Contagion in International Bond Markets During
the Russian and the LTCM Crises

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Abstract

The Russian bond default in August 1998 and the LTCM recapitalization announcement in the following month, represents an unusual period of volatility in international bond markets with bond spreads increasing dramatically across the globe. Using a latent factor model and a new data set spanning bond markets across Asia, Europe and the Americas, we quantify the contribution of contagion to the spread of these crises. The maximum amount of contagion experienced by any of the countries investigated is about 17% of total volatility in bond spreads, with the main effects due to the Russian crisis. The results also show that both emerging and developed markets experienced contagion during the period.

JEL Classification Numbers: C33, E44, F34

Keywords: Financial Crises, Contagion, Spillovers, Russia, LTCM, latent factor model

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International financial markets have experienced several episodes of financial crisis since the mid-1990s. A major concern of financial market participants, central banks and governments during these periods is that a crisis in one country can spread to other markets to create extreme volatility elsewhere in the world. This is the case for the period corresponding to the Russian bond default in August of 1998, followed by the announcement of a recapitalization package for the hedge fund Long Term Capital Management (LTCM), where bond markets in emerging and industrial countries exhibited widespread volatility. The Bank of International Settlements survey of market participants characterised this period as “the worst crisis” in recent times (Bank for International Settlements, Committee of the Global Financial System 1999:p40). A special feature of this crisis was that the duration was extremely short possibly as a result of the aggressive easing of monetary policy by the U.S. Federal Reserve in the period following the recapitalization announcement.

This paper identifies the transmission mechanisms of shocks from both the Russian bond default and the LTCM recapitalization announcement, to bond markets in emerging and industrial countries. Most analyses of recent financial crises tend to focus on either currency, banking or equity markets. In contrast, there is little empirical literature on the spread of crises through international bond markets. This is partly because a consistent and comprehensive historical timeseries database on bonds for many emerging economies is difficult to obtain. It is also partly the result of bond markets being relatively more stable during other financial crises such as the Asian crisis, where it was equity and currency markets that exhibited relatively greater volatility.

The empirical analysis is conducted on a panel of daily bond spreads for a broad range of emerging and industrial countries over 1998. The spreads of the emerging economies are the long-term sovereign bonds issued in international markets relative to a comparable risk-free benchmark, whilst the spreads of the industrial countries are the long-term corporate bonds issued in the domestic economy relative to a comparable risk-free benchmark. One advantage of working with bond spreads is that they reflect the risk premium that investors assign to prospective borrowers. These risks include the perceived creditworthiness of borrowers, the willingness of lenders to take on risk, and the liquidity in the market, all of which are entangled during crisis episodes.¹

¹ This interpretation is consistent with the widening of the liquidity premium on otherwise similar assets (e.g. on-the-run 30-year versus off-the-run 29-year U.S. Treasury bonds) following the LTCM recapitalization announcement. The credit risk view of the Russian (continued)
The identification of the crisis transmission mechanisms between international bond markets is based on specifying a latent factor model of bond spreads. The factors include common shocks which impact upon all bond markets, and country-specific shocks which are idiosyncratic to a specific bond market. The set of factors investigated also consist of shocks that represent the impact of unanticipated movements in one market on other markets. This transmission channel is referred to as contagion as it represents an additional linkage in excess of movements in bond spreads that arise from changes in market fundamentals; see, for example, Sachs, Tornell and Velasco (1996), Masson (1999a,b,c), Dornbusch, Park and Claessens (2000) and Pericoli and Sbracia (2003). The origins of the approach stem from the models investigated by Diebold and Nerlove (1989) and Mahieu and Schotman (1994). More recently, Dungey, Martin and Pagan (2000) demonstrate how this type of model can be identified and estimated using indirect estimation techniques. An important feature of this modelling strategy is that it is possible to decompose the observed volatility in bond spreads into various components and thereby identify the contribution of contagion to total volatility in each country’s bond market.2

The results of the empirical analysis show evidence of contagion from the Russian crisis to other bond markets, whereas the contagious channels operating at the time of the LTCM recapitalization announcement appear to be more limited. The evidence also suggests that while the U.S. experienced some contagion from Russia, contagion in the reverse direction is found to be even smaller.

In proportionate terms, the contagion effects from Russia are particularly substantial for the Netherlands, Brazil, Bulgaria and Thailand. Countries relatively unaffected by contagion include the U.K., Indonesia, Mexico and Argentina. Overall, the results suggest that contagion is important not just for emerging countries, but also for countries with developed financial markets. This feature of the empirical results is in contrast to the views of the Committee on the Global Financial System (1999: pp7-8) who claim that the Russian crisis affected only emerging markets. It also contrasts with the empirical findings of Bae, Karyoli shock is also consistent with a cash-out of liquid markets with increased credit risks as investors’ rebalanced their portfolios.

2 Another advantage of the latent factor model is that it circumvents the need to use proxy variables to measure market fundamentals, as they are identified by extracting the common movements in bond spreads. Examples of using proxy variables to measure market fundamentals include Eichengreen, Rose and Wyplosz (1996), Glick and Rose (1999) and Forbes and Rigobon (2002).
and Stulz (2003) who find that equity markets in emerging countries are more likely affected by contagion than equity markets in developed markets.

One interesting feature of the empirical results is that Brazil is one of the countries most affected by contagion from Russia. Given that the sample period chosen ends just prior to the Brazilian crisis which unfolded in January 1999, this suggests that at least some of the seeds of this crisis date back to the volatility on global bond markets sparked by the default on Russian bonds in August of 1998.

The remainder of this paper is organized as follows. Section I reviews the background of events and proposes a set of hypotheses to test. This is followed by a discussion of the empirical characteristics of the data in Section II. A model of contagion is described in Section III, and is then related to the existing literature on contagion in Section IV. The estimation method is discussed in Section V followed by the empirical results in Section VI. Section VII concludes.

I. BACKGROUND OF EVENTS AND HYPOTHESES

I.1 Stylised Facts

During the Asian crisis, the turmoil which began with the devaluation of the Thai baht in July 1997, quickly precipitated declines in currencies and equities in the region and in other emerging markets (Granger, Huang and Yang (2000)). This contrasts with debt markets during this period where the effects on the risk premia of international bonds issued by emerging countries were rather limited. Apart from the relatively short period of turmoil in global financial markets resulting from the speculative attack on Hong Kong on October 27, 1997, bond spreads remained relatively stable in non-Asian countries during the second half of 1997 (see Figure 1).
Figure 1. Bond Spreads, January 1997-May 1999 \(^1\) (basis points)

\(^1\) The shaded areas refer to episodes of crisis in international bond markets: the Hong Kong speculative attack on October 27, 1997; the Russian bond default on August 17, 1998; the LTCM recapitalization announcement on September 23, 1998; the inter-FOMC Fed interest rate cut on October 15, 1998; and the Brazilian effective devaluation on January 13, 1999 followed by several weeks of internal turmoil at the central bank. Data Sources: U.S. Federal Reserve, Bloomberg, Scotia Capital and Credit Swiss First Boston.
Figure 2. Bond Spreads, January 1998-December 1998 \(^1\) (basis points)

\(^1\) The shaded areas refer to episodes of crisis in international bond markets during this period: the Russian bond default on August 17, 1998; the LTCM recapitalization announcement on September 23, 1998; and the inter-FOMC Fed interest rate cut on October 15, 1998. Data Sources: U.S. Federal Reserve, Bloomberg, Scotia Capital and Credit Swiss First Boston.
Figures 1 and 2 also show that the stability experienced in international bond markets in the second half of 1997, continued into the first part of 1998. However, on August 17, 1998, when Russia widened the trading band of the ruble, imposed a 90-day moratorium on the repayment of private external debt and announced its plan to restructure official debt obligations due to the end of 1999, financial turmoil ensued. Following the Russian default, spreads in other bond markets jumped, particularly in emerging markets, as markets reassessed global credit risks, see Figures 1-2.

