

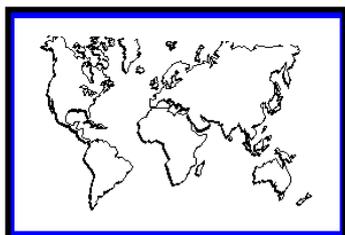
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## **Some critics to the contagion correlation test**

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# SOME CRITICS TO THE CONTAGION CORRELATION TEST

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JEL: International economics, contagion correlation test

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## **1.Introduction.**

The term contagion<sup>2</sup> is generally used to refer to the spread<sup>3</sup> of market shocks from one country to another. However, identifying what is meant by contagion and its consequences has become in recent years a literature in itself<sup>4</sup>, given the importance of such consequences on economies all over the world.

Despite the lack of theoretical consensus, some authors try to measure contagion through the use of correlation tests. The aim of my work is to raise a technical and conceptual critique concerning these models. To support my concerns I provide a broad vision and background of contagion literature and an insight in the particular field of contagion correlation test.

The work is organized in four parts. Firstly, an overview of definitional issues concerning contagion, as presented in the literature, is explained together with the different crisis transmission channels that authors have identified. Secondly, a detailed description of the contagion correlation test –as the most common means to search for contagion—is presented, giving a full overview of the models used in the literature. Thirdly, I will express my concerns about the test and the models of the previous section. Finally, some conclusions are stated.

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<sup>2</sup> Contagion is an epidemiology term, which defines a mathematical theory that helps to predict the course of an infection of a illness.

<sup>3</sup> Notion that financial trouble is capable of spreading like a contagious disease.

<sup>4</sup> A more in depth discussion of alternate definition is stated at the web site:<http://www.worldbank.org/economicpolicy/>

## **2.Contagion and Categories of crisis propagation.**

Episodes of volatility in international capital markets have occurred many times in recent history<sup>5</sup> but the issue of financial contagion did not summon the attention of policymakers and economists until the East Asian crisis.

The most popular<sup>6</sup> definition of contagion identifies it as a significant increase in cross-market linkages after a shock to one country (or group of countries) –as measured by the degree to which asset prices or financial flows move together across markets— relative to these comovements in tranquil times. The size of these comovements have led many economists to raise the question of whether ‘tranquil periods’ and ‘crises’ are different regimes in the international transmission of financial shocks<sup>7</sup>.

The possibility of such discontinuities is a concern for both investors –because diversification of international portfolios may fail to deliver just when its benefits are most needed— and policymakers<sup>8</sup> --because excessive financial comovements may spread a country-specific shock to other economies, even when these have better fundamentals, triggering recession and devastating countries around the world.

Crisi transmission can be conceptually divided into two categories <sup>9</sup>.

The first category, “Fundamentals-based contagion”<sup>10</sup>, involves spillovers that result from the normal interdependence among market economies due to real and

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<sup>5</sup> 1989 Japon,1992-3 Central Europe, 1994 Mexico, 1997 Asia,1998 Russia and 1999Brazil.

<sup>6</sup> Calvo(1999), Calvo and Mendoza (2000), Caramazza et al. (2000), Claessens et al. (2001),Corsetti et al. (2000a), Edwards (1998), Eichengreen et al. (1996), IMF (1998 and 1999), Jeanne and Masson (1998), Kaminsky and Reinhart (2000), Kaminsky and Schmukler (1999), Kodres and Pritsker (2002), and Schinasi and Smith (2001).

<sup>7</sup> Cosetti and Sbracia(2002)

<sup>8</sup> “Japan, Europe and the United States agree on this: we are on the eve of a new financial architecture” (Gerhard Schröder speech, Bloomberg News, January 20, 1999) “..it is now time for the world to take the next steps of implementing a new financial architecture and long-term reform of the global financial system. This should include steps to reduce the entire financial system’s vulnerability to rapid capital flows...” (Bill Clinton speech,Market News International, April 20, 1999).

<sup>9</sup> Masson1998;Wolf1999;Forbes and Rigobon2000;Pritsker 2000 and Karolyi 2002.

<sup>10</sup> Calvo and Rinhart(1996)

financial linkages. These forms of comovements would not normally be defined as contagion.

The fundamental causes that drive these comovements are of two main types.

-Macro or Common factors, such as major economic shifts in industrial countries or a shock to commodity prices, can trigger crises in or large capital flows into or out of markets.

-Micro or Local shocks that can be transmitted by several channels:

1. Trade Links. Any major trading partner of a country in which a financial crisis has led to a currency depreciation could experience declining asset prices and large capital outflows, or become the target of a speculative attack.
2. Competitive devaluation. Devaluation in a country hit by a crisis reduces the export competitiveness of the countries with which it competes in third markets. A game of competitive devaluation can be triggered, leading to a greater currency depreciation than that required by any initial deterioration in fundamentals<sup>11</sup>.
3. Financial link. The spread of a crisis depends on the degree of financial market integration<sup>12</sup>. A financial crisis in one country can lead to direct financial effects (reductions in trade credits, foreign direct investment, and other capital flows abroad) in other countries.

The second category of contagion, “irrational contagion”, emphasizes the comovements unaccounted for by global or micro shocks (interdependence) as detailed above. It is assumed to be solely the result of the behaviour of investors or

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<sup>11</sup> Corsetti and others (1999),

<sup>12</sup> The higher the degree of integration, the more extensive could be the contagious effects to another country and vice versa. Countries that are not financially integrated, because of capital controls or lack of access to international financing, are immune to contagion. In this sense, financial markets facilitate the transmission of shocks but do not cause them.

other financial agents and is associated with financial panics, herd behaviour, loss of confidence, and increased risk aversion.

