

CENTRE FOR APPLIED MACROECONOMIC ANALYSIS

The Australian National University



CAMA Working Paper Series

June, 2005

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CAMA Working Paper 15/2005

<http://cama.anu.edu.au>

Shocks and Systemic Influences: Contagion in Global Equity Markets in 1998*

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June 2005

Abstract

The transmission of the financial crises in 1998 through international equity markets is estimated through a multi-factor model of financial markets specifically allowing for contagion effects. The application measures the strength of contagion emanating from the Russia crisis of 1998, and the LTCM near collapse, using a panel of 10 emerging and developed financial markets. Pre and post default periods for Russia are distinguished. The results show that contagion is significant and widespread from both crises, although the LTCM crisis has more impact on developed than emerging markets. Consistent with the existing literature, regional effects are found to be strong during financial crises. Asian markets are found to be relatively immune from contagion, perhaps reflecting the effect of their own recent crisis.

Key words: Contagion.

JEL Classification: C15, F31

*This project was funded under ARC large grant A00001350. The views expressed in this paper are those of the authors and do not necessarily coincide with those of the IMF or IMF policy. The authors contact details are: m.dungey@cerf.cam.ac.uk; renee.fry@anu.edu.au; bgonzalez@imf.org; vance@unimelb.edu.au.

1 Introduction

This paper examines the transmission of shocks in equity markets across key emerging and industrial countries during the 1998 Russian crisis and near-default of the US hedge fund Long-Term Capital Management (LTCM). This period is characterised by extreme distress in global financial markets in both developing and industrial countries, and is considered by some observers to represent the worst turbulence in international financial markets in the last few decades (Upper (2001), Committee on the Global Financial System (1999)).

Russian financial markets were highly volatile in 1998. Concerns about the underlying stability of the Russian GKO debt market, the ongoing problems in the Russian economy, political uncertainty and multiple support programs from international agencies such as the IMF and the World Bank, led investors to become increasingly nervous about Russian investments. However, many investors retained a substantial exposure to emerging markets. One such investor was LTCM (Jorion (2000)). While many of the investments in Russia were hedged by forward rouble contracts with the Russian banking system, those very exposures contributed to the fragility of the banking system itself (Steinherr (2004)). Even though Russia was essentially in crisis over all of 1998, the defining event of the period was the suspension of Russian bond payments and the floating of the rouble on August 17. Although this shock was sourced in bond markets, there were also substantial effects documented in equity markets.

The fortnight from August 14 to 28 was complicated by the actions of the Hong Kong Monetary Authority (HKMA) in intervening in the HK equity market to support the HK currency board (Goodhart and Dai (2003)). From August 28 the negative effects of these events on LTCM were beginning to create their own problems. Over the next month the difficulties facing LTCM became increasingly apparent with a leaked letter to shareholders on September 2, and the public announcement of a recapitalisation plan on September 23. The LTCM associated liquidity crisis continued until October 15, ending with the surprise inter-FOMC meeting cut in US interest rates; see Kumar and Persaud (2001), Upper and Werner (2002) Committee on the Global Financial System (1999). A full chronology of these events is given by Lowenstein (2001), Jorion (2000) and Kharas, Pintos and Ulatov (2000).

The role of equity markets acting as a conduit of both the Russian bond crisis

and the LTCM near collapse, have been studied by the Committee on the Global Financial System (1999) for industrial countries, Rigobon (2003) and Hernández and Valdés (2001) for emerging markets, Kaminsky and Reinhart (2003) for industrial and emerging markets, and Baig and Goldfajn (2001) specifically for transmissions to Brazil. The transmission of the Russian and LTCM shocks through international bond markets have been studied in Dungey, Fry, González-Hermosillo and Martin (2005a), Jorion (2000) and Committee on the Global Financial System (1999).