In a matter of weeks after the Russian crisis, on September 23, 1998, financial markets learned of the plan to rescue LTCM, a large U.S. hedge fund which was in danger of collapse. LTCM operated by placing highly leveraged positions on the the expectation of falling yield spreads based on historical evidence. Many historical correlations were overturned following the Russian crisis with LTCM losing enormous amounts of money on these positions; see Jorion (2000) who documents the evolution of LTCM's problems. The situation became serious quickly, to the extent that the New York Federal Reserve acted to facilitate a meeting between major banks which eventually co-operated to provide a bailout package to the troubled hedge fund.

During this period the U.S. Federal Reserve cut interest rates in three steps, on 29 September, 15 October and 17 November, partly due to concerns that the dramatic rises in bond spreads, particularly for corporate debt, were indicative of a liquidity crisis. The October 15 interest rate cut was considered as a surprise, as it occurred between FOMC meetings. This cut was also interpreted as signalling a return to confidence in the markets, according to market participants surveyed in Bank for International Settlements, Committee on the Global Financial System (1999:pp9,39,45).

3 See Kharas, Pinto and Ulatov (2001) for a discussion of the Russian crisis

4 The exact timing of the LTCM crisis is necessarily approximate as pressures began building before the announcement of the recapitalization package for LTCM. Here we date the crisis as beginning with the recapitalization announcement on September 23, 1998 and ending with inter-FOMC Fed interest rate cut on October 15, 1998 which signaled the beginning of the (continued)
Informal examination of the data for the second half of 1998 (Figure 2) suggests that the Russian crisis had a substantial impact on bond markets in both developed economies and emerging markets. The LTCM recapitalization announcement also appears to have had an impact on all the countries, with a relatively smaller hump experienced by most emerging countries relative to the effect of the Russian shock. The data seem to suggest that the Russian and the LTCM recapitalization announcement shocks were reinforcing in their effects on other financial markets as practically all markets experienced two jumps in their spreads: one following the Russian default (the first band in Figure 2) and another one following the announcement of the LTCM financial problems (the second band in Figure 2). Similarly, the fact that corporate bond spreads began to rise in the U.S. following the Russian crisis and that the Russian sovereign spread rose even further in the aftermath of the LTCM recapitalization announcement suggests that these two events may not have been independent.

Unlike other recent financial crises, the shocks that occurred during August and September 1998, seem to have been transmitted across countries with little in common. This includes countries that do not fit traditional explanations of contagion based on trade links, competitive devaluation or regional effects as suggested in the taxonomies of contagion by Lowell, Neu and Tong (1998) and Goldstein (1998). These crises affected countries as diverse as the U.K. and Brazil, and spanned emerging and developed markets. Disentangling the crisis of 1998 is particularly complex because of its relative brevity and the fact that two distinct shocks occurred within weeks of each other.

I.2 Hypotheses

The discussion above suggests that a number of hypotheses can be formulated to test the transmission of contagion across national borders. Four broad hypotheses are formulated. The first is based on the existence of contagion, whereas the other three hypotheses are

“end” of the LTCM crisis. This otherwise arbitrary “end” to the crisis of 1998, is supported by the findings of Kumar and Persaud (2001).
concerned with the conditions that control the strength of contagious transmission mechanisms.

**Hypothesis A: Transmission of the crises through contagion**

The first aim of the paper is to identify the strength of contagion in transmitting crises between international bond markets. If contagion is not important, then the transmission mechanisms solely arise from trade and other macroeconomic linkages which occur during non-crisis periods as well.

**Hypothesis B: Exposure through the banking system**

<table>
<thead>
<tr>
<th>Country</th>
<th>Size of Economy (GNI, US$ bil)</th>
<th>Offshore Banking Exposure, US$ million</th>
<th>Total banking exposure to size of economy (%)</th>
<th>Russian exposure to total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>8447</td>
<td>160784</td>
<td>7781</td>
<td>1.9</td>
</tr>
<tr>
<td>U.K.</td>
<td>1327</td>
<td>165815</td>
<td>1834</td>
<td>12.5</td>
</tr>
<tr>
<td>Netherlands</td>
<td>403</td>
<td>94394</td>
<td>3979</td>
<td>23.4</td>
</tr>
</tbody>
</table>

Source: Column (1) is drawn from World Bank World Tables provided in dX Data; Columns (2) and (3) are sourced from the historical data from Table 9C in the *BIS Quarterly Review*.

Countries whose financial institutions have relatively larger exposures to Russia are expected to experience greater contagion. The implications of financial and institutional linkages between countries as a channel of contagion have been investigated by Kaminsky and Reinhart (2000), Van Rijckeghem and Weder (2001, 2003), Pritsker (2001). Table 1 provides information on the relative size of offshore banking exposure for the industrial economies of the U.S., U.K. and the Netherlands. These figures show that as a proportion of the total economy, total offshore banking exposure is 23.4% for the Netherlands in 1998, which is nearly twice that of the U.S. and more than 10 times that of the U.K. In terms of exposure to Russia, the proportion is nearly 10 times more than both the U.S. and the U.K. These figures
suggest that the Netherlands is potentially more vulnerable to contagion arising from the Russian bond default than either the U.S. or the U.K.

**Hypothesis C: Regional effects**

If contagion impacts within regions, it is expected that the Russian bond default should particularly impact upon the Eastern European countries, Poland and Bulgaria. The importance of testing the regional effects of contagion is emphasized by Eichengreen, Rose and Wypolz (1996), Glick and Rose (1999) and Kaminsky and Reinhart (2000).

**Hypothesis D: Fundamentals – vulnerabilities**

Countries with strong market fundamentals are less susceptible to the effects of contagion (Mody and Taylor, 2003, Sachs, Tornell and Velasco, 1996). This suggests that the emerging market economies investigated here are more likely to be prone to contagion than the developed economies; namely the U.S., U.K. and the Netherlands. In a similar vein, the Committee for Global Financial System (1999: pp7-8) claims that the Russian crisis affected emerging markets, while the LTCM recapitalization announcement affected developed markets. In the equity markets Kaminsky and Reinhart (2002) find that developed markets act as a conduit for financial crises between emerging markets, while Bae, Karolyi and Stulz (2003) find greater impact of crises on emerging equity markets.

**II. The Data and Sample**

The dataset comprises daily data for twelve countries collected for February to December 1998 (Mexico, Argentina, Brazil, Indonesia, Korea, Thailand, Bulgaria, Poland, Russia, the Netherlands, the U.K. and the U.S.). This sample period allows our estimation to incorporate a clear ‘pre-crisis’ period and the two crisis events of the Russian bond default and the LTCM recapitalization announcement. The choice of daily data, over lower frequency data, is made in order to disentangle the effects of the Russian shock and the LTCM recapitalization announcement which occurred in close proximity to each other.
The data represent the spread of long-term debt over the appropriate risk-free yield for each country (see Appendix A for source descriptions, definitions and details). We label this spread as the ‘premium’ while recognizing that it does in fact reflect a myriad of factors, including the liquidity premium and the term structure of the yield curve. The choice of the risk-free rate is specific to each long-term bond. In the case of emerging countries, sovereign bonds are issued in U.S. dollars and hence the spread is calculated against the comparable maturity-matched U.S. Treasury bond rate. Where possible, the bonds selected for emerging markets are sovereign issues to reflect the true cost of new foreign capital – the exceptions are Poland and Bulgaria which are represented by Brady bonds. In the case of the developed bond markets, which are able to issue international bonds in domestic currency, BBB investment grade corporate bonds are compared to the corresponding risk-free Treasury bond in each country.5

The data for the U.S. are obtained directly from the Federal Reserve, and not from published sources. The source of the data for countries other than the U.S. is the authorities of each country. This data set was originally collated for the Committee on the Global Financial System to examine the events surrounding the market stresses in the third quarter of 1998 and is summarized in the Committee on the Global Financial System (1999). In those cases where there are missing observations, the data are obtained from either Bloomberg database or Credit Swiss First Boston directly (see Appendix A for more details).