The literature differs on the scope of rational versus irrational investor behaviour, both individually and collectively<sup>13</sup>. To clarify this, a classification of types of investor behaviour and their consequences is useful:

- “Investors practices”: Investors behaving rationally can take actions that are ex ante individually rational but that lead to excessive comovements. These also can be sorted by the problems they address:

1. Liquidity problems: Market crash in one country can induce investors to sell off securities in other markets to raise cash (in anticipation of a higher frequency of redemptions). If banks experience a marked deterioration in the quality of their loans to one country, they may attempt to reduce the overall risk of their loan portfolios by reducing their exposure to other high-risk investments elsewhere.
2. Incentive problems: An initial crisis may induce investors to sell off their holdings in other countries because of their tendency to maintain certain proportions of a country’s or a region’s stock in their portfolios. As a result, asset markets in a range of economies may lose value, and the currencies of these economies may depreciate significantly. The value-at-risk models explain why banks and investors may find it optimal to sell most high-risk assets when a shock affects one of such assets<sup>14</sup>.
3. Information asymmetries and coordination problems. If a crisis reveals weak fundamentals, investors may rationally conclude that similarly situated countries are also likely to face such problems, and then they will attack

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<sup>13</sup> Pritsker 2000

<sup>14</sup> Schinasi and Smith (2000),

their currencies. This is based on the assumption that investors often do not know the conditions of every single country due to the high cost of country-specific information. As financial investors can be divided into “Informed” investors and “Uninformed” investors, and as the latter follow the investment patterns of the former, the existence of these information asymmetries can lead to herd behaviour<sup>15</sup>. The tendency to herd together can increase with, firstly, the number of countries in which investments can be placed and, secondly, the range of investors

4. Changes in the international financial system, or in the rules of the game, which can induce investors to alter their behaviour after an initial crisis. A common example is that a default in the debt of one country increases fears that other countries might follow similar unilateral policies regarding foreign private creditors.

- Multiple equilibria contagion, as a consequence of sudden shifts in market expectations and investors confidence. An intuitive example arises when a crisis in one market causes another market economy to move to a adverse equilibrium<sup>16</sup>. The result would be a sudden withdrawal of funds from this second country by investors concerned that delayed action may forfeit their claim to a stake in the limited pool of foreign exchange reserves.

Empirical literature on the evidence of contagion has been abundant in the last 8 years. Additionally, potential reforms of the international financial architecture, intended to avoid this contagion, are being discussed, as yet without settlement. The multiple approaches to the topic, the great variety of tests applied, as well as

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<sup>15</sup> Calvo and Mendoza (forthcoming)

<sup>16</sup> devaluation, asset prices decrease, capital outflows, or debt default

the different outcomes for the same periods depending on the methodology used, have made a summary close to impossible<sup>17</sup>.

I will provide a detailed explanation of the “Correlation of asset prices or exchange rates test” in the next section, since it is the most important and common approach to the topic.

### **3. Contagion and correlation**

The observed increase in comovements of asset prices across markets and borders during periods of financial turmoil have historically led analysts to raise the hypothesis of ‘contagion’ in the international transmission of currency and financial shocks.

Empirical literature shows that periods of crisis coincide with a high covariance of returns across national markets and a high volatility of asset prices<sup>18</sup>. Moreover, many of these studies conclude that the correlation between market returns is higher<sup>19</sup> during periods of turmoil.

Nevertheless, interpreting any increase in cross-country covariances or correlations purely as evidence of contagion may be an error<sup>20</sup>.

One of the most recurrent approaches to this issue is to define contagion in opposition to interdependence.

Contagion then occurs “if cross-market comovements increase significantly after a shock”<sup>21</sup>. Whenever this increase is not significant, the phenomenon is seen as interdependence. This narrow definition has two important advantages. Firstly,

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<sup>17</sup> The book *International Financial Contagion* edited by Claessens and Forves, Kluwer Academic Publishers (ISBN:0792372859) based on the World Bank conference of contagion of 1999 states all the empirical works on contagion and the different approach.

<sup>18</sup> For excellent empirical reviews refer to Pericoli and Sbracia (2001) and Claessens et al. (2001).

<sup>19</sup> Cosetti et al. (2000b and 2001) show that in some episodes the correlation falls in the beginning of a crisis, thus, raises the issue of assessing the importance of country-specific factors relative to common factors as the main cause of market volatility during periods of turmoil.

<sup>20</sup> See Boyer et al. (1999) and Forbes-Rigobon (1999 and 2002).

it provides a straightforward framework for testing if contagion occurs, based purely on empirical grounds. Secondly, it avoids the need to measure directly and distinguish between the various propagation mechanisms discussed in the literature.

### Models overview

#### ***First models of contagion and correlation.***

The standard test of contagion across stock markets measures the correlation coefficient of asset returns in tranquil times, and then compares it to the estimation of the same coefficient in the turmoil period. The hypothesis of contagion is accepted when the correlation coefficient increases significantly during the crisis. If, on the other hand, the increase cannot be taken as significant, the contagion hypothesis is rejected in favour of interdependence. The first major empirical papers<sup>22</sup> using this approach found that there was a statistically significant increase in cross-market correlation coefficients during the relevant crises and therefore concluded that contagion occurred in the tested periods.

The initial assumptions of this model are that the rates of return of the stock markets in two countries are linearly related:

$$y_t = \alpha + \beta x_t + \varepsilon_t,$$

$y_t$  is the stock market return of the country under study,  $x_t$  is the stock market return of the country related and  $\varepsilon_t$  is a independent stochastic noise ( $E(\varepsilon_t) = 0$  ,  $E(x_t \varepsilon_t) = 0$  ) while  $\alpha$  and  $\beta$  are constants.

The tool generally used to measure contagion was the correlation coefficient:

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<sup>21</sup> Forbes and Rigobon(2002)

<sup>22</sup> King and Wadhvani(1990) test for stock market correlation between U.S., U.K. and Japan , Lee and Kim(1993) test for stock market correlation in the 12 major markets, Calvo and Reinhart(1996)test for stock prices and Brady bonds in 1994 Mexican crisis.

$$\text{Corr}(y_t, x_t) = \rho = \frac{\text{Cov}(y_t, x_t)}{\sqrt{\text{Var}(y_t)}\sqrt{\text{Var}(x_t)}} = \sqrt{\frac{1}{1 + \frac{\text{Var}(\varepsilon_t)}{\beta^2 \text{Var}(x_t)}}$$

If  $\rho$  increases significantly in crisis periods (due to an increase of  $\text{Var}(x_t)$  or an increase of  $\beta$ , or both) they state that there is evidence of contagion.

The empirical results for the studies using these models show that contagion occurred to several countries during the 1997 Asian crisis, the 1994 Mexican devaluation, and the 1987 U.S. market crash.

