Testing for financial contagion: comparing limited and full-information methods

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Abstract

This paper pursues two objectives. We test for the presence of nonlinearities in the transmission of country-specific shocks during the 1997/98 Asian crisis. Using the full-information methodology of Favero and Giavazzi (2002) we find that the null hypothesis of no contagion is widely rejected. The pattern of contagion is asymmetric with important implications for international portfolio diversification. Since our results contrast with those obtained by Rigobon (2001, 2002) using a limited information methodology, we present Monte Carlo simulations which show that certain necessary conditions must be satisfied for this method to have power.

JEL Classification: C3, F3, F4, G1.

Keywords: Contagion, nonlinearities, international financial markets, Asian crisis, simultaneous equation models.

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1 Introduction and motivation

During the last decade international financial markets have been affected by several major currency and financial crises. The high degree of international transmission of these crises has triggered a large research effort both at the theoretical and empirical levels. The keyword is contagion. The empirical literature focuses on two related sets of issues[1]. The first set of issues deals with the channels through which country-specific shocks such as sharp devaluations are propagated across borders: trade and financial linkages, macroeconomic similarities, common lender effects, etc. The second set of issues deals with the existence of contagion defined as a *rejection of the null hypothesis that the transmission mechanism of country-specific shocks is stable across tranquil periods and episodes of high financial turbulence*. Contagion is sometimes interpreted as stronger cross-market linkages in periods of high turbulence. However, comovements could also decrease, so that allowing for a *change* and not specifically an *increase* will be important in empirical work.

Assessing the stability of the propagation mechanism is important for international portfolio management. Financial market participants benefit from international portfolio diversification. The process of globalisation offers new investment opportunities and to the extent that economic and political shocks are mostly seen as idiosyncratic, investing in a higher number of countries allows for a reduction in risk exposure. In this context, the key variable is the degree of comovement across financial markets. If the strength of the transmission mechanism of idiosyncratic shocks changes when such large shocks occur in one country, the benefits of international diversification will be modified. It must be noted that comovements may not necessarily increase but they could also decrease. If we consider a geographical region consisting of strong and weak countries, as defined by their macroeconomic fundamentals, it could be the case that investors pull their funds out of weak countries into strong countries. As a consequence, the degree of covariation among financial markets would become lower. In any case, portfolio management requires

[1] Claessens, Dornbusch and Park (2000) provide an overview of the contagion literature. Dungey et al. (2005a) present various methodologies in a unifying framework.

knowledge of the degree of comovements among financial markets, and changes in the strength of these comovements will have important effects.

Early analyses of the existence of contagion focus on changes in correlation coefficients (King and Wadhwani, 1990; Baig and Goldfajn, 1999). This measure, however, suffers from numerous adjustment problems (Forbes and Rigobon, 2002; Boyer, Gibson and Loretan, 1999; Corsetti, Pericoli and Sbracia, 2005). More importantly, it does not properly model the interdependence across international financial markets. Consequently, more recent research builds upon structural models of simultaneous equations so as to properly account for interdependencies between financial markets and to avoid a spurious detection of contagion. The estimation of such models is not straightforward, in particular because of identification problems. However, Rigobon (2000) proposes an innovative procedure which does not require any arbitrary restrictions on the econometric specification. Rather, it uses the heteroscedasticity of the data to identify different volatility regimes and to classify the observations accordingly so as to build an instrumental variable. A test of the existence of contagion is then simply a test of the validity of the constructed instrument. Rigobon (2001, 2002) applies this approach to emerging market countries and concludes in favour of a stable transmission mechanism.

An alternative full-information approach, pioneered by Favero and Giavazzi (2002), also makes use of a structural model of interdependence. It starts by estimating the reduced-form model to identify country-specific shocks. These are then included into the structural model which is estimated using a full-information procedure, making arbitrary restrictions on the lag structure to obtain identification. A test for contagion is simply a test of whether shocks in one country have a significant coefficient in the equations for other countries, having controlled for interdependence. Favero and Giavazzi (2002) apply this approach in the context of the parities of the Exchange Rate Mechanism in the early nineties and find widespread evidence of rejection of the stability of the propagation mechanism.

This paper pursues two objectives. Firstly, we apply the full-information methodology to test for the existence of contagion among five south-east Asian stock markets during the 1997/98 Asian crisis. In contrast with Rigobon (2002), we uncover strong evidence

against a stable transmission mechanism. Country-specific shocks are propagated across countries in a nonlinear way. Positive shocks can have either a positive or a negative impact on other stock markets, whereas negative shocks have a more systematic negative effect on other stock markets. This points toward the existence of an asymmetric international transmission of country-specific extreme events. Secondly, since the empirical results on the existence of contagion appear to depend upon the chosen methodology, we make use of Monte Carlo simulations to study possible reasons for these diverging results. We find that the power of the limited information approach depends critically on the relative sizes of the sub-samples conditional on volatility, the relative degree of heteroscedasticity across these sub-samples, as well as the total number of observations.

The paper is organised as follows. Section 2 outlines the limited information methodology and the full-information methodology to test for contagion. Section 3 discusses the data and the sample period. Section 4 presents the empirical results about the existence of contagion, while section 5 presents the evidence from our Monte Carlo simulations. Section 6 provides concluding remarks.

2 Limited and full-information estimators

Early studies of contagion focus on changes in correlation coefficients between national stock market returns. Aside from the numerous adjustment problems associated with the computation of correlation coefficients, this approach abstracts from the modeling of interdependence itself, thereby leading to the possibility of a spurious detection of contagion (Favero and Giavazzi, 2002; Pesaran and Pick, 2004). Any analysis of the propagation of shocks must allow for explicit two-way interdependencies between international stock markets and restrictions on the contemporaneous relationships remain inappropriate. Recent work has therefore developed dynamic structural systems of simultaneous equations to model interdependence adequately, and to test for the stability of specific parameters.

The standard dynamic structural model of interdependence can be written in general form as

$$BS = \Gamma(L)S + \Psi Z + E \tag{1}$$

where S is a vector of stock market returns, B is a non-diagonal matrix of coefficients capturing contemporaneous relationships, Z is a matrix of common external shocks, and E is a vector of country-specific disturbances. Controlling for common external sources of comovement will be essential in our empirical implementation in so far as omitting them would lead us to conclude that a country-specific shock spreads to other countries, when in fact the shock is external and common to all countries[2]. For the sake of the exposition, and without loss of generality, let us assume that $Z = 0$ and consider only two countries, denoted as 1 and 2. Therefore, the system reduces to

$$\begin{pmatrix} 1 & -\beta_{12} \\ -\beta_{21} & 1 \end{pmatrix} \begin{pmatrix} s_{1,t} \\ s_{2,t} \end{pmatrix} = \begin{pmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{pmatrix} \begin{pmatrix} s_{1,t-1} \\ s_{2,t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix} \tag{2}$$

where neither β_{12} nor β_{21} are restricted to be zero. In general, the estimation of the structural parameters is conducted either equation by equation using a limited information estimator, or jointly using a full-information estimator. Favero and Giavazzi (2002) rely on full-information maximum likelihood, whereas Rigobon (2000, 2002) provides an instrumental-variable methodology to test for contagion. The remainder of this section presents both approaches and the relevant tests for contagion.