A potential problem with using just price data is that prices may be biased due to lack of active market makers during the crisis periods. This is especially true during the LTCM recapitalization announcement period which was a crisis of liquidity. To circumvent this problem would require data on trade quantities. However, quantity data are not available at high frequency for the range of countries considered. Using lower frequency data would have the disadvantage of yielding insufficient information to characterize the Russian and LTCM

5 Below-investment grade corporate issues experienced even bigger jumps in their spreads and in their volatility. However, data limitations restricted the study to investment grade bonds.
recapitalization announcement crises, which are of a relatively short duration. For this reason, attention is focused on using daily price data.

The statistical characteristics of the data are summarised as follows, with full details given in Appendix B. The rise in spreads over the period is approximated by a unit root, as the corresponding risk free rates remained relatively constant. Both larger means and absolute movements are evident in the premia of developing markets compared with the industrialized countries. The data display non-normality, and fitting univariate integrated GARCH(1,1) models to the changes in the premia suggests that there is a common time-varying volatility structure underlying the data. This feature of the structure is exploited in the model described in the following section.

III. A FACTOR MODEL OF THE “PREMIUM”

Volatility in the premia of each country is hypothesized to be influenced by events that are country-specific and events that are common to all economies. However, it is difficult to ascertain both the timing and nature of these events. In the existing literature, contagion is tested by conditioning on events chosen by the researcher after the observed financial crises, for example the work of Eichengreen, Rose and Wyplosz (1995, 1996), Sachs, Tornell and Velasco (1996), and Glick and Rose (1999) follows this approach. The economic indicators chosen in this way are often statistically insignificant, and it is difficult to know whether they are the ‘correct’ choice even ex-post. A desirable alternative, noted by authors such as Dooley (2000) and Edwards (2000), is to use a modelling specification which does not require the choice of specific indicators with which to associate the crises, that is to use latent factors.

Latent factor models have been specified for a number of markets. The majority of the existing empirical work has focused on currency and equity markets, such as represented in Diebold and Nerlove (1989), Ng, Engle and Rothschild (1992), Mahieu and Schotman (1994), and King, Sentana and Wadhwani (1994). Empirical work on interest rates is rather less extensive. Gregory and Watts (1995) explore long bond yields across countries, while
Dungey, Martin and Pagan (2000) apply a latent factor model to the spreads between individual country bonds and the US bond.\(^6\)

The basic model of the bond market adopted in this paper is similar to that specified by Forbes and Rigobon (2002) and King, Sentana and Wadhwani (1994) for equity markets. Letting \( r_{it} \) be the interest rate on the bond in country \( i \), the interest rate is determined by a risk-free rate of interest, \( rf_{it} \), a world factor, \( W_t \) and a time-varying country-specific factor \( f_{it} \),

\[
    r_{it} = rf_{it} + \lambda_i W_t + \phi_i f_{it}, \quad i = 1...n, \tag{1}
\]

where \( n \) is the number of bond markets. The loadings on these world and country-specific factors are given by the parameters \( \lambda_i \) and \( \phi_i \) respectively. The common factor, \( W_t \), affects the premia in all countries, but with a differing parameter in each case.

Regional effects have been posited to be important in the spread of crises, for example in the work of Kaminsky and Reinhart (2002) and Glick and Rose (1999). To incorporate these effects, equation (2) is extended as follows:

\[
    r_{it} = rf_{it} + \lambda_i W_t + \phi_i f_{it} + \gamma_k R_{kt}, \quad i = 1,...,n, k = Lat, As, Eur, \tag{2}
\]

where \( R_{kt} \) is a time-varying regional factor and \( K=3 \) is the number of regions. The first regional factor is common to Latin American countries (Argentina, Brazil and Mexico) and is denoted \( R_{Lat,t} \). The second is a regional factor common to the Asian economies (Indonesia, Korea and Thailand), denoted \( R_{As,t} \) whilst the third regional factor of Eastern Europe (Bulgaria, Poland and Russia) is denoted \( R_{Eur,t} \). No regional factor is included for the industrialized countries comprising the U.S., the U.K. and the Netherlands. Defining the premium to be \( P_{it} = r_{it} - rf_{it} \), the model without contagion is specified as

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\(^6\) A similar class of models has recently been adopted by Kose, Otrok and Whiteman (2004) in studying business cycles.
To incorporate the large movements in the premia over the sample period identified in Section II, the common factor is specified as integrated of order one

\[ W_t = W_{t-1} + \eta_t, \]  

where \( \eta_t \) is a stationary disturbance term. The regional factors in (3) are also specified as integrated processes of order one

\[ R_{k,t} = R_{k,t-1} + \nu_{k,t}, \quad \text{where} \quad k = \text{Lat, As, Eur}, \]  

where \( \nu_{k,t} \) are stationary disturbance terms. In addition, equation (3) shows that each premium has a unique idiosyncratic error, or country-specific factor, \( f_{i,t} \). To complete the specification of the non-contagion model, the disturbance processes are assumed to be distributed as

\[ \eta_t, \nu_{\text{Lat},t}, \nu_{\text{As},t}, \nu_{\text{Eur},t}, f_{1,t}, f_{2,t}, \ldots f_{12,t} \sim N(0, H_t), \]  

where in general \( H_t \) is a 16-variate system of independent GARCH processes normalized to have unit unconditional variances. Whilst the factors are assumed to be independent, the
model nonetheless is able to capture the comovements in bond spreads in the mean, as well as in the variance. An important advantage of adopting a factor structure is that it provides a parsimonious representation of the data, thereby circumventing the need to estimate highly parameterized multivariate GARCH models. Here we restrict the GARCH to the world factor, following the preliminary GARCH results reported in Appendix B, Table B4, which showed a high degree of commonality amongst the conditional variance structure of the premia.\footnote{The three regional factors were initially assumed to exhibit GARCH processes, but were found to be statistically insignificant.}

To allow for contagion, the effects of unanticipated movements from other countries, on the premium in country \(i\), are incorporated by augmenting (3). The augmented system is shown in equation (7). Contagion from country \(j\) is represented by the effect of \(f_{j,t}\) on the \(i\)th equation with the strength of this linkage being determined by the loading parameter, \(\delta_{i,j}\). There are no own effects, that is \(\delta_{i,i}=0\), when \(i=j\).