I have run a standard test for the East Asian 1997 crisis and found contagion between the returns of four currencies<sup>23</sup>.

***Rigobon and Forbes(2002) 'No contagion, just interdependence' model***

A new wave of studies<sup>24</sup> focused on proving that the previous tests were biased upwards. Cross-market correlation coefficients are by definition conditional on market volatility; during crises, estimated correlation coefficients tend to increase. A significant increase in the correlation expression shown above (assuming  $\beta$ , the measure of the 'strength' of the link between the two markets, does not change), could be provoked just by an increase of  $\text{Var}(x_t)$ , that is consistent with a stable international transmission of financial shocks. They do not necessarily reflect discontinuities in the transmission mechanisms, and therefore this significant increase of  $\rho$  could be just interdependence. Thus, the early test and its definition of contagion failed, from the point of view of this new approach, to identify whether there has been contagion or not. They also showed that, under certain assumptions, it is possible to specify the magnitude of this bias and correct for it.

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<sup>23</sup> Appendix 1 shows my findings with two correlation matrix between the returns of the currencies.

<sup>24</sup> Ronn(1998), Boyer, Bibson and Loretan(1999) Loretan and English(2000) and Rigobon and Forbes(2001).

After adjusting for the magnitude of the bias, these tests based on the unconditional correlation rejected the hypothesis of contagion.

Their proof of that argument is simplified below:

Given the model  $y_t = \alpha + \beta x_t + \varepsilon_t$  and  $E(\varepsilon_t) = 0$   $E(\varepsilon_t^2) < \infty$   $E(x_t \varepsilon_t) = 0$   $|\beta| < 1$

The sample is divided into two subsamples, 1 (tranquil period) and h (turbulence period), with different variances  $\sigma_{xx}^h > \sigma_{xx}^1$ .

By  $E(x_t \varepsilon_t) = 0$  assumption  $\beta_{OLS}$  is a consistent and efficient estimator of  $\beta$  and

therefore as  $\beta^h = \beta^1 \Rightarrow \beta^h = \frac{\sigma_{xy}^h}{\sigma_{xx}^h} = \frac{\sigma_{xy}^1}{\sigma_{xx}^1} = \beta^1$ , which implies that  $\sigma_{xy}^h > \sigma_{xy}^1$

The covariance of the turmoil period (h) is higher than the one corresponding to a tranquil period.

Through the assumptions that  $E(\varepsilon_t^2) < \infty$  and constant, and  $|\beta| < 1$  they find

$$\frac{\sigma_{xx}^h}{\sigma_{yy}^h} > \frac{\sigma_{xx}^1}{\sigma_{yy}^1}$$

And as  $\rho = \frac{\sigma_{xy}}{\sigma_x \sigma_y} = \beta \frac{\sigma_x}{\sigma_y} \Rightarrow \rho^h > \rho^1$  that confirm their hypothesis of biased tests.

The corrected model by Forbes and Rigobon(2001) posit once again a linear relationship between rates of returns in country x and y:  $y_t = \alpha + \beta x_t + \varepsilon_t$

Assuming no endogeneity or omitted variables<sup>25</sup> ( $Corr(x_t, \varepsilon_t) = 0$  and  $Var(\varepsilon_t) = c$ ), they quantify the extent of the bias<sup>26</sup> and calculate the conditional correlation coefficient as

$$\rho^* = \rho \sqrt{\frac{1 + \delta}{1 + \delta \rho^2}}$$

<sup>25</sup> In Appendix B of Forbes and Rigobon(2002)analyse the impact of relaxing this restrictive assumptions.

<sup>26</sup> See Appendix A in Forbes and Rigobon(2002)

$\delta$  is the relative increase in the variance of  $x$  (a measure of market volatility) and can be expressed as:

$$\delta \equiv \frac{\sigma_{xx}^h}{\sigma_{xx}^l} - 1$$

As  $\rho^*$  is increasing in  $\delta$  and markets tend to be more volatile after a crisis (which increases  $\delta$ ),  $\rho^*$  will increase after a shock even if  $\rho$  (the unconditional correlation coefficient) is the same as during more stable periods.

Without adjusting for the bias, in this test it is impossible to deduce if an increase on  $\rho^*$  is provoked by an increase on  $\rho$  or by an increase on  $\delta$ ; by the authors' definition, only an increase on  $\rho$  constitutes contagion.

The adjustment of the bias is expressed by: 
$$\rho = \frac{\rho^*}{\sqrt{1 + \delta[1 - (\rho^*)^2]}}$$

They state that this adjustment is only valid if their initial assumption<sup>27</sup> holds, and admit that these suppositions are clearly a simplification.

Their results were that, using the adjustment derived above, there was virtually no contagion during the 1997 Asian crisis, the 1994 Mexican devaluation, and the 1987 U.S. market crash.

### ***Corsetti et al (2002) 'Some Contagion, Some Interdependence' model***

Corsetti,G, Pericoli,M and Sbracia,M (2002) followed the Rigobon et al(1999) approach, but attempted to be more general.

They state a new and more accurate definition of contagion: “a structural break in the international transmission of financial shocks so that the observed pattern of comovements in asset prices is too strong relative to what can be predicted when the mechanism of international transmission is constant”.

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<sup>27</sup> No exogenous global shocks and no feedback from stock market  $y$  to  $x$  (Endogeneity and omitted variables)

They developed a test of contagion in financial markets, based on bivariate correlation analysis, that does not impose restrictions on the variance of common factors relative to the variance of country-specific risks. They applied it to the international stock market crisis of Hong Kong in 1997. Their empirical results are in contrast with the findings of the preceding literature<sup>29</sup> (according to which there is ‘no contagion, only interdependence’) as they found contagion in some of the cases. They argue that the result of the other authors is very extreme due to unnecessary restrictions on the variance of the market specific noise in the country where the crisis originates. This approach is a more general model in which some of the assumptions of Rigobon and Forbes model<sup>30</sup> are relaxed.