2.1 Full-information method: Favero and Giavazzi (2002)

Favero and Giavazzi (2002) propose a three-step procedure to test for nonlinearities in the propagation mechanism of country-specific shocks[3]. The first step is to estimate a

[2]There is widespread evidence that economic conditions in major industrialised countries and at the world level have a significant impact on emerging market countries. For example, Calvo, Leiderman and Reinhart (1993) find that capital inflows into Latin America in the late eighties and early nineties were partly driven by external factors such as low international interest rates and a recession in the United States. Frankel, Schmukler and Serven (2004) find that emerging market economies exhibit a high degree of sensitivity to international interest rates, especially under fixed exchange rate regimes.

[3]The term "nonlinearities" is used instead of contagion so as to avoid the implicit meaning of contagion as a significant reinforcement of cross-market relationships during episodes of high market turbulence. Significant reductions in these relationships should also be interpreted as contagion.

reduced-form vector-autoregressive model and to identify, using dummy variables, large residuals as country-specific shocks. The second step is to estimate the structural model of interdependence, including the dummy variables, and making some arbitrary assumptions on the lag structure to obtain identification. Finally, we can test for the existence of contagion.

The reduced form of the general dynamic structural model is expressed as a vector-autoregressive specification, so that

$$\begin{pmatrix} s_{1,t} \\ s_{2,t} \end{pmatrix} = \begin{pmatrix} \pi_{11} & \pi_{12} \\ \pi_{21} & \pi_{22} \end{pmatrix} \begin{pmatrix} s_{1,t-1} \\ s_{2,t-1} \end{pmatrix} + B^{-1} \begin{pmatrix} \epsilon_{1,t} \\ \epsilon_{2,t} \end{pmatrix} \tag{3}$$

The residuals in (3) are heteroscedastic and non-normal since the sample includes episodes of high financial market turbulence. These are captured by dummy variables, thereby eliminating heteroscedasticity and non-normality. We can therefore rewrite the error term as

$$\begin{pmatrix} \epsilon_{1,t} \\ \epsilon_{2,t} \end{pmatrix} = \left(I + \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} d_{1,t} & 0 \\ 0 & d_{2,t} \end{pmatrix} \right) \begin{pmatrix} \epsilon^{l}_{1,t} \\ \epsilon^{l}_{2,t} \end{pmatrix} \tag{4}$$

$$\begin{pmatrix} \epsilon^{l}_{1,t} \\ \epsilon^{l}_{2,t} \end{pmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma \right] \tag{5}$$

The partitioning of the matrix containing the dummy variables is conditional on the country in which the shock originates. Moreover, $\epsilon^{l}_{1,t}$ and $\epsilon^{l}_{2,t}$ are the structural shocks in periods of low volatility. The off-diagonal blocks of the matrix A allow for nonlinearities in the propagation of shocks between countries. A simple test for the absence of nonlinearities specifies the following null hypothesis:

$$H_0 : a_{ij} = 0, \forall\ i \neq j$$

The estimation of the reduced-form model (3) is the first step of the methodology. Then, large residuals are defined as events and represented by dummy variables. Again, this al-

lows to filter out heteroscedasticity and non-normality. The second step is to estimate the structural model of interdependence. In so far as this system of simultaneous equations is not identified, some restrictions are imposed. In the spirit of the general-to-specific approach, it is more appropriate to restrict the coefficients on the lagged endogenous variables than those on the contemporaneous feedbacks. The own lagged dependent variable is thus assumed to be sufficient to capture the structural dynamics[4], i.e. $\gamma_{ij} = 0, \forall\ i \neq j$. In this way, the system of equations is exactly identified as each equation in the system is itself identified.

2.2 Limited information method: Rigobon (2000)

Rigobon (2000) provides an instrumental-variable methodology to test for contagion. Suppose that stock market returns can be classified into two regimes of volatility, low and high, and that the increase in volatility across regimes is entirely the consequence of an increase in the variance of one of the two country-specific shocks. In this case, the sample can be split into two sub-samples accordingly. Rigobon (2000) constructs an instrumental variable and shows that it is valid only under the null hypothesis of no contagion. Therefore, a test for the existence of contagion is simply implemented as a Hausman-type test for the validity of the instrument w_t.

For the sake of the exposition, and without loss of generality, the structural model (2) is simplified by assuming that $\gamma_{ij} = 0, \forall\ i, j$. The approach relies on the identification of two regimes according to whether volatility is high or low. Thus, for the high-volatility regime we have

$$\begin{pmatrix} 1 & -\beta_{12} \\ -\beta_{21} & 1 \end{pmatrix} \begin{pmatrix} s^h_{1,t} \\ s^h_{2,t} \end{pmatrix} = \left(I + \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} d_{1,t} & 0 \\ 0 & d_{2,t} \end{pmatrix} \right) \begin{pmatrix} \varepsilon^l_{1,t} \\ \varepsilon^l_{2,t} \end{pmatrix} \tag{6}$$

and for the low-volatility regime we have

[4]This assumption is not uncontroversial. Rigobon (2001) argues that the theoretical foundations are extremely weak. Consider two countries, home and foreign. If it is true that the home returns are explained by current foreign as well as past home returns, it seems reasonable that past foreign returns should also have some explanatory power for current home returns.

$$\begin{pmatrix} 1 & -\beta_{12} \\ -\beta_{21} & 1 \end{pmatrix} \begin{pmatrix} s^l_{1,t} \\ s^l_{2,t} \end{pmatrix} = \begin{pmatrix} \varepsilon^l_{1,t} \\ \varepsilon^l_{2,t} \end{pmatrix} \tag{7}$$

Suppose that we are interested in estimating the coefficient β_{21}. Rigobon (2000) proposes the following instrument to implement the estimation by instrumental variables:

$$w_t = \begin{pmatrix} \frac{s^h_{1,t}}{T^h} \\ -\frac{s^l_{1,t}}{T^l} \end{pmatrix} \tag{8}$$

