates that within this sample, the test has some power. However, the original paper developing the test studies the power of the test only in the bivariate case. Studying the power of the test in a multivariate setting is extremely cumbersome, so instead the next section reports the results of several sensitivity analyses.

### 3.4 Robustness

The results were examined under several other specifications. The tables are not presented for brevity, but summaries of them are.\textsuperscript{16} First, the introduction of interest rates in the first step does not qualitatively change the results. It is always the case that for Latin America and Other countries the stability of parameters is rejected during Thailand’s devaluation, and the OECD and Asian countries are without rejections.

Second, when the regression is run in domestic currency, the only rejections found are: during the Thailand’s devaluation and whenever one of the countries in the sub-sample experiences a change in nominal exchange rate regime. For example, in Latin America during the Mexican crisis there is a rejection. However, this second type of rejection should be expected. Finding no change in the propagation of shocks in Dollars, but finding one in domestic currency simply captures the change in the nominal regime, but not a change in the fundamental relationship across countries. The same results were found within SEA during the Korean crisis.

Third, returns were constructed as one-day, two-day and weekly returns, and lags were changed from no lags to more than 20 lags. When weekly returns were used, not a single rejection was found. For the other cases, the results were qualitatively the same.
Fourth, changes in the tranquil window for the Asian crises had no impact on the results. I tried several windows: one year before; one and a half years before; the six months starting in 1996; and all of 1996.

Fifth, and probably the most important, changes in the definition of the high-volatility windows by more or less a week did not affect the results. However, if there are major changes in the windows some rejections are found. This should be expected given that sizeable changes in those windows are likely to fail the assumption required on the test to work.

Finally, the country groups were changed and the test reevaluated. However, in these groups I was always careful to put all the countries causing the turmoil to be either within the group or all excluded. Otherwise, the test could be rejected because the heteroskedasticity assumption might be violated.

The results from this section suggest that Thailand's devaluation implied a change in the transmission mechanism across the Latin American group and the Other group in the sample.

4 Conclusions and Extensions

Stock markets throughout the world, and especially those in emerging markets, seem to be excessively correlated. The contagion literature tries to explain such a high degree of co-movement. In its search, two main questions have been raised: Is the transmission of shocks intensified during crises, and what is explanation behind the propagation mechanism? This paper has concentrated on the first question.

The properties of the data make the standard techniques to test for parameter stability inappropriate. Chow tests, principal component tests of stability, as well as the new "breed" of correlation adjustment tests of contagion, are biased and inconsistent. The objective of the paper is to fill this gap and reassess the conclusions drawn based on other methodologies.

The paper uses a new procedure to test for changes in coefficients that is able to deal with simultaneous equations, omitted variables, and heteroskedasticity problems. Tests using this procedure find that the transmission mechanism during the recent financial crises is relatively stable during the Mexican crisis. The sample studied has 36 countries; 7 from Latin America, 8 from South East Asia, 18 among the developed nations, and 3 from the rest of the world. The parameter stability hypothesis was not rejected for that crisis. However, during the Russian collapse (in particular, the LTCM crisis) it was possible to reject the hypothesis that the transmission of shocks across countries was the same. Even stronger rejections were
found during the Asian crises. In fact, it can be claimed that for Latin America, India, South Africa, and Russia the propagation of shocks shifted significantly during Thailand’s devaluation. These results are robust to changes in the specification.

This paper has looked at the behavior of prices around the crises. Research on portfolio flows indicates that capital flows tend to have excess co-movement across countries in the same region as well (see Froot, et al. [1998] and Stulz [1999]). It is possible that while prices do not behave significantly different during crisis (as found here) capital flows do. Indeed, most of the new theories on contagion go in this direction.17

This issue suggests a rich field for further theoretical and empirical work in which tests, such as that used here, could be useful.
References


Rigobon, R. (1998). Informational speculative attacks: Good news is no news. mimeo, MIT.


Notes

1See Goldstein, Kaminsky, and Reinhart [2000] for a theoretical survey on the issue.

2In fact, most of the new literature on contagion is based on common unobservable shocks, such as margin calls in financial markets (Calvo [1999]), wealth shocks (Panageas and Rigobon [2002]), and common lenders (Kaminsky and Reinhart [2000]).

3See Rigobon [2000] for a detailed characterization of the test. This test is based on the new literature on identification through heteroskedasticity. See Rigobon [2002] and Sentana and Fiorentini [2001].

4See Calvo and Reinhart [1995], and Kaminsky and Reinhart [2000].


7See Connolly and Wang [2000], and Eichengreen, Rose and Wyplosz [1996].