They choose a standard single-factor model as a data-generating process of stock market returns,  $r^{31}$ , in country i and country j,

$$\begin{aligned} r_i &= \alpha_i + \gamma_i f + \varepsilon_i \\ r_j &= \alpha_j + \gamma_j f + \varepsilon_j \end{aligned}$$

expressed in matrix form:  $\begin{bmatrix} r_i \\ r_j \end{bmatrix} = \begin{bmatrix} \alpha_i \\ \alpha_j \end{bmatrix} + \begin{bmatrix} \gamma_i \\ \gamma_j \end{bmatrix} f + \begin{bmatrix} 1 \\ 1 \end{bmatrix} \begin{bmatrix} \varepsilon_i \\ \varepsilon_j \end{bmatrix}$

where  $f$  is a common factor that represents the global effect. Calculating the correlation coefficient between  $r_i$  and  $r_j$  they get:

$$\rho = \frac{\text{Cov}(r_i, r_j)}{\sqrt{\text{Var}(r_i)} \sqrt{\text{Var}(r_j)}}$$

$$\text{Var}(r_i) = \gamma_i^2 \text{Var}(f) + \text{Var}(\varepsilon_i)$$

$$\text{Var}(r_j) = \gamma_j^2 \text{Var}(f) + \text{Var}(\varepsilon_j)$$

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<sup>29</sup> Rigobon and Forbes(2002)

<sup>30</sup> The test is interpreted by their authors as an extension of the theorem in Boyer et al.(1999) to the case of a more general structure of the  $\text{Cov}(r_i, r_j)$  and  $\text{Var}(r_i)$

<sup>31</sup> In the earliest models  $r$  is identified with  $y$  and  $x$ .

The main assumptions of this model are that  $f, \varepsilon_i$  and  $\varepsilon_j$  are mutually independent

( $E(f\varepsilon_i)=0$   $E(f\varepsilon_j)=0$   $E(\varepsilon_i\varepsilon_j)=0$ ) that implies:  $\text{Cov}(r_i, r_j) = \gamma_i\gamma_j\text{Var}(f)$

Substituting, 
$$\rho = \frac{\gamma_i\gamma_j\text{Var}(f)}{\sqrt{\gamma_i^2\text{Var}(f) + \text{Var}(\varepsilon_i)}\sqrt{\gamma_j^2\text{Var}(f) + \text{Var}(\varepsilon_j)}}$$

rearranging 
$$\rho = \text{Corr}(r_i, r_j) = \frac{1}{\left(1 + \frac{\text{Var}(\varepsilon_i)}{\gamma_i^2\text{Var}(f)}\right)^{1/2} \left(1 + \frac{\text{Var}(\varepsilon_j)}{\gamma_j^2\text{Var}(f)}\right)^{1/2}}$$

The explanation of an observed increase in the correlation coefficient in crisis periods will depend upon one's hypothesis.

If one takes  $\gamma_j$  and  $\gamma_i$  as given, then the variance of factor  $f$  must increase more, relative to the variance of the residuals.

If, on the other hand, one assumes that what is constant is the variance of the factor  $f$ , then the increment in the correlation coefficient must have been caused by an increase in the coefficients  $\gamma_j$  and  $\gamma_i$ .

From the authors' perspective, in this distinction lies the key for distinguishing between interdependence and contagion phenomena.

Accordingly, this constitutes the premise in which their empirical approach is based.

Consider a financial crisis in a given country  $j$ . The increase in the variance of the rate of return  $r_j$  (an increase in its volatility) may be caused by an increase on the variance of  $f$ , the variance of  $\varepsilon_j$ , or both.

$$\text{Var}(r_j) = \gamma_j^2\text{Var}(f) + \text{Var}(\varepsilon_j)$$

If the ratio  $\text{Var}(\varepsilon_j)/\text{Var}(f)$  decreases because the variance of  $f$  increases more than the variance of the noise term  $\varepsilon_j$ , this results in an increased correlation coefficient;

$$\frac{\text{Var}(r_j)}{\text{Var}(f)} = \gamma_j^2 + \frac{\text{Var}(\varepsilon_j)}{\text{Var}(f)}$$

This change in the correlation is interdependence, in the sense that it is the global factor  $f$  that provokes, by an increase in its variance, the increase in the correlation coefficient.

On the other assumption, contagion occurs when the increment in correlation is due to a change that is more powerful than the one that can be caused by the behavioural equations of the model.

Summarising, contagion takes place when some country-specific shock expands to a regional or even global level. It can be modelled by assuming that an  $\eta$  factor exists, equal to nil during quiet periods and positive during crises. It can be expressed through;

$$r_i = \alpha_i + \gamma_i f + \beta_i \eta + \varepsilon_i$$

(with  $\beta_j$  normalized to unit).

$$r_j = \alpha_j + \gamma_j f + (\eta + \varepsilon_j)$$

-In the interdependency case,  $\beta_i = 0$  where the data generating process is the same as before, with  $\varepsilon_j = \eta + \varepsilon_j$

-Contagion occurs when  $\beta_i \neq 0$ . From this hypothesis it turns out that the interdependence contrast is carried out by testing the hypothesis of  $\beta_i = 0$ .

By re-analysing conditional correlation coefficients we can make this operative in order to contrast interdependence or contagion.

Supposing that some critical event has been identified, let  $\delta$  be the change in the variance of the rate of return of stock market relative to the pre-crisis period.

$$\text{Var}(r_j / C) = (1 + \delta)\text{Var}(r_j) \quad \text{where } C \text{ means "crisis in country } j\text{"}$$

To test whether the changes in the correlation coefficient between  $r_i$  and  $r_j$  are consistent with the data generating process, we need to specify an interdependency measure, under the hypothesis that  $\gamma_i, \gamma_j, \text{Var}(\varepsilon_i)$ , y  $\text{Cov}(\varepsilon_i, \varepsilon_j)$  are invariant with respect to crisis in country  $j$ .

Under this assumptions, the correlation coefficient between  $r_i$  and  $r_j$  can be written as a function of some parameter  $\Phi$ <sup>32</sup>, defined as;

$$\Phi = \rho \left[ \frac{\left( \frac{1 + \lambda_j}{1 + \lambda_j^C} \right)^2 \frac{1 + \delta}{1 + \rho^2 \left[ (1 + \delta) \frac{1 + \lambda_j}{1 + \lambda_j^C} - 1 \right] (1 + \lambda_j)}} \right]^{-1/2}$$

$$\text{with } \lambda_j^C \text{ and } \lambda_j \text{ equal to} \quad \lambda_j = \frac{\text{Var}(\varepsilon_j)}{\gamma_j^2 \text{Var}(f)} \quad \lambda_j^C = \frac{\text{Var}(\varepsilon_j / C)}{\gamma_j^2 \text{Var}(f / C)}$$

As we can see, the parameter  $\Phi$  is a function of  $\lambda_j$ ,  $\lambda_j^C$ ,  $\delta$ , and  $\rho$ . The correlation coefficient  $\rho^C$  (measured in crisis periods), and the theoretical interdependency measure  $\Phi$ <sup>33</sup> are the main elements of the authors' test.