Hence,

$$\widehat{\beta}_{21} = (w' s_1)^{-1} w' s_2 \tag{9}$$

We now demonstrate that this instrument is valid only under the null hypothesis of no contagion, so that a test for the stability of parameters can be simply implemented as a Hausman test for the validity of instruments. The usual conditions for validity and consistency are

$$plim(w_t s_{1,t}) \neq 0 \tag{10}$$

$$plim(w_t \varepsilon_{2,t}) = 0 \tag{11}$$

In the context of the limited information approach, the null hypothesis is defined as parameter stability. However, the alternative hypothesis can be interpreted either as parameter instability or as a violation of the assumption that only the variance of one of the idiosyncratic shocks increases. Let us therefore assume that only $\sigma^2_{\varepsilon_1}$ increases in the sub-sample of high volatility (C), so that

$$\begin{aligned} Var(\varepsilon_1|C) &> Var(\varepsilon_1) \\ Var(\varepsilon_2|C) &= Var(\varepsilon_2) \\ Var(z|C) &= Var(z) \end{aligned}$$

Looking at equation (6) our specific assumption about the variances implies that $a_{12} = a_{22} = 0$. The model simplifies to[5]

$$\begin{pmatrix} 1 & -\beta_{12} \\ -\beta_{21} & 1 \end{pmatrix} \begin{pmatrix} s^h_{1,t} \\ s^h_{2,t} \end{pmatrix} = \left(I + \begin{pmatrix} a_{11} & 0 \\ a_{21} & 0 \end{pmatrix} \begin{pmatrix} d_{1,t} & 0 \\ 0 & d_{2,t} \end{pmatrix} \right) \begin{pmatrix} \varepsilon^l_{1,t} \\ \varepsilon^l_{2,t} \end{pmatrix} \tag{12}$$

$$\begin{pmatrix} 1 & -\beta_{12} \\ -\beta_{21} & 1 \end{pmatrix} \begin{pmatrix} s^l_{1,t} \\ s^l_{2,t} \end{pmatrix} = \begin{pmatrix} \varepsilon^l_{1,t} \\ \varepsilon^l_{2,t} \end{pmatrix} \tag{13}$$

We are now ready to check the two conditions for validity and consistency of the instrument. Firstly,

$$\begin{aligned} plim(w_t s_{1,t}) &= plim\left(\frac{1}{T^h} s_1^{h\prime} s_1^h\right) - plim\left(\frac{1}{T^l} s_1^{l\prime} s_1^l\right) \\ &\simeq var(s_1^h) - var(s_1^l) \\ &= \left(\frac{(\beta_{12} a_{21} + a_{11})\, d_1}{1 - \beta_{12}\beta_{21}}\right)^2 \sigma^2_{\varepsilon_1} > 0 \end{aligned}$$

provided that $\beta_{12}\beta_{21} \neq 1$. Therefore, the instrument is correlated with the original endogenous variable as long as there are abnormal events in country 1, that is, as long as $d_1 \neq 0$. In particular, the efficiency of the instrument will depend on the relative heteroscedasticity across sub-samples of low and high volatility. Secondly, denoting $\varepsilon^*_2 = \varepsilon_2 + a_{21} d_1 \varepsilon_1$,

$$\begin{aligned} plim(w'\varepsilon^*_2) &= plim\left(\frac{1}{T^h} s_1^{h\prime} \varepsilon^*_2\right) - plim\left(\frac{1}{T^l} s_1^{l\prime} \varepsilon^*_2\right) \\ &\simeq cov(s_1^h, \varepsilon^*_2) - cov(s_1^l, \varepsilon^*_2) \\ &= \frac{d_1^2}{1 - \beta_{12}\beta_{21}} \left(\beta_{12} a_{21}^2 + a_{11} a_{21}\right) \sigma^2_{\varepsilon_1} \end{aligned}$$

which is equal to zero only under the null hypothesis of no contagion, that is, when $a_{21} = 0$. Therefore, a test for contagion can be simply implemented as a Hausman test

[5] We would obtain the same model by setting $d_{2,t} = 0$ in (6).

for the validity of the instrument. Clearly, these results illustrate the large-sample, or asymptotic, properties of the constructed instrument. In practice, however, only finite samples of data are available. Therefore, it remains important to study the finite-sample properties of the methodology. Such an investigation being very cumbersome analytically in the present context, we shall make use of Monte Carlo simulations to study the power of the limited information technique.

3 Data

We apply the full-information methodology of Favero and Giavazzi (2002) to test for the existence of contagion during the 1997/98 Asian crisis. The sample focuses on five south-east Asian countries, namely the Philippines, Korea, Malaysia, Thailand and Indonesia and it extends from 1st January 1996 to 31st July 1998. All the data are at the daily frequency and retrieved from Datastream. Stock market indices are expressed in local currency and as calculated by the International Finance Corporation (IFC). These indices are intended to represent the performance of the most active stocks in their respective stock markets and to be the broadest possible indicator of market movements. The present coverage of such indices exceeds 75% of total market capitalization. Stock market returns are obtained through log-differentiation.

The question of the currency denomination of returns remains controversial. On the one hand, it is usually asserted that foreign investors care about returns expressed in their own currency. Arbitrage yields a parity condition whereby the domestic return equals the foreign return plus expected depreciation. In this case, we would make use of stock market returns in foreign currency. On the other hand, focusing on returns in local currency allows us to eliminate the exchange rate component of the return. In fact, exchange rate changes could offset variations in returns in local currency. For example, the Thai stock market experienced a massive surge following the announcement of the devaluation of the baht. This is well reflected by the index expressed in bahts, but the large size of the devaluation leads to a moderate fall in the index expressed in U.S. dollars. Therefore, looking at

indices expressed in foreign currency can be misleading whenever the index expressed in local currency and the exchange rate move in opposite directions.

Common external shocks are captured using log-differentiated series of the three-month U.S. Treasury bill interest rate, the U.S. stock market and the yen/U.S. dollar exchange rate. Corsetti, Pesenti and Roubini (1999) have argued that "the sharp appreciation of the U.S. dollar relative to the Japanese yen and the European currencies since the second half of 1995 led to deteriorating cost-competitiveness in most Asian countries whose currencies were effectively pegged to the dollar"[6].

4 Results and implications

This section presents the results of the estimation of the structural model of interdependence and the test for contagion. It also discusses the implications of our findings for the size and the measurement of the benefits of international portfolio diversification.

4.1 Results

Our results are obtained using the full-information methodology proposed by Favero and Giavazzi (2002). The estimation of the reduced-form vector-autoregressive model requires the determination of the optimal lag length. Three different criteria, namely a sequential modified likelihood ratio test, the Akaike information criterion, and the Schwarz criterion, produce different results. However, only the Schwarz criterion remains insensitive to the hypothesised maximum lag length. Consequently, and given that parsimony is highly desirable in the context of systems of simultaneous equations, this criterion is preferred and leads us to select a unit lag length.