An important, at least implicit, assumption in many of the empirical analyses of the transmission of the two crises is that the Russian crisis affected emerging markets whereas the impact of the LTCM crisis was concentrated on industrial markets as suggested by the Committee on the Global Financial System (1999: p.7-8). To test these propositions a model of financial crises is developed. The basis of the model follows the international capital asset pricing model of Solnik (1974) and the multi-factor extensions proposed by King, Sentana and Wadhvani (1994). The set of factors specified include world and regional factors which capture market fundamentals underlying international equity returns during non-crisis periods. The world factor captures the simultaneous impact of shocks on all equity markets, such as global changes arising from changes to US monetary policy (Forbes and Rigobon (2002)), or the effects on international equity markets of oil price shocks. The regional factors capture movements specific to geographic areas arising from strong trade linkages (Glick and Rose (1999)) or financial linkages (Hernández and Valdés (2001), Van Rijckeghem and Weder (2001) and Kiyotaki and Moore (2002)). Included in the set of regional factors are factors which captures differences in the risks associated with emerging and industrial equity markets. The model also allows for country factors which capture shocks that are idiosyncratic to individual countries.

To model the transmission of shocks from Russia and the LTCM crises to international equity markets, the idiosyncratic shocks associated with Russia and the US are included as additional factors in determining international equity market returns during the pertinent crisis periods. As these linkages are specified to exist only in periods of crises, the proposed model extends upon earlier work by specifying a multi-factor model with multiple regimes. Following the approach of Masson (1999), Forbes and Rigobon (2002) and Dungey, Fry, González-Hermosillo and Martin (2005a), these ad-

ditional linkages are referred to as contagion as they represent the impact of shocks in one market on other markets having conditioned on non-crisis factors.¹ An important feature of the model is that identification of contagion is achieved through the increase in the volatility of equity returns from the non-crisis to the crisis periods. In the case of the LTCM crisis, as this occurs over a sub-period of the Russian crisis, this feature imposes further restrictions on the factor structure of the model and the decomposition of equity market volatility into its various components.

The paper has five main empirical findings. First, there is significant contagion from the Russian and LTCM crises to other international equity markets. Second, the industrial countries have an important role in both crises, a result which is consistent with Kaminsky and Reinhart (2003) who argue that shocks need to affect financial centers in industrial countries to become systemic. Third, contagion effects from the Russian crisis are not contained to emerging markets, and contagion effects from the LTCM crisis are felt in both emerging and industrial markets, although they tended to contribute more to volatility in the industrial markets. The fourth result confirms the importance of regional effects in contributing to volatility during crisis periods. The final result concerns the relatively low contagion effects experienced by Asian economies in the sample. One possibility is that a consequence of the East Asian crisis was an acquired immunity for Asian countries during the Russian and LTCM crises.

The remainder of this paper is organized as follows. Section 2 specifies a multi-regime factor model of financial crises which allow for increase in volatility arising from contagion. A number of preliminary empirical issues are discussed in Section 3, including data filtering, identification of equity market shocks, and estimation strategies. The main empirical results are presented in Section 4, while Section 5 contains some concluding comments and suggestions for future research.

2 A Model of Financial Crises in Equity Markets

In this section a multi-regime factor model of equity markets is specified to identify the transmission mechanisms of financial crises between international equity markets. The model builds on the earlier work of Solnik (1974) and in particular the factor model of

¹Further refinements of the definition of contagion are given by Dornbusch, Park, Claessens (2000) and Pericoli and Sbracia (2003). The current model also nests other important empirical models of contagion as shown in Dungey, Fry, González-Hermosillo and Martin (2005b).

King, Sentana and Wadhvani (1994), by allowing for additional linkages arising from contagion during the Russian and LTCM crisis periods. An important extension of this earlier class of models is the identification of contagion during the crisis periods by allowing for regime shifts in the factor structures.²