The major theoretical findings of this model are that if  $\gamma_i, \gamma_j, \text{Var}(\varepsilon_i)$  and  $\text{Cov}(\varepsilon_i, \varepsilon_j)$  do not change during crisis periods, then  $\rho^C$  and  $\Phi$ , must be equal. On the contrary, if  $\rho^C$  is bigger than  $\Phi$ , contagion occurs (shown by an increase of  $\gamma_i$ ,  $\gamma_j$  or  $\text{Cov}(\varepsilon_i, \varepsilon_j)$ ).

The tested hypothesis is:  $H_0 : \rho^C \leq \Phi \Rightarrow \text{interdependence}$

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<sup>32</sup> See A Appendix I of Cosetti et al.(2002) for the derivation of  $\Phi$

Against  $H_1 : \rho^C > \Phi \Rightarrow$  contagion.

The authors calculated two-day rolling averages (to avoid the problem of non simultaneity of the international markets) of daily returns in US dollars.

The sample used to test the tranquil episode covers the period from 1/01/1997 to 17/10/1997 and, on the other hand, from 20/10/1997 to 30/11/1997 for the crisis period of Hong-Kong.

In their empirical results they found evidence that 1997 Hong Kong stock market crisis was contagious to markets in Singapore, Philippines, France, Italy and the UK.

### ***Dungey et al (2002) 'Contagion, Currency crisis' GARCH models***

The work of Dungey, M and Martin, V (2002) tries to address the problems that arise from the restrictive assumptions of homoskedasticity of the errors and the simplification to one unique common factor  $f$  in the above models, by giving some structure to the errors and adding a number of explanatory variables.

Its starting point is a new definition of contagion that is identified as the “transmission of unanticipated country specific idiosyncratic shocks on neighbouring countries after conditioning on both common and country specific fundamentals”. This implies that one can distinguish between common shocks, country specific shocks and contagion (as defined in part one). They tried to factor all potential contagion channels amongst countries into their empirical application of the model.

According to the authors, their model has two main advantages over current alternatives. Firstly, the data requirements are less stringent (exchange rate data

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<sup>33</sup> Notice that the measure of independence derived by Rigobon et al.  $\rho^*$  and the one derived by Cosetti et al.

$\Phi$  coincide when  $\lambda_j = \lambda_j^C = 0$ , this shows that the Rigobon model is one particular case of the Cosetti model, therefore this late approach is a generalisation.

can be obtained easily for high frequencies). Secondly, many of the supposed empirical characteristics of exchange rates such as unit roots, cointegration to express long-run relationships and GARCH variances to capture the time-varying conditional volatility<sup>35</sup>, were included.

To relax the underlying assumptions, the expansion possibilities of their model follow two paths. Firstly, they undertake a characterisation of the residuals, giving some type of stochastic structure different than white noise (i.e.

$$h_{i,t+1/t} = \alpha_{i0} + \alpha_{i1}\varepsilon_t^2 + \beta_{i1}h_{i,t/t-1}.$$

Secondly, they modify the common factor  $f$  by giving some specific structure and increasing the number of common factors.

The new approach looked for contagion in the framework of the 1997 Asian currency crisis and takes as the main aim of the analysis the relationship between the returns of four exchange rates (South Korea, Indonesia, Thailand and Malaysia).

The 'latent factor' model is developed for the standardized variables  $Z_{i,t}$ , which

are defined as:

$$Z_{it} = \frac{\ln S_{it} - \mu_i}{\sigma_i}$$

Where  $S_{i,t}$  represent the exchange rate of the country  $i$  at time  $t$  relative to the US dollar.  $\mu_i$  and  $\sigma_i$  are the sample mean and standard deviation of  $\ln S_{it}$ . The aim of the 'normalization' is to get a common scale for all exchange rates.

The model assumes a linear relationship between observed  $Z_{i,t}$  and four unobserved components, assuming also that these components are independent

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<sup>35</sup> This allowed the model to avoid the problem of the bias highlighted in the Rigobon-Forbes model.

$$\begin{bmatrix} Z_{1t} \\ Z_{2t} \\ Z_{3t} \\ Z_{4t} \end{bmatrix} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} V_t + \theta F_t + \begin{bmatrix} \sigma_1 & 0 & 0 & 0 \\ 0 & \sigma_2 & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 \\ 0 & 0 & 0 & \sigma_4 \end{bmatrix} \begin{bmatrix} C_{1t} \\ C_{2t} \\ C_{3t} \\ C_{4t} \end{bmatrix} + \begin{bmatrix} 0 & \delta_{12} & \delta_{13} & \delta_{14} \\ \delta_{21} & 0 & \delta_{23} & \delta_{24} \\ \delta_{31} & \delta_{32} & 0 & \delta_{34} \\ \delta_{41} & \delta_{42} & \delta_{43} & 0 \end{bmatrix} \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \\ e_{4t} \end{bmatrix}$$

As an example let us see the specification of the model for the variable  $i=2$ :

$$Z_{2t} = \lambda_2 V_t + \theta F_t + \sigma_2 C_{2t} + \delta_{21} e_{1t} + \delta_{23} e_{3t} + \delta_{24} e_{4t}$$

where  $V_t$  and  $F_t$  are factors that represent common shocks (i.e. affecting all countries). The first one is called “variable shock” because the same shock can have different impacts,  $\lambda_i$ , in each country. The second is referred to as the “fixed shock”, arising from the exchange rates being expressed in terms of a common numeraire currency, and affecting them all by the same impact  $\theta$ . Each exchange rate is affected by a idiosyncratic shock,  $C_{i,t}$ , that is unique to a specific country with an impact given by  $\sigma_i$  that is related with the variance of this shock, as we see below. Finally, a random variable vector,  $e_{j,t}$ , is used to model the effect of shocks (contagion) that affect one country  $j$  idiosyncratically, and can be transmitted to country  $i$ . The impact of each shock is measured by  $\delta_{i,j}$ .