The residuals of the estimated VAR model feature heteroscedasticity as they contain episodes of turbulence. Dummy variables are assigned to residuals which are three times greater than the standard deviation of residuals, thereby capturing extreme country-specific events[7]. We identify 59 country-specific shocks (Philippines, 10; Korea, 13; Malaysia,

[6]Corsetti, Pesenti and Roubini (1999), p. 308-309.

[7]The choice for this threshold value is motivated by parsimony and previous research. Making use of a

12; Thailand, 11; Indonesia, 13), among which 36 are positive and the remaining 23 are negative[8]. The distinction between types of shocks will allow us to examine potential asymmetries in the pattern of contagion. Finally, excluding common external shocks would yield 67 extreme events. Again, in the context of emerging market economies it is important to account for common external shocks in order to avoid thinking of an event as being contagious when all countries are in fact affected by a common shock simultaneously.

Turning to the second step of the methodology, the dynamic structural model of simultaneous equations is estimated by three-stage least squares. The initial specification is fully identified by restricting the lag structure so that only the own lagged variable enters each equation. A simplification search is then carried out, in which simpler cases are tested against the general model using F tests. Testing the restriction that the coefficients on all the variables which are not significant in the fully identified specification are equal to zero leads us to reject the null hypothesis. A systematic analysis is therefore conducted and leads to a parsimonious specification.

TABLE 1 ABOUT HERE

The results in Table 1 show little evidence of interdependence and a strong influence of common external shocks. We find interdependence from Thailand to Malaysia and from Korea to Thailand. Therefore, it seems that permanent cross-market linkages are very weak in normal tranquil times. However, the economic situation in the United States impacts forcefully on the south-east Asian region. Most notably, the behaviour of the U.S. stock market has a significant positive effect: any increase in U.S. stock market returns coincides with an increase in south-east Asian returns. Moreover, higher interest rates in the United States have a consistently positive effect on the region, except for Thailand. Although we initially expected a negative sign consistent with Calvo, Leiderman

threshold of 2 yields 190 country-specific events and an equivalent number of dummy variables. Moreover, Gindraux (2002) provides a detailed sensitivity analysis of threshold values and finds that the dummies that are selected by a threshold of 3 are those which typically survive the testing-down procedure to overidentify the structural system of equations in the second step of the methodology.

[8]The appendix provides the dates, countries, type of shock and the corresponding news retrieved from the online archives of Bloomberg.

and Reinhart (1993), we would argue that changes in the level of interest rates in the United States affect expectations to a significant extent. Such changes in expectations are not directly observable and therefore, we cannot unambiguously determine their impact on emerging stock market returns. Finally, the yen/U.S. dollar exchange rate is important for Korea, Malaysia and Indonesia, with a negative sign indicating that a depreciation of the yen relative to the U.S. dollar represents a loss of competitiveness for these three countries. The reason why the Philippines and Thailand are not affected may be that their respective currencies were substantially devalued early in the crisis.

TABLE 2 ABOUT HERE

The final step of the full-information approach consists in testing for the presence of contagion. The null hypothesis of no contagion can be visually thought of as a null hypothesis of no bold coefficients in Table 2. Clearly, the null hypothesis is rejected and most of the country-specific events are transmitted across countries in a non-linear way. In other words, the propagation mechanism is not stable over time. Moreover, positive or negative shocks do not necessarily imply positive or negative reactions, respectively, of other stock markets. For example, although the devaluation of the Thai baht on 2nd July 1997 leads to a surge in Thailand's stock market, it triggers a fall in the Philippine and Malaysian stock markets. Otherwise, stock markets can collapse together. For example, on 12th February 1998 Stanley Fischer, at the time Deputy Managing Director of the IMF, said that Indonesia was not ready to peg its currency to a reserve currency. This announcement led not only to a crash in the Indonesian stock market, but also to a significant decline in the stock markets of the Philippines and Malaysia. The evidence points out that we should not specify the null hypothesis as no significant increase in cross-market linkages, but rather as no significant change in these linkages.

About half of the positive shocks are transmitted positively (0.52), in the sense that a soaring stock market in one country leads another market to surge as well. Conversely, half of the positive shocks are transmitted negatively (0.48), which points to the fact that investors sell in one market and reinvest in another market. However, three quarters of

the negative shocks have negative effects, in the sense that a crash in one market leads to a crash in another market. Conversely, one quarter of country-specific crashes leads to a rising stock market in other countries. Thus, we obtain *prima facie* evidence of an asymmetric international transmission of country-specific shocks. Positive shocks can lead to increases or decreases in other markets with a nearly equal probability, while negative shocks are more likely to have adverse effects on neighbouring stock markets[9].

One final remark is noteworthy. Country-specific shocks tend to occur in clusters over time. In other words, we observe clusters of very high financial market turbulence with otherwise more tranquil periods. Our findings show clusters such as early July 1997, early September 1997, then a long sequence of shocks from early November to early February 1998, with more dispersed shocks at the end of our sample. Nowadays, the empirical literature on contagion focuses on the so-called 1997/98 Asian crisis. However, we should remember that this crisis was initially considered as a Thai crisis. It is only after a few months that it became clear that speculative attacks and financial crises would affect the whole region, including Korea which had been recently admitted as a member of the OECD. In fact, it is interesting to see that Korea was not affected by contagious effects until early December 1997. The first bold coefficient for Korea corresponds to 8th December 1997. Once this country was undergoing severe difficulties, however, it suffered from contagious effects from neighbouring countries.

4.2 Implications for international portfolio diversification

International portfolio diversification allows for an expansion of the investment opportunity set. Investors are able to allocate wealth between a higher number of securities, thereby reducing the effect of idiosyncratic risk and increasing welfare. This being said, the fact that stock market comovements increase at times of market distress means that the gains

[9]Such evidence could not be obtained with alternative methodologies such as correlation analysis or the limited information approach proposed by Rigobon (2000) which does not require the estimation of a structural model but only computes a test statistic. These approaches do not identify idiosyncratic shocks explicitly and therefore, we cannot examine the direction of the impact of these shocks on other stock markets. See Baur and Fry (2006) for further details on this issue.

from international portfolio diversification will be reduced just when they are most needed. Butler and Joaquin (2002) find that these gains decrease in bear markets. The strategy is to divide the sample of stock market returns into three categories, namely bear, normal and bull markets. Correlations are higher in bear markets than in normal or bull markets. They build an equally weighted portfolio of the domestic market and the international market and find that its return is reduced by about 2% in bear markets compared to what it would have been if cross-market linkages had not changed.