\[
\begin{bmatrix}
 P_{1,j} \\
 P_{2,j} \\
 \vdots \\
 P_{12,j}
\end{bmatrix}
\begin{bmatrix}
 \lambda_1 \\
 \lambda_2 \\
 \vdots \\
 \lambda_{12}
\end{bmatrix}
\begin{bmatrix}
 \gamma_{1,Lat} & 0 & 0 \\
 \gamma_{2,Lat} & 0 & 0 \\
 \gamma_{3,Lat} & 0 & 0 \\
 0 & \gamma_{4,As} & 0 \\
 0 & \gamma_{5,As} & 0 \\
 0 & \gamma_{6,As} & 0 \\
 0 & 0 & \gamma_{7,Eur} \\
 0 & 0 & \gamma_{8,Eur} \\
 0 & 0 & \gamma_{9,Eur} \\
 0 & 0 & 0 \\
 0 & 0 & 0 \\
 0 & 0 & 0 \\
 0 & 0 & 0 \\
 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
 R_{Lat,j} \\
 R_{As,j} \\
 R_{Eur,j}
\end{bmatrix}
\begin{bmatrix}
 \phi_1 \\
 \phi_2 \\
 \vdots \\
 \phi_{12}
\end{bmatrix}
\begin{bmatrix}
 f_{1,j} \\
 f_{2,j} \\
 \vdots \\
 f_{12,j}
\end{bmatrix}
\begin{bmatrix}
 \delta_{1,As} & \delta_{1,Eur} \\
 \delta_{2,As} & \delta_{2,Eur} \\
 \delta_{3,As} & \delta_{3,Eur} \\
 \delta_{4,As} & \delta_{4,Eur} \\
 \delta_{5,As} & \delta_{5,Eur} \\
 \delta_{6,As} & \delta_{6,Eur} \\
 \delta_{7,As} & \delta_{7,Eur} \\
 \delta_{8,As} & \delta_{8,Eur} \\
 \delta_{9,As} & \delta_{9,Eur} \\
 \delta_{10,As} & \delta_{10,Eur} \\
 \delta_{11,As} & \delta_{11,Eur} \\
 \delta_{12,As} & \delta_{12,Eur}
\end{bmatrix}
\begin{bmatrix}
 f_{7,j} \\
 f_{8,j} \\
 f_{9,j} \\
 f_{10,j}
\end{bmatrix}
\]

(7)

Our interest is in the effects of contagion on international bond markets from the Russian shock and the LTCM recapitalization announcement. To allow for contagion in the model,
the idiosyncratic shocks in Russia ($f_{rt}$) and the U.S. ($f_{10t}$) are included as additional determinants of the bond spreads of the other countries. While LTCM had a broad range of liabilities in different currencies, it was a U.S. based fund, which denominated its returns in U.S. dollars. While the collapse of LTCM would have had major implications for global financial markets, for example the Japanese, French and Swiss banks had substantial exposures to LTCM, the major U.S. based banks were the most heavily exposed. Hence, it is natural to use the U.S. high yield spread during this period as a proxy for the LTCM recapitalization announcement shock.

The dominance of U.S. financial markets makes it difficult to argue that U.S. based shocks over the whole sample period represent only the LTCM recapitalization announcement. To isolate the impact of the LTCM recapitalization announcement period, the U.S. country-specific factor, $f_{10t}$ in (7), is preceded by an indicator variable $I_t$. This is a binary dummy, which takes the value of 1 for the period of the LTCM recapitalization announcement shock, the 23rd of September 1998 to the 15th of October 1998, and 0 for the non-LTCM crisis period.8 This choice of dates is consistent with the Committee on the Global Financial System (1999:pp8-9). It begins with the recapitalization package announced on 23rd September, and ends with the inter-FOMC rate cut by the Federal Reserve on October 15th, a date supported by Kumar and Persaud (2001). Whilst it is apparent that there were signals that LTCM was in difficulty pre September 1998, reports suggest that the true size of the problem became clearer around the time of the meetings co-ordinated by the Federal Reserve, see for example Shirreff (1998). As the clearest signal to the market of LTCM's difficulties was the recapitalization announcement, this is used as the starting date.

A useful way of examining the results from estimating a model such as (7) is to consider the contribution that each factor makes to total volatility in the movement of the premium of

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8 In Dungey, Fry, González-Hermosillo and Martin (2002), the indicator variable, $I_t$, was omitted – the influence of the US economy in global markets means that the impact of the LTCM shock was somewhat overstated. We thank Charles Goodhart for his suggestions on the structure of the dummy variable.
each country. As the factors are independent, the total variance of the change in the premia for each economy can be conveniently decomposed as

\[
\text{Var}(\Delta P_i) = \lambda_i^2 + \gamma_i^2 + 2\delta_{i,\text{Rus}}^2 + 2\delta_{i,\text{US}}^2 + 2\phi_i^2.
\]

The results of interest are then given as the proportion of the total volatility in the changes in the premium for country \(i\) due to the:

(i) contribution of the world factor

\[
\frac{\lambda_i^2}{\text{Var}(\Delta P_i)}
\]

(ii) contribution of the regional factor

\[
\frac{\gamma_i^2}{\text{Var}(\Delta P_i)}
\]

(iii) contribution of country-specific factor

\[
\frac{2\phi_i^2}{\text{Var}(\Delta P_i)}
\]

(iv) contribution of contagion from Russia

\[
\frac{2\delta_{i,\text{Rus}}^2}{\text{Var}(\Delta P_i)}
\]

(v) contribution of contagion from the U.S.

\[
\frac{2\delta_{i,\text{US}}^2}{\text{Var}(\Delta P_i)}
\]

IV. RELATIONSHIP WITH EXISTING LITERATURE

The models estimated in this paper decompose volatility in the premium between long term bonds and an appropriate ‘risk-free’ rate, for a variety of economies into a set of latent factors. In common with a substantial portion of the literature the effects of idiosyncratic shocks which transmit across national borders are denoted as contagion; here these shocks originate in Russia and the U.S..

The concept of contagion from both a theoretical and empirical viewpoint is controversial in the literature. Recent overviews of the issues are provided by Dornbusch, Park and Claessens (2000) and Pericoli and Sbracia (2003). The definition of contagion adopted in this paper is that contagion reflects the spillover effect of unanticipated contemporaneous movements across countries. This definition of contagion is related to the approach of Favero and
Giavazzi (2002) and Forbes and Rigobon (2001, 2002) and under certain scenarios is also equivalent to Eichengreen, Rose and Wyplosz (1996) and Bae, Karolyi and Stulz (2003); see Dungey, Fry, González-Hermosillo and Martin (2003).

Contagion is viewed here as a residual, which is a common theme in the literature, for example the work of Sachs, Tornell and Velasco (1996) and Masson (1999a,b,c). Masson decomposes exchange rate changes into four components. These are “monsoonal shocks”, or global shocks affecting all countries simultaneously, \((W_t\) in (7)); linkages which occur through normal trade and economic relationships, (a combination of \(W_t\) and \(R_{k,t}\) in (7)); country-specific shocks, \((f_{i,t}\) in (7)), and a residual, which is the component unexplained by these systematic relationships. It is this last concept that both Masson and we denote as contagion. For the model specified here this residual is a combination of effects from \(f_{7,t}\) and \(f_{10,t}\) which are the shocks from Russia and the U.S..

Masson (1999a,b,c) attributes part of the residual process to multiple equilibria, or sunspots, where there is a role for self-fulfilling expectations leading to contagion if opinions are coordinated across countries, an approach also taken by Loisel and Martin (2001). Multiple equilibria models are also consistent with other channels for contagion, such as wake-up calls due to Goldstein (1998) or heightened awareness due to Lowell, Neu and Tong (1998). In these cases a reappraisal of one country’s fundamentals leads to a reappraisal of the fundamentals in other countries, thereby resulting in the transmission of crises. Kyle and Xiong (2001) explain contagion in the LTCM and Russian crises as a wealth effect, as traders operating in risky markets encounter shocks and liquidate their portfolios. Thus, a shock in one market can reverberate in seemingly unconnected markets. Both the wake-up call, wealth effect model and Masson's definition of contagion are consistent with the model presented in Section III.

The transmission of expectations in both the multiple equilibrium and wake-up call models can lead to herd behavior as in work by Kaminsky and Schmukler (1999) and Calvo and Mendoza (2000). Herd behavior leads to a concept distinguished as unwarranted contagion by Kruger, Osakwe and Page (1998), which occurs when a crisis spreads to another country.
that otherwise would not have experienced a speculative attack. This also corresponds with contagion defined as a residual. A further potential channel of contagion is through asset bubbles created by self-fulfilling expectations, moral hazard, or government guarantees, either implied or explicit. Krugman (1998) shows how herd behaviour may burst these bubbles.