The authors consider that the different unobserved component variables are defined by the behavioural equations stated below:

$$V_t = V_{t-1} + e_{Vt} \quad e_{Vt} = \sqrt{h_{Vt}} u_{Vt} \quad u_{Vt} \rightarrow N(0,1)$$

$$h_{Vt} = 1 - \alpha_V - \beta_V + \alpha_V e_{Vt-1}^2 + \beta_V h_{Vt-1}$$

$$F_t = F_{t-1} + e_{Ft} \quad e_{Ft} = \sqrt{h_{Ft}} u_{Ft} \quad u_{Ft} \rightarrow N(0,1)$$

$$h_{Ft} = 1 - \alpha_F - \beta_F + \alpha_F e_{Ft-1}^2 + \beta_F h_{Ft-1}$$

$$C_{it} = \rho_i C_{it-1} + e_{it} \quad e_{it} \rightarrow N(0,1)$$

The model contains 29 parameters and so the estimation procedures can become complicated. They follow the simulation procedures of some authors<sup>36</sup>, implementing an indirect estimator involving the simulation of the latent factor model and the matching of the characteristics of the simulated exchange rates with the observed exchange rates via an auxiliary model, whose likelihood function is approximated by four types of moment conditions<sup>37</sup>.

The empirical results show statistically significant contagion effects in the Asian currency crisis among the four economies in question, and provide evidence on the direction of transmission and the relative importance of contagion for individual countries in the region.

#### **4.Criticisms of the models**

Two related topics arise when trying to identify the consistency of the studies that measure contagion by correlation test: the validation of the test itself and the validation of the model that supports the test.

To approach the first topic, the validation of the test itself, I evaluate the criticisms stated in the literature.

To assess the second topic I raise a natural question: Does the data support the model in tranquil periods? The answer to this question is vital in order to continue with the testing procedure: if it is negative then the result of the test will not be consistent; furthermore it can be misleading.

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<sup>36</sup> Fourieroux and Monfort and Renault (1993,1995), Gallant and Tauchen(1996), Duffie and Singleton(1993)

<sup>37</sup>See for more detail Favero and Giavazzio (2000)

## A.The Test

The most important technical problem that affects all tests of contagion using correlation analysis is the intrinsically low power of the test. The power of the test depends on the sample size, and the ‘crisis’ period contains relatively few observations compared with the ‘tranquil’ period.

Dungey and Zhumabekova (1999) proved that the result of Forbes and Rigobon on contagion from the 1987 U.S. stock market crash, generally rejecting the hypothesis of contagion, is due to the comparison of a large sample ‘no crisis’ period, with a small sample ‘crisis’ period.

The Fisher transformation<sup>38</sup> on the calculated correlation coefficient is required to achieve a distribution closer to the normal. The transformation,  $\overline{\rho^*} = \frac{1}{2} \ln \frac{1+\rho}{1-\rho}$ , is asymptotically distributed as a normal random variable<sup>39</sup>, and this result is best suited for sample sizes  $>50$ <sup>40</sup>.

However, Rigobon applies the Fisher test to incomparable subsamples in the 1987 U.S. stock market crash above mentioned. This test is undertaken between non-turmoil periods of 466 observations<sup>41</sup> and turmoil periods of as few as 35 observations<sup>42</sup>.

The authors carry out Monte Carlo experiments in testing correlations, simulating populations of bivariate normal observations. For given correlation matrices, the correlation coefficients are statistically different for the two populations at 1% level of significance. The aim of this experiment is to investigate the impact of the

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<sup>38</sup> Given the estimated correlation coefficient  $\rho$ ,  $\overline{\rho^*} = \frac{1}{2} \ln \frac{1+\rho}{1-\rho}$  is defined as the mean and  $s_i = \sqrt{\frac{1}{n_i - 3}}$  as the

standard deviation where  $n_i$  is the size of the sample and given this transformation the two-sample test on independent means is performed.

<sup>39</sup> Anderson, 1984, pag.123-124 and Stuart y Ord (1991,1994)

<sup>40</sup> Kendall y Stuart, 1979

<sup>41</sup> 1Jan1986 to16Oct1987

sample size in the result of the correlation coefficient standard test (where interdependence is the null hypothesis). They find that with reasonably sized samples the ability to produce reliable estimates of the true correlation coefficients and their standard errors is acceptable. As the sample size declines, however, the estimates of the standard errors are seriously affected because the test has very little power, and so the ability to reject the null hypothesis is somewhat limited. They conclude by cautioning against using Forbes and Rigobon's approach of identifying contagious episodes.

As the Rigobon model is a specific case<sup>43</sup> of Corsetti's model, most of the criticisms for Corsetti's model also apply to Rigobon's, and vice versa.

I must highlight that the critics above explained for Rigobon can be applied to Corsetti's as they uses as well Fisher transformation for . non-turmoil periods of 146 observations<sup>44</sup> and turmoil periods of only 22 observations<sup>45</sup>.for the test of contagion of 1997 Hong Kong stock market crash.

The original nature of a financial crisis clearly implies that it takes place within a small amount of time (2-3 weeks) and so a small amount of data can be collected within that period. If the decrease in asset prices, the change in the exchange rate and the other consequences of a crisis happen in a relatively long period of time, we would not call that a crisis but a slowdown of the economy and it has not the same drastic consequences.

So if we try to compensate for the lack of necessary data by including more observations, we would smooth the impact of the crisis and the result would be even more inaccurate.

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<sup>42</sup>17Oct1987 to 4Dec1987

<sup>43</sup> Notice that the measure of independence derived by Rigobon et al.  $\rho^*$  and the one derived by Cosetti et al.

$\Phi$  coincide when  $\lambda_j = \lambda_j^C = 0$ .

<sup>44</sup> 1Jan1997 to 17Oct1997

<sup>45</sup>20Oct1997 to 30Nov1997

The intrinsic nature of this phenomenon goes against the requirements of the Fisher test and a good many statistical properties. This may indicate that we cannot capture this phenomenon statistically.