The common feature of studies which quantify the reduction in gains from diversification is the assumption that cross-market linkages increase during periods of high turbulence. However, as our results show, we should really focus on *changes* in cross-market linkages and not exclusively on increases. Positive and negative shocks affect other stock markets with different probabilities. These features of contagion should be taken into account. We have found cases where cross-market relationships actually decrease, thereby potentially increasing the gains from diversifying across markets. Assuming then that markets exhibit greater comovements at times of distress is a limiting assumption.

5 Monte Carlo simulations

This section examines possible reasons behind the divergence of our results relative to those obtained by Rigobon (2001, 2002) with the limited information approach. Rigobon (2001) uses this methodology to test for the stability of the propagation mechanism of shocks across stock and bond markets for a sample of fourteen Latin American and south-east Asian countries. The central finding is that the transmission channel is remarkably stable for stock markets, whereas there is some limited evidence of instability of parameters in bond markets. Rigobon (2002) focuses on a wider sample of thirty-six industrialised and emerging market economies and concludes that "the high comovement across international stock markets is not the result of changes in the propagation mechanism, but the outcome of strong interdependence among these markets that is present at all times"[10]. We make

[10]Rigobon (2002), p. 2

use of Monte Carlo simulations and show that this approach features some limitations which may lead to not rejecting the null hypothesis of no contagion when it should in fact be rejected.

5.1 Setup

Monte Carlo simulations assume that the true data generating process is known to the researcher. This process should be specified either under some null hypothesis or some alternative hypothesis. Once that the data have been generated, we can apply estimation methods and/or statistical tests to examine the problem under investigation. The underlying econometric model is given by

$$\begin{pmatrix} 1 & -\beta_{12} \\ -\beta_{21} & 1 \end{pmatrix} \begin{pmatrix} s_{1,t} \\ s_{2,t} \end{pmatrix} = \begin{pmatrix} \gamma_{11} & 0 \\ 0 & \gamma_{22} \end{pmatrix} \begin{pmatrix} s_{1,t-1} \\ s_{2,t-1} \end{pmatrix} + \begin{pmatrix} 1 \\ \delta \end{pmatrix} z_t + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix} \tag{14}$$

Since we are interested in studying the power of the test proposed by Rigobon (2000) we will generate the values for the endogenous variables under the alternative hypothesis. However, a rejection of the null hypothesis implies either that the parameters are not stable or that the necessary assumption that the variance of only one of the idiosyncratic shocks increases in a sub-sample of the data is not satisfied. Therefore, we will assume that only the variance of ε_1 changes in a sub-sample of the data, whereas the variances of ε_2 and z are constant over the entire sample. In this way we guarantee that a rejection of the null hypothesis is really a rejection of parameter stability.

The stock market in country 1 is affected by occasional abnormal high-volatility events. Such events are drawn from a binomial distribution in which the probability of an event is varied across successive experiments. Then, we can construct two sub-samples according to whether an event has taken place or not. In the low-volatility regime, where no event occurs, the standard deviation of all the shocks is identical and normalized to 0.02. In the high-volatility regime, we increase the standard deviation of ε_1 by a factor $\lambda > 1$ in successive experiments, whereas the standard deviations of the other shocks remain

constant. In all experiments, idiosyncratic and common unobservable shocks are drawn from a normal distribution with mean zero and variance defined as explained.

Different values are assigned to the structural parameters. Since we generate the observations under the alternative hypothesis of parameter instability, we select different values for the interdependence coefficients conditional on the volatility regime, either low (L) or high (H). Given that we are dealing with a dynamic model we must also specify starting values. The focus of our analysis being stock market returns, we choose $s_{1,0} = s_{2,0} = 0$. We use the reduced-form model to generate observations for both endogenous variables and then construct the appropriate instruments. Finally, we compute the test and check whether the instrument is valid or not[11].

This whole analysis is replicated 100 times for each value of the probability of an event and for each value of the increase in the variance of the idiosyncratic shock in country 1. These two values are varied across successive experiments. We conjecture that the smaller the size of the sub-sample of events, and the smaller the relative increase in $\sigma^2_{\varepsilon_1}$, the smaller the power of the test. Intuitively, asymptotic results will not apply if the size of the high-volatility sub-sample is very small. Moreover, the efficiency of the instrumental-variable estimator will increase with the relative heteroscedasticity across sub-samples of high and low volatility.

5.2 Simulation results

Table 3 presents our simulation results for the baseline model. The numbers in the table are probabilities (multiplied by 100) that the estimator rejects the null hypothesis, as it should. To interpret the results, the first row of numbers in italics of the table contains values ranging from 0.02 to 0.20. These correspond to the standard deviation of the idiosyncratic shock in country 1. As expected, as this standard deviation increases, the instrumental-variable estimator gains power in rejecting the null hypothesis. Clearly, if there is no increase in the variance of any idiosyncratic shock the test has no power. This

[11] We implement the Hausman test making use of artificial regressions. For more details, see Davidson and MacKinnon (1993), chp. 7.

is illustrated by the fact that probabilities in the second column of Table 3 are close to zero. The first column of numbers in italics contains values ranging from 0.01 to 0.10. These correspond to the percentage of observations which are abnormal. In other words, it is the relative size of the high-volatility sub-sample. As expected, the instrumental-variable estimator gains power as this relative size increases.

TABLE 3 ABOUT HERE

In our analysis of the Asian crisis we determined that between two and three percent of all observations for each country correspond to abnormal events. Now, consider the realistic scenario whereby the standard deviation of the idiosyncratic shock in a country roughly doubles in periods of high turbulence. This combination of parameters yields a value in Table 3 equal to 0.55. In words, although the model features a structural break in both equations of the dynamic system the probability that the test proposed by Rigobon (2000) rejects the null hypothesis is only about half. This value is far from the expected value of 0.95.

On the basis of our results we conclude that the instrumental-variable estimator should be used with caution. Its power depends both on the relative size of the sub-sample of abnormal events and on the relative degree of heteroscedasticity across the two sub-samples. The evidence provided by Rigobon (2001, 2002) that the null hypothesis of no contagion in stock markets cannot be rejected for the 1997/98 Asian crisis could stem from the lack of power of the limited information methodology. Our evidence is a first step towards a better understanding of the divergence in the results on the existence of contagion.

The sensitivity of our baseline simulation results is examined by changing key parameters. First, we restrict the total number of observations to 100, while keeping other parameters constant. Table 4 presents the results. Clearly, the power deteriorates when the total sample size decreases. Relative to the baseline model there are less observations and asymptotic results should hold even less than under a total sample size equal to 500. In general, the larger the overall sample size, the larger the power of the test.