Existing empirical work which also uses definitions of contagion fitting into the current framework, include Forbes and Rigobon (2002) who test for changes in the correlation structure between asset returns, and Favero and Giavazzi (2002) who concentrate on testing for the transmission of large shocks across markets. The effect of ‘news’ announcements in transmitting crises is investigated by Baig and Goldfajn (1999) and Ellis and Lewis (2000) for a range of countries. Kaminsky and Schmukler (1999) also analyze the effects of news, where contagion is defined as the spread of investors’ moods across national borders. Their key result is that some of the largest swings in the stock market occurred on days of no news. However, Baig and Goldfajn (1999) and Kaminsky and Schmukler (1999) make no distinction between anticipated or unanticipated news.

Alternative definitions of contagion which lie outside the framework adopted in this paper are based on market fundamental linkages. In the framework of Section III, these channels are captured by the global and regional factors of the model. For example, Reside and Gochoco-Bautista (1999) define contagion as the spillover effects of domestic disturbances on nearby or related economies, using lagged changes in the exchange rates as their contagion variable. Goldstein, Kaminsky and Reinhart (2000) construct a contagion vulnerability index based on correlations between stock markets, trade linkages, presence of common markets and inter-linkages between banking systems. Van Rijckegehem and Weder (2001) construct a subjective binary variable to examine contagion effects due to financial and trade linkages. Eichengreen, Rose and Wyplosz (1996), Wirjanto (1999), and Kruger, Osakwe and Page (1998) condition their models on the existence of a crisis elsewhere, which implies that volatility is anticipated.
V. Estimation Method

Gourieroux and Monfort (1994) have shown that direct estimation of the factor model in Section III by likelihood methods is infeasible as a result of the nonlinearisation arising from the GARCH conditional variance structure. Estimation procedures based on the Kalman filter or GMM only produce an approximation to the likelihood and thereby yield inconsistent parameter estimates. To circumvent problems of parameter inconsistency we adopt the indirect estimation techniques of Gourieroux, Monfort and Renault (1993) and Gourieroux and Monfort (1994) to estimate the models specified in Section III. Indirect estimation belongs to a class of techniques whereby the parameters are estimated by matching the characteristics of the sample data, with those of data simulated from the hypothesized model. The key to this technique is that while the model is analytically complex to evaluate directly, it is relatively straightforward to simulate. Other forms of this technique are known as Simulated Method of Moments (SMM) and Efficient Method of Moments (EMM). SMM is associated with the work of Duffie and Singleton (1993) and EMM with Gallant and Tauchen (1996). The differences between the three methods lie in the way in which the matching of moments between actual and simulated data proceeds.

In indirect estimation, the matching of moments is accomplished via specifying an auxiliary model which acts as an approximation to the true likelihood function. The auxiliary model is chosen to capture the key empirical characteristics of the data which are needed to identify the unknown parameters. The first set of conditions is based on a VAR(1) of the levels of the premia, where the moments are given by the product of the residuals and the lagged values of all premia in the VAR, \( P_{t-1} \). That is,

\[
K_i^1 = \{u_{it} P_{t-1}' , u_{i1} P_{t-1}' , u_{i2} P_{t-1}' , ..., u_{i32} P_{t-1}' \}.
\]

(9)

This is of dimension (1x144).

The second set of moment conditions corresponds to the variance of the level of the premia. Formally,
\[ k_i^1 = P_{i,j}^2, \quad i \geq 1, 2, ..., 12. \] (10)

The third set of moment conditions captures the AR(1) structure of the changes in the premia,

\[ k_i^2 = (\Delta P_{i,j} - \Delta P_{i,j-1})(\Delta P_{i,j-1} - \Delta P_{i,j-2}), \quad i = 1, 2, ..., 12. \] (11)

The fourth and fifth set of moment conditions capture conditional volatility in the premia arising from the GARCH characteristics of the data discussed in Section II. It comprises AR(1) and AR(2) loadings for the squared changes in the premia. In a similar manner to Diebold and Nerlove (1989), the number of overidentifying conditions is controlled by including only the ‘own’ squared autocorrelations of the change in the premium. These additional expressions contain a total of 12 elements each

\[ k_i^3 = (\Delta P_{i,j}^2 - \Delta P_{i,j-1}^2)(\Delta P_{i,j-1}^2 - \Delta P_{i,j-2}^2), \quad i = 1, 2, ..., 12, \] (12)

\[ k_i^4 = (\Delta P_{i,j}^2 - \Delta P_{i,j-1}^2)(\Delta P_{i,j-2}^2 - \Delta P_{i,j-3}^2), \quad i = 1, 2, ..., 12. \] (13)

Collecting all \((144+12+12+12+12)\) time series from (9) to (13) into a \((1 \times 192)\) vector

\[ g_t = \{k_i^0, k_i^1, k_i^2, k_i^3, k_i^4\}, \] (14)

and taking the sample average of \(g_t\) defines all of the moment conditions that summarize the auxiliary model at time \(t\).

Analogous to the moment conditions based on the sample data, a set of moment conditions based on the simulated data is given by taking the sample averages of,

\[ v_h = \{k_h^0, k_h^1, k_h^2, k_h^3, k_h^4\}, \] (15)

where \(k_h^0, k_h^1, k_h^2, k_h^3\) and \(k_h^4\) are the analogs of equations (9) to (13) with the actual data replaced by the simulated data for the \(h^{th}\) simulation of the premia, \(P_{t,h}\).

Letting \(\theta\) be the set of unknown parameters of the latent factor model, the indirect estimator, \(\hat{\theta}\), is the solution of:
\[ \hat{\theta} = \arg \min_{\theta} \left[ \bar{g} - \frac{1}{H} \sum_{h=1}^{H} \bar{v}_h \right] \Omega^{-1} \left[ \bar{g} - \frac{1}{H} \sum_{h=1}^{H} \bar{v}_h \right], \]  
\tag{16}

where \( \bar{g} \) and \( \bar{v}_h \) are respectively the sample means of equations (14) and (15). The matrix \( \Omega \) is a weighting matrix computed as follows, see Gourieroux, Monfort and Renault (1993),

\[ \Omega = \frac{1}{T} \bar{g}, \bar{g} + \frac{1}{T} \sum_{i=1}^{L} \omega_l (g_t, g_{t-l} + g_{t-l} g_{t-t}) \]  
\tag{17}

where

\[ \omega_l = \frac{1}{L+l}, \]  
\tag{18}

are the Newey-West weights. In constructing this weighting matrix, the blocks are assumed to be independent.

The indirect estimator in equation (16) is solved using the gradient algorithms in OPTMUM, GAUSS version 3.2, where the gradients are computed numerically. The simulations are based on normal random numbers using the GAUSS procedure RNDN.\(^9\)

VI. Empirical Results

To examine the differences between the transmission of contagion from the Russian crisis and the LTCM recapitalization announcement, the unconditional variance decomposition estimates using equation (8), are presented in Table 2, and summarized in Figure 3.\(^{10}\) Total

\(^9\) All results are based on \( H=500 \) simulation paths in (16) with a convergence tolerance of 0.001 and a lag window of \( L=5 \) in equation (17).

\(^{10}\) Experiments extending this class of models to allow for contagion from the Latin American and Asian regions in conjunction with contagion from the U.S. and Russia, were undertaken to allow for the most general specification. However, this line of research was not pursued due to an undesirable amount of parameter instability inherent in estimating the larger models. The present model is an extension of the model investigated in Dungey, Fry, (continued)
volatility is decomposed into the contribution due to the world factor, regional factors, country-specific factors and the contagion effects from Russia and the LTCM recapitalization announcement shocks.