### B.The models.

Rigobon and previous studies assume that the asset returns of one country only depend on the asset returns of another country. Of course, this simplification does not hold in the data during 'non crisis' periods. The error, if  $X_t$  and  $Y_t$  are stationary series, would absorb all omitted variables, making it heteroskedastic. This affirmation is supported by empirical studies that also support the evidence that assets returns have always high volatility.

The main hypothesis of Corsetti's model laid on the existence of a common factor that determines the behaviour of the returns of all the assets. That latent factor is assimilated to an average of the market indexes of the G-7 or a world capital market index. In general, an extension of the property of the model to the rest of the markets –an Index of the exchange rates, for example— would be desirable.

The series of returns of financial assets (shares, exchange rates, etc.) frequently shows evidence of heteroskedastic behaviour. The GARCH models are, in many cases, quite appropriate to capture this special behaviour. But as before, the pertinence of the model used must be tested regarding the sample evidence. For that reason I checked the statistical properties of the data of the Dungey, M and Martin, V (2002) empirical analysis.

The authors' behavioural hypothesis of the South Korean won, the Indonesian rupiah, the Thai baht and the Malaysian ringgitt (with the US as the numeraire) is

that the four of them follow a GARCH(1,1) process<sup>46</sup>. This finding allows them to justify the specification of the structure of the two unobservable common factors of their model ( $V_t$  and  $F_t$ .)

I have tested the hypothesis of GARCH(1,1) with the data<sup>47</sup> in the same period that the authors, and found that an increased structure is also accepted by the data.

The general structure of a GARCH(p,q) process is:

$$R_t = \mu + \varepsilon_t \text{ where } h_t = \alpha_0 + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^p \beta_i h_{t-i}$$

I have estimated all the combinations (GARCH(1,1), GARCH(1,2), GARCH(2,1) and GARCH(2,2)) for the following expression:

$$R_t = \varepsilon_t \text{ where } h_t = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \varepsilon_{t-2}^2 + \beta_1 h_{t-1} + \beta_2 h_{t-2} \quad (1)$$

and I have found different structure specifications for all the currencies. These results are summarized in table 1.

**Table 1.** Maximum likelihood parameter estimates models in equation (1) for alternative countries, 3rd of June 1997 to 30th of August 1998 (E-VIEWS) Z-statistics in brackets.

Parameter	Country			
	South Korea	Indonesia	Thailand	Malaysia
$\alpha_0$	2.02E-07 (6.069151)	8.18E-07 (3.100958)	1.23E-05 (2.162401)	5.98E-07 (3.723714)
$\alpha_1$	0.808526 (10.37130)	0.529197 (5.498479)	0.606758 (5.656933)	0.376989 (5.434865)
$\alpha_2$	-0.675564 (-8.609630)	-0.430444 (-4.607680)	-0.418492 (-3.801187)	-0.298753 (-4.359454)
$\beta_1$	0.908011 (90.84178)	0.931111 (131.9069)	0.815483 (13.91634)	0.932858 (98.34952)
$\beta_2$	NA	NA	NA	NA
<b>Model</b>	<b>GARCH(1,2)</b>	<b>GARCH(1,2)</b>	<b>GARCH(1,2)</b>	<b>GARCH(1,2)</b>

<sup>46</sup> See table 2 of Dungey et al.(2002)

<sup>47</sup> Data source: <http://pacific.commerce.ubc.ca/xr>

With these new specifications of the data structure, it would be desirable to find out to what extent they may also change the specification of the common factors of the model, and therefore the final outcome of the contagion test.

I must also highlight that when the model tries to be more realistic or more general as in the Dungey et al.(2002) approach, the number of parameters grows and so does the possibility of inclusions of non linear relationships. The price to pay for the generalization is then the increased difficulty of estimation and the inaccuracy of the estimated parameters. This also raises the well-known problems of model identification, robustness or consistency in estimation, as well as goodness of fit.

The overparametrization of the model implies that any small change in the sample period which significantly alters the properties of the data can lead to large changes in the estimated parameters and therefore in the diagnostic of contagion.

I have tested the robustness of the model related to changes in the sample period by adding a further 186 observations at the end of the period<sup>48</sup>. I have found that none of the relevant currencies follow either the GARCH(1,1) model suggested by the authors or my own GARCH(1,2) model (see Table 2). This could imply that the behavioural hypothesis of the currencies are not consistent along the time period, and therefore the specification of the common factors of the model would not be well supported.

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<sup>48</sup> The initial values of the sample can be easily justified by the beginning of the Thailand crisis (June 1997). However, in my opinion, there is no clear criterion for the selection of the end of the sample, and any decision in this regard has to be arbitrary.

**Table2.** Maximum likelihood parameter estimates models in equation (1) for alternative countries, 3rd of June 1997 to 31st of January 1998 (E-VIEWS) Z-statistics in brackets.

Parameter	Country			
	South Korea	Indonesia	Thailand	Malaysia
$\alpha_0$	3.05E-07 (5.313981)	8.97E-07 (3.129107)	3.32E-06 (2.527491)	2.62E-08 (8.093498)
$\alpha_1$	0.297816 (14.52130)	0.455591 (5.873929)	0.572141 (6.011677)	0.120910 (45.76940)
$\alpha_2$	NA	-0.366893 (-4.853000)	-0.449537 (-4.736755)	NA
$\beta_1$	0.335174 (4.463937)	0.933794 (146.9917)	0.885594 (37.29270)	1.532001 (2.68E+102)
$\beta_2$	0.447837 (6.523101)	NA	NA	-0.590828 (-1.0E+102)
<b>Model</b>	<b>GARCH(2,1)</b>	<b>GARCH(1,2)</b>	<b>GARCH(1,2)</b>	<b>GARCH(2,1)</b>

Apart from the above concerns surrounding data specification and robustness, I find another main concern related with the standardized values of the exchange rate levels, given that they are the only observable variable of the model.

$$Z_{it} = \frac{\ln S_{it} - \mu_i}{\sigma_i}$$

It is a normal feature that the time series data of exchange rates suffer a sharp structural break of the stationary property at the beginning of a financial crisis. Thus,  $S_{i,t}$  exchange rate series are non stationary<sup>49</sup>, and neither are their logarithms in the period under study: it does not meet the first condition for a standardization (mean must be stationary). What is, then, the meaning of  $\mu_i$ ? It cannot be estimated, and so it has no meaning: it is just calculated as the arithmetic mean of the data. The same problem arises for the calculation of the standard deviation  $\sigma_i$ .