8In this framework is easy to show why standard tests can be rejected in the presence of heteroskedasticity but cannot be in their absence. If the data are homoskedastic then a change in the covariance matrix of the observed variables ($\Omega_t$) can be explained only if $A$ or $\Gamma$ have changed. If the data are heteroskedastic, then changes in $\Omega_t$ are uninformative about parameter stability. It is possible that the coefficients are stable and because the underlying shocks have heteroskedasticity, then the reduced form covariance matrixes change. The existence of simultaneous equations and omitted variables implies that the estimates are biased. Those biases, unfortunately, are function of the underlying variances. If the data is heteroskedastic, then changes in the variances imply that the biases, by themself, are shifting as well.

9To estimate the covariance matrix using all 36 countries requires more than 600 observations - which accounts for almost three years of data.

10See Baig and Goldfajn [2000] and Glick and Rose [1998].
The idea is to analyze the stability of the parameters using these smaller groups. However, given the flexibility of the model studied here, it does not matter if a country is or is not included in the group in order to test for the stability of its relationship. In this model, if a country is excluded, then its shock is interpreted as a common unobservable shock. The resultant smaller model is a transformation of the original system, where the parameters share the same properties: a rejection in the smaller model occurs only if a rejection in the larger one is also found (see Appendix A).

In other words, two South East Asian countries under crises can be modeled as changes in the volatility of a sub-set of the idiosyncratic shocks when the countries are included in the regression, or as a change in the subset of the common shocks if both are excluded. Hence, this satisfies the assumptions under the null hypothesis. A violation of the heteroskedasticity assumption would occur if one country is included in the regression and the other one is not.

For brevity, the results from the VAR are not reported.

Again, if the mass is too small or too large it means that the determinant is different from zero. The last column reports when the mass below zero is larger than 0.95 or smaller than 0.05. In other words, when the null hypothesis is rejected at 10 percent confidence. Remember that the test is rejected if the determinant is different from zero. Thus, by looking at the mass below zero is enough to make that assessment.

See Rigobon [2001].

The data and the programs are in my web page.

For example, see Calvo [1999], Chari & Kehoe [1999], Rigobon [1998], among others.
A DCC: Exclusion of variables, an example.

The objective of this example is to show that the stability of the coefficients can be tested even if one of the endogenous variables is excluded from the model.

Assume there are three countries that satisfy the following model:

\[
A \cdot \begin{pmatrix} X_{1t} \\ X_{2t} \\ X_{3t} \end{pmatrix} = \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{pmatrix} + \begin{pmatrix} 1 \\ \gamma_2 \\ \gamma_3 \end{pmatrix} z_t,
\]

where two simplifications have been imposed: there are no lags, and there is only one common shock. The goal, though, is to highlight that the exclusion of \(X_{3t}\) from the setup still tests for the stability of all the coefficients in the larger model.

Assume that from \(t\) to \(t+1\) the DCC is satisfied by the original model. Assume that the only heteroskedastic shock is \(\varepsilon_{1t}\) then if all the coefficients in \(A\) and \(\Gamma\) are stable the determinant is zero.

Excluding \(X_{3t}\) from the original model is equivalent to solving for it in the third equation and substituting back in the first two. After a re-normalization of the variances, the smaller model collapses to

\[
A^* \begin{pmatrix} X_{1t} \\ X_{2t} \end{pmatrix} = \begin{pmatrix} \varepsilon_{1t}^* \\ \varepsilon_{2t}^* \end{pmatrix} + \Gamma^* \begin{pmatrix} \varepsilon_{3t}^* \\ z_t^* \end{pmatrix}
\]

where \(\varepsilon_{1t}^*, \varepsilon_{2t}^*, \varepsilon_{3t}^*,\) and \(z_t^*\) are all orthogonal (as the original shocks) and the only one that continues to be heteroskedastic is \(\varepsilon_{1t}^*\). Additionally, \(A^*\) and \(\Gamma^*\) are functions of the original coefficients of \(A\) and \(\Gamma\). Hence, they are stable, too.

Note that the smaller model has the exact same setup as the models studied in the main body of the paper. If there is one heteroskedastic shock and the parameters are stable, the DCC is satisfied in the smaller model, too. Moreover, if the heteroskedastic shock is \(\varepsilon_{3t}\), then in the final reduced model \(\varepsilon_{3t}^*\) would be the only heteroskedastic. Therefore, even though the heteroskedastic shocks moved from being idiosyncratic to become a common shock, still the DCC is satisfied.

The only case in which the DCC is not satisfied in the smaller model is when the elimination of one of the endogenous variables splits the heteroskedasticity from shocks that all idiosyncratic to some idiosyncratic and some common. In this case the DCC is rejected in the smaller model and not in the original one.