Table 2: Volatility Decomposition of Changes in the Premia (contribution to total volatility, in percent)

<table>
<thead>
<tr>
<th></th>
<th>World</th>
<th>Country</th>
<th>Regional</th>
<th>Contagion</th>
<th>From Russia</th>
<th>From U.S.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industrial</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S.</td>
<td>84.972</td>
<td>11.833</td>
<td>-</td>
<td>3.196</td>
<td>-</td>
<td>3.196</td>
<td></td>
</tr>
<tr>
<td>U.K.</td>
<td>99.735</td>
<td>0.013</td>
<td>-</td>
<td>0.099</td>
<td>0.153</td>
<td>0.252</td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>82.289</td>
<td>0.520</td>
<td>-</td>
<td>16.941</td>
<td>0.251</td>
<td>17.191</td>
<td></td>
</tr>
<tr>
<td><strong>Eastern Europe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>94.733</td>
<td>5.058</td>
<td>0.107</td>
<td>-</td>
<td>0.102</td>
<td>0.102</td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>93.708</td>
<td>0.046</td>
<td>0.659</td>
<td>5.314</td>
<td>0.273</td>
<td>5.587</td>
<td></td>
</tr>
<tr>
<td>Bulgaria</td>
<td>91.334</td>
<td>0.204</td>
<td>0.516</td>
<td>7.573</td>
<td>0.374</td>
<td>7.946</td>
<td></td>
</tr>
<tr>
<td><strong>Asia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>98.847</td>
<td>0.269</td>
<td>0.205</td>
<td>0.299</td>
<td>0.381</td>
<td>0.679</td>
<td></td>
</tr>
<tr>
<td>Korea</td>
<td>88.853</td>
<td>4.950</td>
<td>0.880</td>
<td>1.571</td>
<td>3.746</td>
<td>5.317</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>90.521</td>
<td>1.318</td>
<td>0.376</td>
<td>6.181</td>
<td>1.603</td>
<td>7.784</td>
<td></td>
</tr>
<tr>
<td><strong>Latin America</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>99.736</td>
<td>0.001</td>
<td>0.006</td>
<td>0.148</td>
<td>0.109</td>
<td>0.257</td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td>86.828</td>
<td>12.676</td>
<td>0.045</td>
<td>0.352</td>
<td>0.099</td>
<td>0.451</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>83.153</td>
<td>0.184</td>
<td>0.004</td>
<td>16.410</td>
<td>0.249</td>
<td>16.659</td>
<td></td>
</tr>
</tbody>
</table>

The results in Table 2 indicate that the dominant factor in the volatility decomposition of the change in the bond premia is the world factor, pointing strongly towards commonality in the movements in premia experienced over the sample period (Figures 1 and 2). This result is consistent with the view that increasing financial market integration has led to high (and expected) co-movements in asset prices. The world factor accounts for between 82 percent

González-Hermosillo and Martin (2002) which allowed for contagion effects just from Russia.
(Netherlands) and 99.7 percent (U.K. and Mexico) of total volatility. A corollary of this is that the regional factors have little influence on volatility, with all accounting for less than one percentage point of total volatility. Country-specific factors are relatively important for the U.S. (11.8 percent) and Argentina (12.7 percent), with the contribution to all the other countries being relatively small at less than 6 percent of total volatility.

The substantial contagion effects recorded in Table 2 are consistent with Hypothesis A in Section I.2, that contagious links exist during the crisis period. Most of the contagion effects in the results are sourced from Russia. The empirical results also show that contagion affects a wide range of countries across the regions investigated. Of the industrial nations, the Netherlands experiences almost 17 percent of its total volatility from contagion originating in Russia. The other developed markets experience less than 4 percent. These results provide support for Hypothesis B in Section I.2, that financial exposure to the Russian markets made economies vulnerable to contagion. The U.S. financial exposure to Russia is also partly evident in the results, with contagion representing 3 percent of total U.S. volatility.

The Russian crisis results provide some support for the regional hypothesis, Hypothesis C in Section I.2. Contagion from the Russian crisis was most consistently present in Eastern Europe, where it represents 5 and 7 percent of volatility for Poland and Bulgaria.

In contrast, contagion from the LTCM recapitalization announcement shock is very small as a proportion of total volatility, although its effects are nonetheless widespread across countries and regions. The largest contagion effect from the LTCM recapitalization announcement shock is under 4 percent of total volatility, experienced by Korea. It is possible that the relatively small LTCM recapitalization announcement effects are the result of the coordinated action of the U.S. Fed to halt its spread.

The results for Indonesia, Brazil, and Argentina are worthy of further examination. Indonesia drew comment as the hardest hit by contagion effects in currency markets during the 1997 Asian crisis; see for example discussions by Radelet and Sachs (1998) and Goldstein, Kaminsky and Reinhart (2000). However, the contagion effects in Indonesian bond markets during 1998, as measured here, are relatively small. Contagion may still have been
transmitted to Indonesia through asset markets other than the bond market, possibly due to illiquidity in the sovereign bond market during the political turmoil prevailing in Indonesia. An alternative interpretation is that Indonesia became extremely sensitive to global financial events in this period, consistent with a large value of $\lambda_i$, compared with the East Asian crisis.

The Brazilian results show a relatively large proportionate effect of contagion, predominantly sourced from Russia, consistent with the view developed by Baig and Goldfajn (2000) that the withdrawal of foreign capital from Brazil during the Russian crisis precipitated the Brazilian crisis of January 1999. The relatively large contagion effect to Brazil may be a reflection of the vulnerability of Brazilian fundamentals, consistent with Hypothesis D in Section I.2. Brazil at the time had recently managed to reenter global markets as a sovereign issuer and let domestic interest rates fall to stimulate the economy. In response to the Russian
shock it experienced sharp capital outflows as foreign investors withdrew, which eventually
promoted higher domestic interest rates and a tighter fiscal stance. However, the relief was
short-lived as these reforms came to be viewed as unsustainable in the light of the
depreciation of the Brazilian real (IMF (2001)).

Argentina appeared in relatively good economic condition at that time, which is consistent
with the fundamentals hypothesis. The International Monetary Fund (2001:9) pointed out that
Argentina had not had to access financial markets to meet its current financing commitments
during the crisis period. It was only later that the combination of policy settings was revealed
to be unsustainable. In light of this it is noteworthy that the factors determining total
volatility in the sample period for Argentina are more like those determining the U.S. than
the other countries examined. In particular, the contributions to total volatility coming from
the country-specific factors in Argentina and the U.S. are the largest of the countries
examined. This may reflect the fact that Argentina was the only emerging economy in our
sample with a currency board regime that appeared to be credible during this time.

The results provide little evidence to support the hypothesis that contagion emanating from
Russia is confined to developing nations, or that contagion emanating from the LTCM
recapitalization announcement was confined to developed markets, as suggested by the
Committee on the Global Financial System (1999: p7-8). However, it is difficult to derive
any stylized facts to support or refute the contention that emerging markets are more affected
by contagion than developed markets. The evidence presented here suggests that both types
of markets can be affected by contagion to varying degrees. For example, countries where
the effect of contagion from Russia is less than one percentage point include the U.K., Mexico,
Argentina and Indonesia.

To address these issues further, we transform the results in Table 2 into their squared basis
point equivalent by multiplying the values in Table 2 by the variance in the changes in the
premia for each country (i.e. the square of the standard deviations which are reported in
Table B.2 in Appendix B). The estimated variance decompositions in squared basis points are reported in Table 3.

