Contagion: How to Measure it?[1]

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Abstract

In this paper, .

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1 Introduction

The issue of "contagion" has been one of the most debated topics in international finance since the Asian crises. One interesting aspect of this discussion is the strong agreement on which events have constituted instances of contagion: Mexican crisis, Asian crises, Russian crisis, LTCM, Brazilian crisis, etc. Paradoxically, there is no accordance on what exactly contagion means. Therefore, a paper that asks how to measure something that nobody agrees on what exactly it is should have either zero pages or infinite.

Hence, instead of providing a list of definitions of contagion and procedures for each of them (the infinitely long paper) I concentrate on the two most frequently asked questions raised by applied papers on contagion: First, what are the channels through which shocks are propagated from one country to the other. In other words, is it trade, macro similarities, common lender, learning, market phycology, etc. what determines the degree of vulnerability or contagion. And second, does the transmission mechanism is stable through time? or more specifically, is it stable during the crises?

Independently of the definition of contagion, providing the answer to any of these questions requires a measurement of the transmission mechanism across markets and countries. Nonetheless, the fact that the data exhibits simultaneous equations problems, omitted variables problems, heteroskedasticity, non-normality, etc. makes this estimation a difficult task.[1,2] In this paper, I evaluate several of those techniques, I indicate their problems and offer alternative procedures to solve them. Although, in some circumstances their is simply no solution. Obviously, there is not enough space to discuss all the possible techniques to measure the propagation of shocks, nor all the problems. Therefore, I will concentrate on what I consider the most widely used procedures (linear regressions, principal components, logit-probit, ARCH, and correlation coefficients)[3] and the three main problems: simultaneous equations, omitted variables, and heteroskedasticity.

The paper is organized as follows: Section 2 presents a brief description of the statistical models that are going to be used in the discussions to follow. Section 3 discusses the problems to test for changes in the propagation mechanism. Section 4 analyzes issues involved in the measurement of the transmission channels. Section 5 applies some of the techniques to measure contagion in Latin American countries. Section 6 discuss avenues for future research. Section 7 concludes.

[1] The data suffers from the worst problems of macro and finance at the same time. Firstly, it has simultaneous equation problems and omitted variable bias. And secondly, the errors are serially correlated, non-normal, and have huge heteroskedasticity.

[2] For example, traditional techniques to deal with changes in regime under simultaneous equations are biased in the presence of heteroskedasticity.

[3] I am leaving important aspects of the measurement of the propagation of shocks out of this analysis. Mainly measures based on cointegration (see Cashin, et. al. [1995], Longuin and Slonick [1995]), switching regimes (see again Longuin and Slonick [1995]), factor regression model (see Sentana and Fiorentini [1999]), and non-linearities.

2 The models

In order to discuss the problems involved in the measurement of contagion I use several models. The main reason is that even though I think the true description of country interrelationships are the union of these particular pieces, it is easier to highlight the problems in simple statistical frameworks.

The country variables of interest are denoted by x_t and y_t. They reflect either stock market returns, exchange rates, interest rates, or combinations of them. Without loss of generality, I assumed that x_t and y_t have being demeaned. Aggregate unobservable shocks are denoted by z_t. These should be interpretted as liquidity shocks, risk preferences, investor's sentiments, etc. In general, these are shocks that are common and assumed to be unobservables. All the innovations are denoted by ε_t, η_t, and ν_t. It is assumed (otherwise indicated) that they are independent with mean zero. Additionally, it is assumed that these shocks are also independent of the aggregate shocks.

I concentrate on the bivariate case, although most of the results can be easily extended to larger setups.

When I discuss problems of simultaneous equations I use the following model to describe the interrelationship between the countries:

$$\begin{aligned} y_t &= \beta x_t + \varepsilon_t, \\ x_t &= \alpha y_t + \eta_t, \end{aligned} \qquad \text{(Model 1)}$$

where $E[\varepsilon_t] = 0$, $E[\eta_t] = 0$, and $E[\varepsilon_t \eta_t] = 0$, and their variance denoted as σ_ε and σ_η. When I discuss problems of omitted variables the model used is

$$\begin{aligned} y_t &= \beta x_t + \gamma z_t + \varepsilon_t, \\ x_t &= z_t + \eta_t. \end{aligned} \qquad \text{(Model 2)}$$

where additionally to the previous moment restrictions it is also assumed that $E[\varepsilon_t z_t] = 0$, and $E[\eta_t z_t] = 0$. The variance of the aggregate shock is σ_z.