In summary, the model I used in this paper is flexible (and general) enough that the properties of the lack of rejection are unaffected by inclusions or exclusions of endogenous variables, as well as their lags. If an endogenous variable is excluded it is interpreted in the new setup as a common shock. This flexibility is crucial for testing contagion given the near impossibility of including all the relevant variables in the regression.
B Test on the reduced form residuals

This appendix illustrates why testing on the reduced form residuals is enough to test for all structural parameters. Assume there is a shift in the lagged structural coefficients as follows:

\[
AX_t = \phi_1(L)X_t + \Gamma z_t + \varepsilon_t \quad \text{for } t < T
\]
\[
AX_t = \phi_2(L)X_t + \Gamma z_t + \varepsilon_t \quad \text{for } t > T,
\]

which imply the reduced forms

\[
X_t = A^{-1}\phi_1(L)X_t + A^{-1}\Gamma z_t + A^{-1}\varepsilon_t \quad \text{for } t < T
\]
\[
X_t = A^{-1}\phi_2(L)X_t + A^{-1}\Gamma z_t + A^{-1}\varepsilon_t \quad \text{for } t > T.
\]

In the VAR, I require the lag coefficients to be the same in both samples, so the actual estimate is a weighted average of \(A^{-1}\phi_1\) and \(A^{-1}\phi_2\). Denote this estimate by \(\hat{\Phi}\). The residuals from the reduced form in each subsample is:

\[
\nu_t = \begin{cases} 
A^{-1}\phi_1(L)X_t & \text{for } t < T \\
A^{-1}\phi_2(L)X_t & \text{for } t > T
\end{cases}
\]

As can be seen, the residuals of the reduced form are a function of \(\phi_1\) and \(\phi_2\). The covariance matrixes of the reduced form residuals are

\[
\Omega_1 = \Psi_1X_tX_t'\Psi_1' + A^{-1}\Omega_1^2X_t'X_tA^{-1} + A^{-1}\Omega_2^2A^{-1}
\]
\[
\Omega_2 = \Psi_2X_tX_t'\Psi_2' + A^{-1}\Omega_1^2X_t'X_tA^{-1} + A^{-1}\Omega_2^2A^{-1}
\]
\[
\Psi_1 \triangleq A^{-1}\phi_1(L) - \hat{\Phi}(L)
\]
\[
\Psi_2 \triangleq A^{-1}\phi_2(L) - \hat{\Phi}(L)
\]

Note that if heteroskedasticity is explained by the shift in \(\phi\) then the change in the covariance matrix is

\[
\Delta\Omega = \Psi_2X_tX_t'\Psi_2' - \Psi_1X_tX_t'\Psi_1'
\]

which, in general, has a determinant different from zero.
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<td>85.1%</td>
<td>75.5%</td>
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<tr>
<td>US</td>
<td>90.1%</td>
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</table>

Table 1: Simple correlations.
Table 2: Windows for the DCC Test.

<table>
<thead>
<tr>
<th></th>
<th>Tranquil Window</th>
<th>High Volatility Window</th>
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<tbody>
<tr>
<td></td>
<td>Starts</td>
<td>Ends</td>
</tr>
<tr>
<td>Mexican Crisis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian Crises</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russian Crisis</td>
<td></td>
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Table 3: Average changes in variance per regime and group.

<table>
<thead>
<tr>
<th></th>
<th>Variance Changes of</th>
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<tbody>
<tr>
<td></td>
<td>OECD</td>
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<tr>
<td>Mexican Crisis</td>
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</tr>
<tr>
<td>(1) December Devolution</td>
<td>0.97</td>
</tr>
<tr>
<td>(2) No Rollover</td>
<td>1.59</td>
</tr>
<tr>
<td>(3) After Rollover</td>
<td>1.61</td>
</tr>
<tr>
<td>Asian Crises</td>
<td></td>
</tr>
<tr>
<td>(1) Hong Kong</td>
<td>6.21</td>
</tr>
<tr>
<td>(2) Korea</td>
<td>3.11</td>
</tr>
<tr>
<td>(1)+(2)</td>
<td>4.21</td>
</tr>
<tr>
<td>(3) Thailand</td>
<td>1.40</td>
</tr>
<tr>
<td>(1)+(2)+(3)</td>
<td>2.84</td>
</tr>
<tr>
<td>Russian Crisis</td>
<td></td>
</tr>
<tr>
<td>(1) Russian devaluation</td>
<td>5.30</td>
</tr>
<tr>
<td>(2) LTCM</td>
<td>6.07</td>
</tr>
<tr>
<td>(1)+(2)</td>
<td>5.75</td>
</tr>
<tr>
<td>(3) Brazil's Speculative Attack</td>
<td>2.36</td>
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</table>