### Table 3: Volatility Decomposition of Changes in the Premia
(contribution to total volatility, in squared basis points)

<table>
<thead>
<tr>
<th>Region</th>
<th>Total</th>
<th>World</th>
<th>Country</th>
<th>Regional</th>
<th>Contagion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industrial</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S.</td>
<td>6.380</td>
<td>0.888</td>
<td>-</td>
<td>0.240</td>
<td></td>
</tr>
<tr>
<td>U.K.</td>
<td>13.876</td>
<td>0.002</td>
<td>-</td>
<td>0.035</td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>23.907</td>
<td>0.151</td>
<td>-</td>
<td>4.994</td>
<td></td>
</tr>
<tr>
<td><strong>Eastern Europe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>55685.890</td>
<td>2973.197</td>
<td>62.971</td>
<td>59.942</td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>494.421</td>
<td>0.245</td>
<td>3.479</td>
<td>29.476</td>
<td></td>
</tr>
<tr>
<td>Bulgaria</td>
<td>9138.896</td>
<td>20.378</td>
<td>51.620</td>
<td>795.107</td>
<td></td>
</tr>
<tr>
<td><strong>Asia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>3085.454</td>
<td>8.385</td>
<td>6.408</td>
<td>21.210</td>
<td></td>
</tr>
<tr>
<td>Korea</td>
<td>728.813</td>
<td>40.602</td>
<td>7.219</td>
<td>43.616</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>452.579</td>
<td>6.591</td>
<td>1.882</td>
<td>38.918</td>
<td></td>
</tr>
<tr>
<td><strong>Latin America</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>525.311</td>
<td>0.006</td>
<td>0.034</td>
<td>1.352</td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td>984.339</td>
<td>143.707</td>
<td>0.505</td>
<td>5.118</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>2923.097</td>
<td>6.472</td>
<td>0.138</td>
<td>585.600</td>
<td></td>
</tr>
</tbody>
</table>

Comparing the results in Tables 2 and 3 highlights the differences between emerging and developed markets. Consider the Netherlands. In proportionate terms in Table 2, contagion contributes 17 percent to volatility in the Netherlands. However, in Table 3, this corresponds to 5 squared basis points, only greater than the other developed markets and Mexico. On the other hand, Brazil, which had the second greatest proportionate contribution from

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11 This result may also reflect the choice of the corporate bond used for the Netherlands, it would be interesting to expand the empirical analysis to a wider set of corporates.
contagion, also has the second greatest squared basis point contribution, at around 590 squared basis points. The largest squared basis point contribution from contagion was experienced by Bulgaria. Bulgaria had a proportionate contribution from contagion of almost 8 percent, similar to that for Thailand, but contagion contributed 795 squared basis points in Bulgaria, compared with 39 squared basis points in Thailand. The bond markets of emerging countries experienced a greater squared basis point contribution from contagion than the developed countries due to their absolute higher levels of volatility.

VII. CONCLUSION

The international spillover effects stemming from the Russian debt default and the LTCM recapitalization announcement in 1998 seemed to be different from those of other financial crises in the 1990s. In 1998, bond markets in both developed and emerging economies experienced a significant widening of spreads between long-term bonds and their corresponding risk-free rate of return. In other episodes of financial crisis during the 1990s, the impact of crises seemed to be limited to emerging markets, or even a regional subset of them.

This paper examined the crises associated with the Russian bond default in August 1998, and the LTCM recapitalization announcement in September 1998. Using a latent factor model, the change in the premia of twelve markets was decomposed into components associated with a common world factor, country-specific factors, regional factors and contagion effects. Contagion was defined as the contemporaneous effect of idiosyncratic shocks transmitting across country borders. This definition of contagion is consistent with those offered in a substantial portion of the literature on this topic, including Masson (1999a,b,c), Favero and Giavazzi (2002) and Forbes and Rigobon (2001, 2002). The novelty of this paper is both in the application to bond markets and that we provide numerical estimates of the contribution of contagion to volatility in those markets.

The results show clear evidence of contagion effects from Russia, to both emerging and developed countries, while the global contagion effects from the LTCM recapitalization announcement tended to be smaller. In proportionate terms, contagion effects from Russia
were particularly substantial for the Netherlands, Brazil, Bulgaria and Thailand, ranging from 8 percent to about 17 percent of total volatility. The results showed that the strength of market fundamentals and the extent of offshore exposures of countries to Russia were important factors in determining the strength of contagion across national borders. Further, there is also strong evidence that contagion operated within regions, with the Russian bond default affecting the bonds markets of Poland and Bulgaria.

The absence of substantial contagion from the LTCM recapitalization announcement, as a global liquidity shock, is somewhat surprising given the anecdotal evidence offered by traders surveyed by the Committee on the Global Financial System (1999: chapter 3). However, these results may reflect the short duration of the LTCM recapitalization announcement period (spanning about three weeks) as the Fed acted to contain a potential credit crunch by easing monetary policy aggressively. The evidence also suggests that while the U.S. experienced some contagion from Russia, contagion from the LTCM recapitalization announcement crisis to Russia was very small.

The proportion of volatility in the premia attributed to contagion did not provide clear evidence as to whether the crises had a greater effect on emerging or developed markets. When the results were transformed to squared basis point effects, the evidence generally supported the contention that contagion was greater in emerging markets, due to the overall higher degree of volatility typically experienced in those markets. While most of the literature on contagion generally espouses the notion that contagion is only a concern for emerging countries, the results in this paper suggest that contagion can also be meaningful for developed economies, at least in the bond market.

Our results also give support to the view that Brazil was affected by contagion prior to its currency crisis in January 1999. The relatively large contagion effects from Russia to Brazil, may be a reflection of the vulnerability of this country. That the contagion to Brazil is evident in the data prior to its own crisis provides scope for interesting future work in establishing at what point pre-crisis jitters are evident in financial markets.
References


Appendix A. Data Definitions and Sources

Source: U.S. Federal Reserve.

Brazil: Republic of Brazil bond spread over U.S. Treasury.
Source: U.S. Federal Reserve.


Indonesia: Indonesian Yankee Bond Spread over U.S. Treasury.
Source: U.S. Federal Reserve.

Source: Bloomberg (50064FAB0)

Thailand: Kingdom of Thailand Yankee Bond Spread over U.S. Treasury.
Source: U.S. Federal Reserve. (The longer series used in Figure 1, 7.75% 15/04/07, comes from Credit Swiss First Boston).


Poland: Poland Par Stripped Brady Bond Yield Spread over U.S. Treasury.
Source: U.S. Federal Reserve.

Source: Bloomberg (007149662).


U.K.: U.K. Industrial BBB Corporate 5-year Bond Spread over Gilt. Source: Bloomberg (UKBF3B05)

Source: Bloomberg (IN10Y3B1)

The data obtained from the U.S. Federal Reserve was for the Bank for International Settlements, Committee on Global Financial System to aid in their inquiry into the turmoil of 1998 (Bank for International Settlements, Committee on the Global Financial System (1999)). The estimation is based on daily data on spreads from February 12 to January 1, 1999. The bond spreads, or “risk premia,” are constructed by taking a representative long-term sovereign bond issued in U.S. dollars by an emerging country and subtracting from it a U.S. Treasury bond of comparable maturity. For developed economies, the risk premia are constructed by taking a representative long-term corporate bond in domestic currency and subtracting from it a Government Treasury bond of comparable maturity.