TABLE 4 ABOUT HERE

TABLE 5 ABOUT HERE

TABLE 6 ABOUT HERE

We also test the power of the method when the structural interdependence coefficients break in one country only. Table 5 presents the results when the baseline model is changed to $\beta_{21}^{L} = \beta_{21}^{H} = 0.2$. Finally, we assume larger structural breaks in both equations. In particular, relative to the baseline model, we assume that $\beta_{12}^{H} = 0.6$ and $\beta_{21}^{H} = 0.6$. Table 6 summarizes these results. Overall the power of the limited information methodology does not seem to depend substantially on the number of structural breaks or on the magnitude of these breaks. However, our sensitivity analysis shows that not only the relative size of the high-volatility sub-sample matters, but also the total size of the sample of data. This approach is very convenient since it does not require to impose arbitrary restrictions to obtain identification and to estimate structural models. However, it is only appropriate under certain conditions. Our Monte Carlo simulations emphasize some key parameters.

6 Concluding remarks

This paper pursues two objectives. First, we have applied the full-information methodology proposed by Favero and Giavazzi (2002) to test for contagion during the 1997/98 Asian crisis. Our results reject the null hypothesis of no contagion, so that the transmission mechanism of country-specific shocks changes in the face of high-volatility abnormal events. In contrast with the earlier correlation approach we find that stock market comovements are either reinforced or weakened in periods of high turbulence. As a result, it is not necessarily true that the benefits of international portfolio diversification become reduced just when they are most needed. Further research should look into the implications of our results for optimal portfolio management in the presence of high market turbulence. Finally, we uncover prima facie evidence that investors discriminate among stock markets in good times, but tend to exit all markets in bad times. While negative shocks mostly have a negative impact on other markets, positive shocks can lead to either a positive or a negative effect on these other markets, with a probability of about half.

Second, our results on the existence of contagion diverge from those obtained by Rigobon (2001, 2002) and we have presented some Monte Carlo simulations to examine the necessary conditions for the power of the limited information approach. We find that the total size of the sample of data, the relative size of the sub-sample of abnormal events, as well as the relative degree of heteroscedasticity between sub-samples of low and high volatility, are important determinants of the power of the methodology. The potential lack of power of the limited information approach does not imply that it is inferior relative to other methodologies. It remains very easy to implement and does not require potentially weak assumptions for identification. For example, the full-information methodology of Favero and Giavazzi (2002) relies on exclusion restrictions on the lag structure which are not theoretically grounded. Indeed, Dungey et al. (2005b) review several methodologies and conclude that the full-information test tends to be oversized in that it tends to find contagion when none exists. Our results remain helpful in identifying precisely the necessary conditions to apply the limited information methodology.

Appendix

Date	Country	Type	News in Bloomberg
07/10/96	Thailand	-	Bank of Thailand imposes new measures on offshore lending by foreign-owned banks in an effort to better control the flow of foreign funds. Stock market index plunges amid concern that high annual economic growth is a thing of the past. Investors sell bahts and switch to a rising yen.
18/11/96	Thailand	-	Phone issues fall on expectations that new projects and revised contracts will not materialize soon.
02/07/97	Thailand	+	Devaluation of the baht, in order to boost exports, scrapping a formula used since 1984 that pegged the baht to a basket of foreign currencies but dominated by the U.S. dollar.
03/07/97	Thailand	+	Thai stocks extend their biggest rally since 1992 on optimism a devaluation will help revive its flagging economy.
11/07/97	Philippines	+	Devaluation of the currency. Stocks soar after the central bank allows the peso to weaken, giving up a costly defense strategy that drove interest rates up and threatened to slow down growth significantly.
28/08/97	Philippines, Malaysia	-	Philippine stock market crashes in the midst of panic. Malaysian stocks tumble to four-year low after the stock exchange curbs trading in the 100 stocks of the benchmark index. Prime Minister Mahathir Mohamad asks local state-run pension funds to buy stocks the next day, and blames George Soros.
02/09/97	Thailand	+	Stocks rally, reversing a rout that slashed more than 20 percent off the benchmark index in 13 days after banks reveal that bad debts are no worse than investors expected.
03/09/97	Malaysia, Indonesia	-, +	Malaysian stock index plunges led by an electric utility, a weakening of the currency, and the failure of the government's efforts to prop up the market for a third day. Indonesia announces "credible proactive measures" to restore stability to its currency and economy.
05/09/97	Malaysia, Indonesia	+	Malaysian Prime Minister Mahathir Mohamad says the government will raise 30 billion ringgit through a bond sale and use the money to buy Malaysian stocks in a bid to prop up the declining stock market. Indonesian stock index surges – its biggest one-day gain in almost four years – after the government announces plans to boost exports and says that it will abolish the 49-percent limit on foreign ownership of shares in initial public offerings.
23/10/97	Philippines	-	Bankers and brokers say that a bill pending in Congress would set back the development of the Philippine capital markets by taxing stocks and bonds more heavily than in other countries.
29/10/97	Indonesia	+	Stocks jump led by domestic phone monopoly PT Telkom and tobacco company Gudang Garam.
03/11/97	Korea, Malaysia	+	Korean stocks rise, recovering from early declines, as the raised ceiling on foreign ownership of shares takes effect. Malaysian stock index increases, its largest one-day percentage gain in two months, as investors buy stocks they see as attractive relative to potential earnings.
18/11/97	Malaysia	-	Stock index plunges after the speedy approval of United Engineers' purchase of share in its parent company raises concern about a lax regulatory environment.
20/11/97	Malaysia	-	Stock index plunges as investors flee some of the country's largest stocks after Renong's bailout by a cash-rich unit raises concern about corporate transparency.
24/11/97	Korea	-	Stock index suffers its worst plunge in history as the country prepares to forfeit years of economic growth for a bailout from the IMF, imposing tax raises and spending cuts.
04/12/97	Korea	+	Stocks surge for the biggest rally ever after the country's agreement to accept a $55 billion international bailout. The government promises to increase access to financial markets in return for the IMF bailout.
08/12/97	Malaysia	+	Stock index posts record gains after the government takes action to avoid asking the IMF for help.
09/12/97	Malaysia	-	Stock index sinks amid concern that the government's measures to slow