The standardization is justified by the authors as it helps them to circumvent potential numerical problems in estimation when the variables display enormous

different magnitudes. But even then, they find hugely atypical values, and so  $Z_{i,t}$  is as well non stationary<sup>50</sup>.

If  $Z_{i,t}$  helps to standardise the scale to achieve the normalization of virulent changes, one ought to inquire the extent to which this transformation is neutral, related to the contagion test.

Another concern is that the modelling of  $Z_{i,t}$  variables has many ad hoc restrictions that will affect the final results of the test, and so I will comment on their consistency.

The problem of choosing explanatory variables is more acute when the factors are unobservable, as occurs in this case.

We can see by the model specification stated in section 2, that it has two ad hoc common factors  $V_t$  and  $F_t$ , each of which is supposed to follow a random walk process with a GARCH(1,1) errors structure as discussed above. They have to impose an arbitrary initial value of  $V_t$  and  $F_t$  for the random walk, as these variables are unobservable. The model also has a country-specific factor ( $C_{i,t}$ ) that, by assumption, follows an Autoregressive process.

Some of these assumptions make most of the variance of  $Z_{i,t}$  explainable by the variances of  $V_t$  and  $F_t$  (absorbed by the GARCH process of its residuals) and so less of this variance is explained by the residuals of the model itself. That can imply less contagion evidence.

The whole model is plagued by questionable ad hoc restrictions. For example: why do they not specify just one common factor that absorbs all the GARCH behaviour of the returns? Why must the country specific factor follow an autoregressive process and not, for example, a moving average process instead?

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<sup>49</sup> See figure1 Dungey et al.(2002)

## **5. Conclusions**

Critiques concerning the low power of tests<sup>51</sup> apply to the work of Forbes & Rigobon and that of Corsetti, since both of these use results based on asymptotic distributions. Corsetti attempts to generalise Forbes & Rigobon's model, although it constitutes essentially the same methodology, based on contrasting changes in the estimated correlation coefficient in two different samples. The sample drawn from the crisis period will invariably have fewer data.

Concerning the use of GARCH or any alternative models, one ought simultaneously to contrast the model's validity in order adequately to represent the behaviour of the data. My empirical research of that aspect has shown, firstly, that the GARCH structure can be increased at little cost (which sheds some doubt on the model's ultimate specification). Secondly, these model specifications lack robustness.

The main idea that I must highlight is that there is a great challenge, previous to modelling, when the appropriate model is not known. The main, as yet unanswered, question concerns the conceptual and theoretical model that correctly describes the determination of the prices of those financial assets whose contagion effects one is trying to measure. The models by Forbes & Rigobon and Corsetti are gross simplifications of an extremely complex phenomenon. The model by Dungey et al., on the other hand, attempts greater generality, but is unfortunately plagued with ad hoc restrictions.

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<sup>50</sup> See figure 2. Dungey et al.(2002)

<sup>51</sup> Dungey, M. and Shumabekova, D.(1999)

There are different measures of association or linkage among random variables in existence; the coefficient of lineal correlation is not the only one. Other association measures can be taken into account, especially regarding nonlinear phenomena, leading to very different conclusions.

The models in question fail to cover the main problem of clarifying the concept of contagion. When it is stated in some model that a given period was or was not characterised by contagion (as defined in the model itself), there does not seem to be much progress made either in understanding the phenomenon or in suggesting measures to curb the problem accruing to investors and policymakers.

While the analogy may be suggestive, attempting to measure an effect whose theoretical identification is as yet unsatisfactory may prove a sterile course of action. In this sense surveys on contagion (like that of Dornbusch et al) come to the fore, in which there is a discussion of a variety of channels and factors that theoretically explain the issue. These are in sharp contrast with the articles considered in this paper, where contagion is reduced to a simple correlation test.

There are a number of unresolved informational issues concerning market microstructure that are important in any consistent research of the subject, as other studies<sup>52</sup> have also conclude. Such information could help identify characteristics that make countries vulnerable to contagion and could contribute to the development of specific policy prescriptions to reduce the risks of contagion and therefore manage its impact.

## **Appendix 1**

I have estimated the sample correlation between the returns of South Korean won, Indonesian Rupiah, Thailand Bath and Malaysian Ringgitt in two periods.

My aim is to show that by running a standard correlation test (without the suggested adjustment for the upwards bias) between financial asses(returns of exchange rates) it is easily to check whether this coefficient has significantly increased or not.

I summarize my findings in the two correlation matrix tables below.

Data source: <http://pacific.commerce.ubc.ca/xr>

**Non Crisis sample:** 2 January 96 – 30 May 97

		<b>South Korea</b>	<b>Indonesia</b>	<b>Thailand</b>	<b>Malaysia</b>
		WON	RUPIAH	BATH	RINGGITT
<b>South Korea</b>	WON	1	-0.001616	0.027252	-0.040233
<b>Indonesia</b>	RUPIAH	-0.001616	1	0.114782	-0.055727
<b>Thailand</b>	BATH	0.027252	0.114782	1	-0.018781
<b>Malaysia</b>	RINGGITT	-0.040233	-0.055727	-0.018781	1

**Crisis sample:** 2 June 97 – 30 August 98

		<b>South Korea</b>	<b>Indonesia</b>	<b>Thailand</b>	<b>Malaysia</b>
		WON	RUPIAH	BATH	RINGGITT
<b>South Korea</b>	WON	1	0.111085	0.081615	0.111249
<b>Indonesia</b>	RUPIAH	0.111085	1	0.530289	0.471916
<b>Thailand</b>	BATH	0.081615	0.530289	1	0.382979
<b>Malaysia</b>	RINGGITT	0.111249	0.471916	0.382979	1

<sup>52</sup> Dorbusch et al(2000)

So by a simple overview of these two tables we can reject the null hypothesis of interdependence ( $H_0 : \rho_{nocrisis} = \rho_{crisis}$ ) and thus conclude that by the standard test of correlation we would accept the hypothesis of contagion for the East Asian crisis of 1997.

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