Missing observations were dealt with by removing all contemporaneous observations for that date across countries. The original sample of 231 observations was reduced to 209 observations after accounting for missing observations. The exact details of the missing observations are contained in Dungey, Fry, Gonzalez-Hermosillo and Martin (2002).
Appendix B: Descriptive Statistics

Table B.1: Descriptive Statistics of Premia (in levels)

<table>
<thead>
<tr>
<th>Statistic</th>
<th>U.S.</th>
<th>U.K.</th>
<th>Netherlands</th>
<th>Russia</th>
<th>Poland</th>
<th>Bulgaria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>106.06</td>
<td>122.92</td>
<td>58.59</td>
<td>2871.81</td>
<td>261.21</td>
<td>951.72</td>
</tr>
<tr>
<td>Maximum</td>
<td>153.00</td>
<td>203.00</td>
<td>109.10</td>
<td>6825.78</td>
<td>521.00</td>
<td>2279.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>67.00</td>
<td>76.00</td>
<td>34.20</td>
<td>392.35</td>
<td>162.00</td>
<td>535.00</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>28.85</td>
<td>36.26</td>
<td>20.38</td>
<td>2512.65</td>
<td>75.73</td>
<td>431.92</td>
</tr>
<tr>
<td>AR(1)</td>
<td>0.99</td>
<td>0.99</td>
<td>0.96</td>
<td>0.99</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>AR(2)</td>
<td>0.98</td>
<td>0.98</td>
<td>0.93</td>
<td>0.98</td>
<td>0.90</td>
<td>0.94</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.44</td>
<td>0.72</td>
<td>0.95</td>
<td>0.28</td>
<td>0.95</td>
<td>1.35</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>1.38</td>
<td>2.03</td>
<td>2.42</td>
<td>1.20</td>
<td>3.17</td>
<td>4.26</td>
</tr>
<tr>
<td>Jarque-Bera</td>
<td>29.51</td>
<td>26.11</td>
<td>34.24</td>
<td>30.96</td>
<td>31.53</td>
<td>77.52</td>
</tr>
<tr>
<td>(p value)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
</tbody>
</table>

Table B.2: Standard Deviations of the Change in the Premia

<table>
<thead>
<tr>
<th>Statistic</th>
<th>U.S</th>
<th>U.K</th>
<th>Netherlands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.74</td>
<td>3.73</td>
<td>5.39</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Dev.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Russia</th>
<th>Poland</th>
<th>Bulgaria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>242.45</td>
<td>22.97</td>
<td>100.03</td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Dev.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Indonesia</th>
<th>Korea</th>
<th>Thailand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>55.87</td>
<td>28.64</td>
<td>22.36</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Dev.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Mexico</th>
<th>Argentina</th>
<th>Brazil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Dev.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table B.3: Augmented Dickey Fuller and Phillips Perron Unit Root Tests of the Premia

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Industrial</th>
<th>Eastern Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U.S.</td>
<td>U.K.</td>
</tr>
<tr>
<td>ADF Test</td>
<td>-0.602</td>
<td>-0.605</td>
</tr>
<tr>
<td>Phillips Perron Test</td>
<td>-0.641</td>
<td>-0.577</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Asia</th>
<th>Latin America</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indonesia</td>
<td>Korea</td>
</tr>
<tr>
<td>ADF Test</td>
<td>-1.219</td>
<td>-1.302</td>
</tr>
<tr>
<td>Phillips Perron Test</td>
<td>-1.216</td>
<td>-1.433</td>
</tr>
</tbody>
</table>

MacKinnon critical values for rejection of the hypothesis of a unit root for the ADF test are:
1% critical value -3.4634 (* represents rejection at the 1% level of significance)
5% critical value -2.8756 (** represents rejection at the 5% level of significance)

MacKinnon critical values for rejection of the hypothesis of a unit root for the PP test are:
1% critical value -3.4631 (* represents rejection at the 1% level of significance)
5% critical value -2.8755 (** represents rejection at the 5% level of significance)
Table B.4 presents the results from estimating an integrated GARCH(1,1) model for changes in each of the premium series. The changes are examined in order to highlight the properties of the short-term adjustment process in the data.

\[
\Delta P_{i,t} = \rho_0 + e_{i,t} \\
e_{i,t} = \sqrt{h_{i,t}} u_{i,t} \\
h_{i,t} = \alpha_0 + \alpha_1 e_{i,t-1}^2 + (1-\alpha_1) h_{i,t-1} \\
u_{i,t} \sim N(0,1),
\]

where \(\Delta P_{i,t}\) is the change in the premium for country \(i\) recorded at time \(t\).

<table>
<thead>
<tr>
<th>Country</th>
<th>Parameter</th>
<th>Parameter</th>
<th>Parameter</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\rho_0)</td>
<td>(\alpha_0)</td>
<td>(\alpha_1)</td>
<td>(\ln L)</td>
</tr>
<tr>
<td><strong>Industrial</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>0.061</td>
<td>1.059</td>
<td>0.595</td>
<td>-467.876</td>
</tr>
<tr>
<td></td>
<td>(0.124)</td>
<td>(1.320)</td>
<td>(0.446)</td>
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</tr>
<tr>
<td>U.K.</td>
<td>0.070</td>
<td>1.627</td>
<td>0.409</td>
<td>-553.957</td>
</tr>
<tr>
<td></td>
<td>(0.233)</td>
<td>(0.776)</td>
<td>(0.113)</td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>-0.022</td>
<td>1.583</td>
<td>0.213</td>
<td>-626.669</td>
</tr>
<tr>
<td></td>
<td>(0.322)</td>
<td>(1.602)</td>
<td>(0.144)</td>
<td></td>
</tr>
<tr>
<td><strong>Eastern Europe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>-0.022</td>
<td>1.584</td>
<td>0.213</td>
<td>-636.669</td>
</tr>
<tr>
<td></td>
<td>(0.374)</td>
<td>(1.609)</td>
<td>(0.145)</td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>-0.209</td>
<td>22.949</td>
<td>0.325</td>
<td>-896.909</td>
</tr>
<tr>
<td></td>
<td>(0.902)</td>
<td>(30.524)</td>
<td>(0.254)</td>
<td></td>
</tr>
<tr>
<td>Bulgaria</td>
<td>0.150</td>
<td>59.091</td>
<td>0.317</td>
<td>-1088.000</td>
</tr>
<tr>
<td></td>
<td>(2.152)</td>
<td>(37.833)</td>
<td>(0.070)</td>
<td></td>
</tr>
<tr>
<td><strong>Asia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>-1.216</td>
<td>251.212</td>
<td>0.413</td>
<td>-1088.470</td>
</tr>
<tr>
<td></td>
<td>(2.553)</td>
<td>(212.662)</td>
<td>(0.164)</td>
<td></td>
</tr>
<tr>
<td>Korea</td>
<td>-0.535</td>
<td>20.813</td>
<td>0.203</td>
<td>-947.494</td>
</tr>
<tr>
<td></td>
<td>(1.212)</td>
<td>(11.063)</td>
<td>(0.044)</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>-0.700</td>
<td>32.425</td>
<td>0.250</td>
<td>-906.889</td>
</tr>
<tr>
<td></td>
<td>(0.862)</td>
<td>(30.407)</td>
<td>(0.138)</td>
<td></td>
</tr>
<tr>
<td><strong>Latin America</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>0.145</td>
<td>11.528</td>
<td>0.338</td>
<td>-854.152</td>
</tr>
<tr>
<td></td>
<td>(0.649)</td>
<td>(6.980)</td>
<td>(0.098)</td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td>0.324</td>
<td>12.602</td>
<td>0.288</td>
<td>-916.035</td>
</tr>
<tr>
<td></td>
<td>(0.897)</td>
<td>(6.989)</td>
<td>(0.065)</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>1.015</td>
<td>26.714</td>
<td>0.242</td>
<td>-1023.260</td>
</tr>
<tr>
<td></td>
<td>(1.524)</td>
<td>(18.608)</td>
<td>(0.055)</td>
<td></td>
</tr>
</tbody>
</table>