			economic growth will hurt corporate profits.
15/12/97	Korea	+	The country steps back from the financial brink as the prospect of billions of dollars in emergency credit from the IMF restores confidence. The Finance Ministry announces that it will remove its 10-percent daily fluctuation limit on trading of the won from the next day onwards.
23/12/97	Korea	-	International credit rating agencies downgrade Korea's foreign-currency denominated debt.
26/12/97	Korea	+	Financial markets rally after the IMF and G-7 nations pledge $10 billion in accelerated aid to the country. The Bank of England asks British banks to extend the length of their loans to Korean banks to ease Korea's financial crisis. Korea says that it will let its banks dismiss a large number of employees, removing a key obstacle to acquisitions by foreign rivals.
08/01/98	Indonesia	-	Financial crisis deepens as concerns that the IMF will suspend its $23 billion bailout package sends the stock market to a four-year low.
09/01/98	Philippines	-	Stocks plunge on fears that the economy is headed for a recession brought on by rising interest rates and a plummeting currency.
12/01/98	Korea	+	Stocks rise on optimism that the country is emerging from its financial crisis. An official tells the Japanese Finance Minister Mitsuzuka that Korea's economic situation is improving because of the smooth rollover of its foreign debt.
13/01/98	Indonesia	+	The government announces that it will reduce the cost of foreign investment to boost confidence. The currency strengthens after the IMF says it would drop a demand that Indonesia run a budget surplus in the next fiscal year. Stocks rally as investors bet talks among President Suharto, the United States, and the IMF will yield new reforms to put the derailed economy back on track. The government announces that it will postpone 15 power and highway projects to demonstrate commitment to reforms.
15/01/98	Indonesia	-	Promises of economic reforms are met with increasing scepticism. The latest package of reforms arrives with a thud as the stock market falls.
16/01/98	Thailand	+	Stocks rally, posting their second-biggest gain in two months, after the IMF indicates it could ease some terms of its $17.2 billion bailout.
19/01/98	Philippines, Korea, Malaysia, Thailand	+	Philippine stocks rally as the peso rises to a two-week high, prompting optimism that the country would be the first to emerge from the Asian crisis. Seven UK banks decide to roll over loans to Korean banks until March 31st in a bid to ease Korea's economic crisis. Malaysian stock index soars as investors cheer remarks by the IMF on the previous Friday that the country does not need a bailout. Thai stock surge amid confidence that the country will be able to loosen the terms of the $17.2 billion international bailout for its troubled economy.
30/01/98	Philippines, Korea, Thailand	+	Philippine stocks soar as the trade gap narrows by 36%, the second smallest deficit in the past three years. Korean stocks rally after international lenders agree to extend $24 billion of commercial bank debt for as long as three years. The new Korean government will support shareholder rights and force companies to provide more information to investors. Thai stocks surge as foreign exchange controls are lifted in a sign of confidence that the baht is starting to stabilize.
02/02/98	Philippines, Thailand, Indonesia	+	Philippine stocks surge on hopes of economic recovery. Thai stocks rally for a fourth day amid optimism that the country has begun to turn around, helped by a lower than expected inflation in January. Indonesian stock index surges, its biggest one-day rise in more than eight years, on hopes that banking reforms unveiled by the government will help put the economy back on track. Indonesia will end monopolies and price controls for a host of basic food commodities in the next two years to meet its promises to the IMF.
03/02/98	Philippines, Malaysia, Indonesia	-, +, -	President Ramos accepts the resignation of Commissioner Kintanar of the National Telecommunications Commission (NTC), who is running for Congress in elections in May 1998. Malaysian stock index in its biggest one-day percentage gain ever, amid optimism that Asia's currency and stock market turmoil may be near an end.

			Indonesian stocks fall as optimism fuelled by previous week's banking reforms is deflated by a weakening rupiah.
04/02/98	Thailand	-	Stock index posts its biggest one-day loss in more than seven years as investors conclude that prices have gone too high given bleak company earnings prospects.
05/02/98	Malaysia, Thailand	+	Malaysia's Commerce Asset says it is in talks to merge its bank unit with RHB. Thai stocks rebound after their biggest tumble since 1990 after investors bet the worst of the crisis is over and the baht may strengthen.
11/02/98	Philippines, Indonesia	+, -	Philippine stocks surge as a strengthening peso bolsters investors' confidence that the crisis is over. Indonesian stock index posts its biggest one-day decline in five weeks on investor concern that capital controls will accompany plans to peg the rupiah to another currency.
12/02/98	Indonesia	-	Stanley Fischer, deputy managing director of the IMF, says that Indonesia is not ready to peg its currency to a reserve currency. A former IMF economist who briefed Indonesian officials on ways to peg the rupiah to the U.S. dollar says he is afraid President Suharto is now rushing headlong into a bad decision to adopt the plan.
10/03/98	Malaysia	+	Stocks rise after the government says that it is prepared to let troubled banks fail, thereby easing investor concerns that cash-rich companies will be coerced into buying cash-strapped companies.
26/03/98	Indonesia	+	Stocks surge as the more stable rupiah and optimism about solutions to the country's foreign debt attracts investors.
04/05/98	Korea	-	Stocks take their biggest tumble in three weeks as violent confrontations between organised labour and riot police shake the government's efforts to stabilize the recession-torn economy.
13/05/98	Indonesia	-	Student protests calling for Suharto's ouster escalate in Jakarta.
19/05/98	Indonesia	+	President Suharto promises to quickly move the country toward new elections in which he will not run.
12/06/98	Korea	-	Stock index plunges to its lowest level in more than eleven years as the weakening yen challenges Korean exports.
17/06/98	Korea	+	Banks will recommend the immediate liquidation of about 50 companies – more than twice what they first proposed – in a key test of the country's resolve to reshape its sprawling conglomerates.
19/06/98	Philippines	-	Stock index takes its biggest plunge in more than five months.
20/07/98	Korea	+	Shares take their biggest rally in a month amid optimism that the combination of a strong won and falling interest rates will bolster corporate profits.

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Table 1: Structural system of interdependence[a]

	Dependent variable				
	s_{PH}	s_{KO}	s_{MY}	s_{TH}	s_{IN}
Constant	*-0.0009*	-0.0019	-0.0011	-0.0029	
s_{PH}	X				
s_{KO}		X		0.2992	
s_{MY}			X		
s_{TH}			0.2784	X	
s_{IN}					X
Lagged dep. var	0.2293	0.1947	0.1017	0.1100	0.1226
U.S. interest rate	0.2411	0.3079	0.1695		0.2833
U.S. stock market	0.4125	0.3366	0.3451	0.3557	0.5898
JPY/USD rate		*-0.2253*	-0.2232		-0.2113
Observations	671	671	671	671	671

[a] Coefficients in italics are significant at the 10% level. All other reported coefficients are significant at the 5% level. Coefficients which are not reported are not significant, either at the 10% or 5% level.