In all these models, the parameter of interest is β (or whether or not it has shifted). Without additional information Model 1 and Model 2 cannot be estimated. However, I assume the equation estimated is the following:

$$y_t = \beta x_t + \nu_t \qquad (1)$$

I assume that there are no good instruments to solve either the problem of simultaneous equations, not the omitted variables problem. For the simultaneous equations problem, however, it could be argued that large economies, such as the OECD's, are unaffected by small markets. Thus, exclusion restrictions could be used (in this particular case $\alpha = 0$). Even though this assumption might be appealing, it raises important questions or why, for example, during both the Hong Kong and Russian crises the US stock markets were so heavily influenced. In fact, part of the FED's justification to lower interest rates at the end of 1998 was motivated by world market stabilization arguments. Thus, for the purpose of this paper, I preffer not to use this assumption. Similarly for the aggregate shocks, measures of investor sentiment at high frequencies, for example, are at best derived by the same prices and volumes the model is trying to explain. In summary, I assume that even though there might exist weak instruments the problems persist.

Models 1 and 2 are mainly used to discuss problems with tests regarding the stability of parameters, for the issues of measurement of the transmission mechanism I use the next three models: In linear regressions the setup is

$$\begin{aligned} y_t &= \beta x_{1,t} + z_t + \varepsilon_t, \qquad \text{(Model 3)} \\ x_{1,t} &= \gamma_1 z_t + \eta_{1,t}, \\ x_{2,t} &= \gamma_2 z_t + \eta_{2,t}, \end{aligned}$$

where $x_{i,t}$ are the other countries or different variables of the same country. As before, the shocks are independent. Because the researcher does not know which $x_{i,t}$ is the one that explains y_t, the equation estimated is

$$y_t = \beta_1 x_{1,t} + \beta_2 x_{2,t} + \nu_t. \qquad (2)$$

The question is, then, in which conditions the estimates in regression (2) are consistent ($\hat{\beta}_1 = \beta$, and $\hat{\beta}_2 = 0$). In Model 3, the setup only assumes problems of omitted variables. An equivalent formulation can be derived in a simultaneous equations framework. The results discussed here are almost identical in both setups.

When I discuss non-linear setups the model used is

$$\begin{aligned} y_t^* &= \beta x_t + \varepsilon_t \qquad \text{(Model 4)} \\ x_t &= \alpha y_t + \eta_t \end{aligned}$$

and the equation estimated is

$$y_t = 1\left[y_t^* < \tilde{y}\right] \tag{3}$$

The main issue discussed in this setup is the identification of β even in the absence of endogenous problems ($\alpha = 0$). In other words, the question is in which circumstances we can estimate β consistently.

Finally, for ARCH models I use an extended versions of Model 1 (which includes lags).

$$A\begin{pmatrix} y_t \\ x_t \end{pmatrix} = \Phi(L)\begin{pmatrix} y_t \\ x_t \end{pmatrix} + \begin{pmatrix} \varepsilon_t \\ \eta_t \end{pmatrix},$$

where

$$A = \begin{pmatrix} 1 & -\beta \\ -\alpha & 1 \end{pmatrix},$$

$\sigma_\varepsilon, \sigma_\eta$ follow a Bivariate ARCH

$$B\begin{pmatrix} \sigma_\varepsilon \\ \sigma_\eta \end{pmatrix}_t = \phi\left(L\right)\begin{pmatrix} \sigma_\varepsilon \\ \sigma_\eta \end{pmatrix}_t + \begin{pmatrix} \nu_{\varepsilon,t} \\ \nu_{\eta,t} \end{pmatrix},$$

and the matrices A and B are not diagonal.

Again, the main question in this model is the identification of A and B.

3 Testing for changes in the propagation mechanism

In this section, I discuss the problems with the techniques used to detect contagion, when it is defined as a change in the propagation mechanism. The general idea of the procedures is to test if there is a change in the estimates across two different samples. Usually, the comparison is between before and after a crisis, or before and during crises. The most widely used procedures are based on linear setups (OLS, GLS, etc.), correlation coefficients, and principal components.