Table 4: DCC results for Latin American countries.
<table>
<thead>
<tr>
<th></th>
<th>Value of Determinant</th>
<th>Standard Deviation</th>
<th>z stat.</th>
<th>Below Zero</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mexican Crisis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) December Devaluation</td>
<td>-14.91</td>
<td>147.04</td>
<td>-0.10</td>
<td>0.287</td>
<td>0</td>
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<td>(2) No Rollover</td>
<td>9.52</td>
<td>36.53</td>
<td>0.26</td>
<td>0.316</td>
<td>0</td>
</tr>
<tr>
<td>(3) After Rollover</td>
<td>-1.37</td>
<td>48.24</td>
<td>-0.03</td>
<td>0.215</td>
<td>0</td>
</tr>
<tr>
<td><strong>Asian Crises</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Hong Kong</td>
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<td>229229.12</td>
<td>0.95</td>
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<td>1625.63</td>
<td>-0.07</td>
<td>0.734</td>
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</tr>
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<td>11530.72</td>
<td>-0.11</td>
<td>0.736</td>
<td>0</td>
</tr>
<tr>
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<td>-1.08</td>
<td>2.47</td>
<td>-0.44</td>
<td>0.175</td>
<td>0</td>
</tr>
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<td>521.81</td>
<td>-0.21</td>
<td>0.363</td>
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<tr>
<td><strong>Russian Crisis</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>-0.06</td>
<td>0.784</td>
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<td>688701.14</td>
<td>-1.03</td>
<td>0.745</td>
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<td>158562.03</td>
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Table 5: DCC results for South East Asian countries.

<table>
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<th>Value of Determinant</th>
<th>Standard Deviation</th>
<th>z stat.</th>
<th>Below Zero</th>
<th>Significance</th>
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<tbody>
<tr>
<td><strong>Mexican Crisis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) December Devaluation</td>
<td>6.26</td>
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<td>0.54</td>
<td>0.861</td>
<td>0</td>
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<tr>
<td>(2) No Rollover</td>
<td>6.76</td>
<td>44.08</td>
<td>0.15</td>
<td>0.788</td>
<td>0</td>
</tr>
<tr>
<td>(3) After Rollover</td>
<td>6.75</td>
<td>27.78</td>
<td>0.24</td>
<td>0.448</td>
<td>0</td>
</tr>
<tr>
<td><strong>Asian Crises</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Hong Kong</td>
<td>136.83</td>
<td>137.61</td>
<td>0.99</td>
<td>0.885</td>
<td>0</td>
</tr>
<tr>
<td>(2) Korea</td>
<td>6.03</td>
<td>18.79</td>
<td>0.32</td>
<td>0.477</td>
<td>0</td>
</tr>
<tr>
<td>(1)+(2)</td>
<td>11.61</td>
<td>25.19</td>
<td>0.44</td>
<td>0.842</td>
<td>0</td>
</tr>
<tr>
<td>(3) Thailand</td>
<td>-5.29</td>
<td>4.92</td>
<td>-1.07</td>
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<td>1</td>
</tr>
<tr>
<td>(1)+(2)+(3)</td>
<td>4.06</td>
<td>3.11</td>
<td>1.30</td>
<td>0.983</td>
<td>1</td>
</tr>
<tr>
<td><strong>Russian Crisis</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Russian devaluation</td>
<td>601.07</td>
<td>757.91</td>
<td>0.79</td>
<td>0.695</td>
<td>0</td>
</tr>
<tr>
<td>(2) LTCM</td>
<td>6827.60</td>
<td>3413.16</td>
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<td>1</td>
</tr>
<tr>
<td>(1)+(2)</td>
<td>1592.24</td>
<td>976.68</td>
<td>1.63</td>
<td>0.573</td>
<td>0</td>
</tr>
<tr>
<td>(3) Brazil’s Speculative Attack</td>
<td>-132.55</td>
<td>254.22</td>
<td>-0.52</td>
<td>0.658</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6: DCC results for OECD countries.

<table>
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<th>Value of Determinant</th>
<th>Standard Deviation</th>
<th>z stat.</th>
<th>Below Zero</th>
<th>Significance</th>
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<tbody>
<tr>
<td><strong>Mexican Crisis</strong></td>
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<td></td>
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<td>0.842</td>
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<tr>
<td>(1)+(2)+(3)</td>
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<td>3.11</td>
<td>1.30</td>
<td>0.983</td>
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</tr>
<tr>
<td><strong>Russian Crisis</strong></td>
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<tr>
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<tr>
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<td>1</td>
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<td>1.63</td>
<td>0.573</td>
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<tr>
<td>(3) Brazil’s Speculative Attack</td>
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<td>254.22</td>
<td>-0.52</td>
<td>0.658</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 7: DCC results for other countries.