Table 2: Existence of contagion[a]

Date	Country	Type	s_{PH}	s_{KO}	s_{MY}	s_{TH}	s_{IN}
07/10/96	TH	-				-0.0657	
18/11/96	TH	-				-0.0630	
02/07/97	TH	+	**-0.0235**		***-0.0225***	0.0811	
03/07/97	TH	+			**-0.0322**	0.0811	
11/07/97	PH	+	0.0741		***0.0245***	**-0.0412**	
28/08/97	PH,MY	-	-0.0813		-0.0781		**-0.0438**
02/09/97	TH	+				0.0659	
03/09/97	MY, IN	-, +			-0.0579		0.0742
05/09/97	MY, IN	+			0.1154	**0.0407**	0.1204
23/10/97	PH	-	-0.0446		***-0.0211***		
29/10/97	IN	+	**0.0304**				0.0485
03/11/97	KO, MY	+		0.0782	0.0615		
18/11/97	MY	-	***-0.0187***		-0.0661		
20/11/97	MY	-			-0.0971		**-0.0427**
24/11/97	KO	-		-0.1137	***0.0231***		**0.0628**
04/12/97	KO	+		0.0754	**0.0335**		**0.0378**
08/12/97	MY	+		**-0.0505**	0.0815	***0.0358***	
09/12/97	MY	-		**-0.0604**	-0.0610		
15/12/97	KO	+		0.1205			**-0.0660**
23/12/97	KO	-	***-0.0191***	-0.0857			
26/12/97	KO	+		0.0703		**-0.0400**	
08/01/98	IN	-	**-0.0328**	**0.0397**		**-0.0533**	-0.1608
09/01/98	PH	-	-0.0671				
12/01/98	KO	+	**0.0384**	0.1209		**-0.0599**	**0.0412**
13/01/98	IN	+	**0.0361**		**0.0376**	**0.0479**	0.0943
15/01/98	IN	-		**0.0617**		**-0.0420**	-0.0583
16/01/98	TH	+		***-0.0385***		0.1057	**0.0894**
19/01/98	PH, KO, MY, TH	+	0.0607	0.0953	0.0588	0.0796	**0.0629**
30/01/98	PH, KO, TH	+	0.0776	0.0788	**-0.0322**	0.0981	
02/02/98	PH, TH, IN	+	0.0755	***-0.0354***	**-0.0320**	0.1238	
03/02/98	PH, MY, IN	-, +, -	-0.0605		0.1904		-0.1024
04/02/98	TH	-				-0.1038	
05/02/98	MY, TH	+			0.0384	0.0746	
11/02/98	PH, IN	+, -	0.0538	***-0.0350***			-0.0928
12/02/98	IN	-	**-0.0316**		**-0.0614**		-0.1112
10/03/98	MY	+		**0.0494**	0.0507		
26/03/98	IN	+					0.0769
04/05/98	KO	-		-0.0760			
13/05/98	IN	-	***-0.0220***			***-0.0373***	-0.0955
19/05/98	IN	+	**-0.0231**				0.0931
12/06/98	KO	-	***0.0206***	-0.0747			
17/06/98	KO	+		0.0802		**0.0527**	**0.0443**
19/06/98	PH	-	-0.0457	**-0.0580**			
20/07/98	KO	+	**-0.0274**	0.1006			

[a] Coefficients in italics are significant at the 10% level. All other reported coefficients are significant at the 5% level. Coefficients which are not reported are not significant, either at the 10% or 5% level. Bold coefficients correspond to dummies for some country which are significant in other countries.

Table 3: Baseline model, 500 observations

$N = 500, \beta_{12}^L = 0.3, \beta_{12}^H = 0.4, \beta_{21}^L = 0.2, \beta_{21}^H = 0.4$										
	0.02	*0.04*	*0.06*	*0.08*	*0.10*	*0.12*	*0.14*	*0.16*	*0.18*	*0.20*
0.01	5	32	64	84	88	92	96	93	98	98
0.02	4	54	79	95	98	100	100	100	100	100
0.03	3	55	92	98	100	100	100	100	100	100
0.04	5	79	100	100	100	100	100	100	100	100
0.05	6	77	98	100	100	100	100	100	100	100
0.06	4	89	99	100	100	100	100	100	100	100
0.07	7	88	100	100	100	100	100	100	100	100
0.08	8	90	100	100	100	100	100	100	100	100
0.09	4	91	100	100	100	100	100	100	100	100
0.10	11	92	100	100	100	100	100	100	100	100

Table 4: Baseline model, 100 observations

$N = 100, \beta_{12}^L = 0.3, \beta_{12}^H = 0.4, \beta_{21}^L = 0.2, \beta_{21}^H = 0.4$										
	0.02	*0.04*	*0.06*	*0.08*	*0.10*	*0.12*	*0.14*	*0.16*	*0.18*	*0.20*
0.01	7	16	18	35	28	53	48	54	58	54
0.02	6	16	40	51	56	66	65	74	76	76
0.03	4	27	49	57	67	81	74	86	86	86
0.04	5	25	59	74	76	84	90	91	94	96
0.05	8	21	57	78	90	90	90	94	98	99
0.06	2	24	63	80	95	98	96	97	96	97
0.07	3	33	73	91	95	94	98	97	98	99
0.08	5	32	76	89	91	97	99	99	100	100
0.09	5	46	78	93	93	96	100	99	99	98
0.10	7	38	80	92	94	98	100	100	100	100

Table 5: Break only in country 1

$N = 500, \beta_{12}^L = 0.3, \beta_{12}^H = 0.4, \beta_{21}^L = 0.2, \beta_{21}^H = 0.2$										
	0.02	*0.04*	*0.06*	*0.08*	*0.10*	*0.12*	*0.14*	*0.16*	*0.18*	*0.20*
0.01	5	30	64	81	93	98	94	95	96	100
0.02	3	53	89	98	99	99	99	100	99	100
0.03	6	71	97	98	100	98	100	100	100	100
0.04	4	74	97	100	100	100	100	100	100	100
0.05	7	80	100	100	100	100	100	100	100	100
0.06	3	82	100	100	100	100	100	100	100	100
0.07	4	92	100	100	100	100	100	100	100	100
0.08	4	86	100	100	100	100	100	100	100	100
0.09	8	97	100	100	100	100	100	100	100	100
0.10	8	97	100	100	100	100	100	100	100	100

Table 6: Larger structural breaks

$N = 500, \beta_{12}^L = 0.3, \beta_{12}^H = 0.6, \beta_{21}^L = 0.2, \beta_{21}^H = 0.6$										
	0.02	*0.04*	*0.06*	*0.08*	*0.10*	*0.12*	*0.14*	*0.16*	*0.18*	*0.20*
0.01	1	36	71	83	88	91	96	97	97	95
0.02	3	51	82	97	100	99	100	99	100	100
0.03	5	63	93	99	99	100	100	100	100	100
0.04	4	68	99	100	100	100	100	100	100	100
0.05	3	80	99	100	100	100	100	100	100	100
0.06	5	85	99	100	100	100	100	100	100	100
0.07	6	90	100	100	100	100	100	100	100	100
0.08	1	89	100	100	100	100	100	100	100	100
0.09	2	95	100	100	100	100	100	100	100	100
0.10	3	89	100	100	100	100	100	100	100	100