It is important to highlight that in the presence of simultaneous equations and omitted variables problems the estimates on linear regressions are inconsistent while the estimates on the other two techniques are consistent. However, in all three cases, if there is *no heteroskedasticity*, the test for stability of parameters is *consistent*. It is the interaction between the heteroskedasticity and the other two problems what makes the tests for changes inconsistent.

The problem is that both the endogenous and the omitted variable biases depend on the relative variances. If the data exhibits heteroskedasticity, then the biases shift across the sample and it is possible to reject the hypothesis that the estimates are the same because of the change in the biases, and not because of a shift in the parameters.

The last part of the section is devoted to alternative procedures to solve the problem.

3.1 Testing using OLS

Assuming that there is no available instrument to solve the simultaneous equations or omitted variable problem, the OLS estimate of the first equation in Model 1 and Model 2 are:

$$\hat{\beta}_{Mod1} - \beta = \alpha (1 - \alpha\beta) \frac{\sigma_\varepsilon}{\alpha^2 \sigma_\varepsilon + \sigma_\eta} \quad (4)$$

$$\hat{\beta}_{Mod2} - \beta = \gamma \frac{\sigma_z}{\sigma_z + \sigma_\eta} \quad (5)$$

The bias in both cases depends on the relative variances of disturbances. Both can be simplified to:

$$\hat{\beta}_{Mod1} - \beta = \alpha (1 - \alpha\beta) \frac{1}{\alpha^2 + \frac{\sigma_\eta}{\sigma_\varepsilon}},$$

$$\hat{\beta}_{Mod2} - \beta = \gamma \frac{1}{1 + \frac{\sigma_\eta}{\sigma_z}}.$$

Assume that the question of interest is whether or not the parameters are stable along the sample.

In general, the tests take two forms: either they estimate β in the two sub-samples and perform a comparison, or introduce a dummy for the period under analysis and test for its significance. Independently of the setup, though, the results indicated below are the same. For simplicity in the exposition, I assume the sample is split and two separate regressions are sun. The question of interest is in which circumstances, assuming the β is stable, the difference in the estimates is zero. In other words, the idea is to explore when the test is at least consistent.

First, lets analyze the case when there is no heteroskedasticity. If this were the case, then regardless of the problem of simultaneous equations or omitted variable the test is consistent. This results comes from the fac that the biases under the null hypothesis are the same in both subsamples. The difference in the estimates is

$$\left(\hat{\beta}_{Mod1,Sample1} - \beta_{Sample1}\right) - \left(\hat{\beta}_{Mod1,Sample2} - \beta_{Sample2}\right) = -\frac{\alpha^2}{\alpha^2 + \frac{\sigma_\eta}{\sigma_\varepsilon}} \left(\beta_{Sample1} - \beta_{Sample2}\right)$$

Note that under the null hypothesis that $\beta_{Sample1} = \beta_{Sample2}$, the difference in the estimates is zero; it is porportional to $\beta_{Sample1} - \beta_{Sample2}$. Thus, the rejection occurs only if the parameters have shifted.

However, if there is heteroskedasticity in the sample, the question is if the rejection is obtained because the parameters have changed, or because the variances (and hence the biases) shifted. For example, assume the parameter β is constant but there is heteroskedasticity, then the difference in the estimates is:

$$\hat{\beta}_{Mod1,Sample1} - \hat{\beta}_{Mod1,Sample2} = \alpha\left(1-\alpha\beta\right)\left(\frac{1}{\alpha^2+\left(\frac{\sigma_\eta}{\sigma_\varepsilon}\right)_{Sample1}} - \frac{1}{\alpha^2+\left(\frac{\sigma_\eta}{\sigma_\varepsilon}\right)_{Sample2}}\right)$$

Note that the biases cancel each other if the heteroskedasticity implies a proportional increase in the variance of both shocks. Otherwise, the estimates are different even though the underlying parameter is stable. In summary, when OLS is used to make comparisons across samples the alternative hypothesis is unclear. We are jointly testing the stability and the homoskedasticity of the data. The alternative hypothesis is that one of these two (or both) are not satisfied. When we are dealing with contagion, in particular, problems of heteroskedasticity and simultaneous equations are important making inference in the linear regresion context hard.

3.2 Testing using Principal Components

The idea of principal components is to find common factors for a set of time series; "in the case where the original series are identical, the first principal component explains 100 percent of the variation in the original series. Alternatively, if the series are orthogonal to one another, it would take as many principal components as there are series to explain all the variance in the original series. In that case, no advantage would be gained by looking at common factors, as non exist."[4]

Principal components have been widely used to test for the stability of the propagation mechanism. The main reason being that the estimates are consistent if the data has simultaneaous equations and omitted variables problems.[5]

Formally, assume there are K variables each with n observations, whose covariance matrix is denoted as X. The idea of the first component is to explain the K series as best as possible. Assume the principal component is denoted as p. Then, it minimizes the discrepancies of

$$X - a'p$$

where a' is a matrix of scalars. p is only identified up to a constant, and therefore some normalization is imposed (usually $p'p = 1$). It can be shown that the first component, p, corresponds to the

[4] Taken from Kamisky and Reinhart [2000]. See Theil [1971] for a formal derivation.
[5] See Calvo and Reinhart [1995], Kamisnky and Reinhart [2000], and Masson [1997].

eigenvector of the largest eigenvalue of $X'X$ (see Theil [1971]). The components of p are known as the loading and reflect the importance of a particular variable in explaining the rest.

As was mentioned before, principal components is consistent if there is no heteroskedasticity. From Model 1 the covariance matrix is:

$$\Omega = \frac{1}{(1-\alpha\beta)^2}\begin{bmatrix} \beta^2\sigma_\eta + \sigma_\varepsilon & \beta\sigma_\eta + \alpha\sigma_\varepsilon \\ \beta\sigma_\eta + \alpha\sigma_\varepsilon & \sigma_\eta + \alpha^2\sigma_\varepsilon \end{bmatrix}$$

where the eigenvalues are given by

$$\frac{1}{2}\sigma_\varepsilon\left[\Theta_1 \pm \sqrt{\Theta_2}\right]$$

were

$$\begin{aligned} \Theta_1 &= 1+\alpha^2+\left(1+\beta^2\right)\theta \\ \Theta_2 &= \left(1+\beta^2\right)^2\theta^2 - 2\left[\left(1-\beta^2\right)\left(1-\alpha^2\right) - 4\alpha\beta\right]\theta + \left(1+\alpha^2\right)^2 \\ \theta &= \frac{\sigma_\eta}{\sigma_\varepsilon} \end{aligned}$$

The eigenvector of the first eigenvalue (the largest one) is

$$\begin{matrix} \frac{1}{2}\frac{\sigma_\varepsilon}{\alpha+\beta\theta}\left(\Theta_3 + \sqrt{\Theta_2}\right) \\ 1 \end{matrix}$$

where

$$\Theta_3 = 1 - \alpha^2 - (1-\beta^2)\theta$$

Note that the eigenvalues and eigenvectors only depend on the parameters (α and β) and the relative variance of the idiosyncratic shocks (θ). Therefore, under the assumption that there is no heteroskedasticity, a change in the loadings of the principal component implies a shift in the parameters. The question is then, what happens to the loadings if there is conditional heteroskedasticity. As should become clear from the previous derivation, a shift in the relative variances (θ) does indeed alters the loadings even if the parameters are stable.

Given the definition of principal components it should be expected that movements in the relative variances, in the end, reflect changes in the loadings. When there is a change in the relative importance of the shocks, by construction, the common component also shifts, and the weights in the eigenvector reflect so.

Again, as before, in the absence of heteroskedasticity, the test of stability based on principal components is consistent. However, it is not when the data is heteroskedastic. The fact that contagion indeed is accompained by large shifts in second moments implies, therefore, that comparisons across samples based on principal components are inadequate.

3.3 Testing using the Correlation

The first paper testing for changes in the propagation mechanism using correlation measures was the seminal paper by King and Wadhwani [1990]. The intuition is

For the correction see Forbes and Rigobon [1998], for additional applications using the adjustment see Baig and Goldfjan [2000] , Gelos and Sahay [2000], and Favero and Giavazzi [2000].(Favero and Giavazzi, 2000)

3.4 What are the alternatives?

In this section, let me briefly summarize some of the alternatives available to solve the problem of estimation. First, I discuss the case of the correlation, then principal components, and finally OLS.

3.4.1 Correlation coefficient

The solution to the estimation of the correlation coefficient is partially summarized in the previous section. It is important, however, to realize that such adjustment is valid ONLY in the circumstances in which it was developed. If any of the assumptions is relaxed then the correction proposed is not valid. Note that indeed it is not valid if the problem of simultaneous equations exists.

However, as we argued in the paper, if the adjustment is only practiced using those countries in which the shock is generated, then it is still possible to get a good approximation based on what has been called near-identification.[6]

Near-identification refers to the circumstance in which the variance of the shock in one of the equations is significantly larger than the shock in the other equation. In this case, as can be seen by equation (4) the bias tends to zero, and the model is closer to XXX. The periods of crises follow closely this description.

The implication of this assumption is that a small set of transmission mechanisms can be tested: only those channels from the country under crises to the rest of the countries in the sample.

[6] See Fisher [1976].

3.4.2 Principal Components

The solution to the Principal components bias is to eliminate the bias generated by the heteroskedasticity. Thus, an alternative is to estimate a rolling ARCH and use the predicted out-of-sample variance to normalize the series.[7] This adjustment produces consistent estimates if there is no simultaneous equations problems.

On the other hand, if there is a shift in the parameters that has an effect on the second moments, then the problem of the adjustment is that it minimizes the differences in the sample, and there is an important loss in power. Therefore, conclusions based on this adjustment that do not find rejection should be taken cautiously.

In the following simulation I summarize the degree of bias and adjustment found.

XXXX

3.4.3 Linear regressions

Finally, when there is simultaneous equations and omitted variables problem it is well known that there is no procedure to consistently estimate equations (1) and (1). Without additional information those equations cannot be estimated.

In a previous paper, I show that even if it is impossible to estimate the coefficients, a test for their changes can be implemented under the following information: the country generating the crisis and its period have to be exogenously provided. In general, knowing the country generating the crisis is relatively uncontroversial, however, determining the exact period in which the increase in the variance occurs is not.

In Rigobon [1999] I describe both the methodology and the power of the test. Because it is impossible to perfectly define the crisis window, I check for the robustness of the results when the window is modified.

This procedure can be implemented both in multivariate as well as bivariate setups and the test is robust to the presence of simultaneous equations and omitted variables. Moreover, the procedure jointly test for the changes in the coefficients of a set of countries (rather than pairwise comparisons).

It is important to mention, however, that if there is misspecification in the crisis window it is possible to find rejections (thus finding a shift in the parameters) even though the true parameters are stable. The main weakness of the test is that it is rejected in two circumstances: when the parameters shift (which is the case of interest) and when there is heteroskedasticity in more than two

[7] In the simulations I did, the results were very similar if rolling variances were used instead of an ARCH model. This is definitely easier to implement.

idiosyncratic shocks. This second rejection is uninteresting. However, so far, there is no procedure to disentangle between the two alternative hypothesis.

4 Measuring the propagation mechanism

A second important question in empirical applications of contagion is related to what determines the propagation of the shocks: trade, country similarities, common lender, learning, liquidity, etc.

In general, these questions are address by determining if the propagation of shocks is stronger to countries that have particular characteristics.

4.1 Measuring using OLS

Using Model 3 it is easy to show that conclusions can be erroneous when there exist simultaneous equations or omitted variables problems. The OLS estimates on equation 2 are (after some algebra)

$$\begin{aligned}
\begin{pmatrix} \hat{\beta}_1 - \beta_1 \\ \hat{\beta}_2 - \beta_2 \end{pmatrix} &= \frac{\sigma_z}{\phi} \begin{pmatrix} \gamma_1 \sigma_{\eta,2} \\ \gamma_2 \sigma_{\eta,1} \end{pmatrix} \\
\phi &= \sigma_z \left[\gamma_2^2 \sigma_{\eta,1} + \gamma_1^2 \sigma_{\eta,2} \right] + \sigma_{\eta,1} \sigma_{\eta,2}
\end{aligned}$$

Note that in Model 3, the true value of $\beta_2 = 0$ and $\beta_1 = \beta$. It is possible that the biases make $\hat{\beta}_2$ larger than zero, and $\hat{\beta}_1$ equal to zero! This makes the conclusion that y_t depends on $x_{2,t}$ and not $x_{1,t}$ wrong. Exactly the same conclusions can be obtained if Model 3 is changed to be one where the problem is simultaneous equations instead of omitted variables.

Moreover, because the variances can be different across countries, conclusions about the dependence of y_t can be driven by those biases and not necessary by the true interrelationship.

4.1.1 Using the "index" regression.

Several papers have followed the methodology derived in Eichengreen, Rose, and Wyplosz [1996] to measure contagion.[8]

4.2 Measuring using Logit-Probit-Tobit

Applications (Eichengreen et al., 1996), (Eichengreen and Mody, 2000)

Econometric problems under heteroskedasticity: Maximum score estimation (Manski, 1985), (Horowitz, 1992), and (Horowitz, 1993)

[8] See Glick and Rose [1998], Baig and Goldfjan [1998, 2000] and De Gregorio and Valdes [2000] for some papers using almost the same technique. See also Van Rijckeghem and Weder [2000] as well as Gelos and Sahay [2000].

4.3 Measuring using GARCH-ARCH models

Empirical applications using GARCH models are Edwards and Susmel [2000]

4.4 Measuring using Principal Components

As was indicated in the previous section, tests for changes in the parameters based on Principal Components are biased in the presence of heteroskedasticity. In this section, I argue that the estimates are also inconsistent.

If equation (**??**) were a linear function of θ_t, then the estimate of the weight is consistent in the presence of heteroskedasticity. However, by inspection, it should be clear that the eigenvector is not a linear function of θ_t. Therefore, when there is heteroskedasticity, the weight is determined by substituting $E\theta_t$ instead of the series of θ_t in equation (**??**).

The loading (equation (**??**)) is a convex function of θ_t if β is positive. In other words, that the two countries are positively correlated (which is almost always the case found in the data). In this case, those countries in which its idiosyncratic variance changes more (more volatile θ_t) have higher loadings (all things equal). It is possible, therefore, that strong linkages are found because the heteroskedasticity is high. Note that this is a statement assuming the same average volatility but a larger change in the variance.

4.5 What are the alternatives?

In this section, I discuss adjustments that can be implemented in the procedures described to solve the problems.

4.5.1 Linear regressions

Finding valid instruments is extremely difficult.

4.5.2 Logit-Probit

For the problem of identification on the non-linear equations under heteroskedasticity see (Chen and Khan, 1999), (Sentana and Fiorentini, 1999), (Klein and Vella, 2000a), (Klein and Vella, 2000b).

For solution of the estimation problem see also (Lomakin and Paiz, 1999).

4.5.3 Principal components

The problem I have just highlighted cannot be solved by normalizing the data to have unit variance across the sample, but it has to be solved by imposing a unitary variance in each of the periods.

4.5.4 ARCH

4.5.5 New procedure

See Rigobon [2000] for simultaneous equations measurement.

5 An application to Latin American Countries.

In this section, I apply to Latin American countries some of the procedures highlighted before to answer both questions: does the propagation of shocks across LA countries is stable? and if it is, then how important are those linkages?

5.1 Stock markets

5.2 Bond prices

5.3 Exchange rate

5.4 Index regressions

6 Future Research

6.1 Prices vs. Volumes

A lot of research on prices, very little on volumes.

The references I know: Eichengreen and Mody [2000], Froot, O'Connell and Seasholes [2000], Karolyi and Stulz [1996], and Stulz [1999].

6.2 Is the propagation through the means or the variances?

An important question is whether the shocks are transmitted by reducing current prices, or the crises mean higher volatilities, that in the end require a higher return. Moreover, (Model 1) and (Model 2) can be a reduce form of both models. Therefore, so far, the procedures here highlighted are unable to disentangled the exact channel.

From the theoretical point of view, this is an important question indeed. Several of the models that have been developed look at the transmission of the shocks through prices, and not necessarily by the second moments.

7 Conclusions

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