2.1 A Non-Crisis Model

Let $s_{i,t}$ represent the equity returns of country i at time t . A total of 10 equity markets are used in the empirical analysis including 6 emerging equity markets (Argentina (AR), Brazil (BR), Hong Kong SAR (HK), Thailand (TH), Poland (PO) and Russia (RU)) and 4 industrial equity markets (Germany (GE), Japan (JA), United Kingdom (UK) and the United States (US)). Defining s_t as a (10×1) vector of all equity returns, the dynamics of equity markets are assumed to be represented by the following vector autoregression (VAR)

$$s_t = \mu + A_1 s_{t-1} + A_2 s_{t-2} + \dots + A_p s_{t-p} + u_t, \quad (1)$$

where μ is a (10×1) vector of parameters to allow for non-zero means in equity returns, A_i is a (10×10) matrix of autoregressive parameters corresponding to the i^{th} lag, and u_t is a (10×1) multivariate disturbance process with zero mean, variance-covariance matrix Ω , and $E u_t u_{t-k} = 0, \forall k \neq 0$.³ The length of the lag distribution of the VAR is given by p .

The disturbance term u_t in (1) represents shocks to equity markets which is assumed

²A related identification strategy is by Rigobon and Sack (2004) in modelling money shocks.

³In an earlier version of this paper, equity returns were also assumed to exhibit conditional volatility by specifying a factor GARCH structure following the class of models proposed by Diebold and Nerlove (1989). In the current version of the paper, changes in volatility are modelled by regime changes caused by financial crises. The adoption of this specification has the advantage of simplifying estimation by circumventing the need to use a simulation based estimation strategy as adopted by Dungey, Martin and Pagan (2000), for example.

to have the following factor structure

$$\begin{bmatrix} u_{AR,t} \\ u_{BR,t} \\ u_{HK,t} \\ u_{TH,t} \\ u_{PO,t} \\ u_{RU,t} \\ u_{GE,t} \\ u_{JA,t} \\ u_{UK,t} \\ u_{US,t} \end{bmatrix} = \begin{bmatrix} \lambda_{AR} & \gamma_{AR} & 0 & \psi_{AR} \\ \lambda_{BR} & \gamma_{BR} & 0 & \psi_{BR} \\ \lambda_{HK} & \gamma_{HK} & 0 & 0 \\ \lambda_{TH} & \gamma_{TH} & 0 & 0 \\ \lambda_{PO} & \gamma_{PO} & 0 & 0 \\ \lambda_{RU} & \gamma_{RU} & 0 & 0 \\ \lambda_{GE} & 0 & \delta_{GE} & 0 \\ \lambda_{JA} & 0 & \delta_{JA} & 0 \\ \lambda_{UK} & 0 & \delta_{UK} & 0 \\ \lambda_{US} & 0 & \delta_{US} & \psi_{US} \end{bmatrix} \begin{bmatrix} w_t \\ e_t \\ d_t \\ r_t \end{bmatrix} + \tag{2}$$

$$\begin{bmatrix} \phi_{AR} \\ \phi_{BR} \\ \phi_{HK} \\ \phi_{TH} \\ \phi_{PO} \\ \phi_{RU} \\ \phi_{GE} \\ \phi_{JA} \\ \phi_{UK} \\ \phi_{US} \end{bmatrix} \begin{bmatrix} v_{AR,t} \\ v_{BR,t} \\ v_{HK,t} \\ v_{TH,t} \\ v_{PO,t} \\ v_{RU,t} \\ v_{GE,t} \\ v_{JA,t} \\ v_{UK,t} \\ v_{US,t} \end{bmatrix},$$

where all blank cells in the last matrix are to be treated as zeros. The factor w_t represents shocks that simultaneously impact upon all equity markets with the size of the impact determined by the loading parameter λ_i . For this reason this factor

is referred to as a world factor. Typical examples of a world factor would be the global effects of changes in US monetary policy on world equity markets (Forbes and Rigobon (2002)), or the simultaneous impact on international equity markets of an oil price shock. One important difference between these choices of factors is that w_t in equation (2) is not assumed to be observable, but is treated as a latent factor. The next two factors are e_t and d_t , which capture shocks that are specific to emerging and industrial markets respectively. The parameters γ_i control the impact of e_t on the 6 emerging equity markets whilst δ_i controls the impact of d_t on the 4 industrial equity markets. The fourth factor r_t , is a regional factor which captures shocks specific to the Americas as it impacts only upon Argentina (AR), Brazil (BR) and the US, with loading parameters given by ψ_i . The last set of factors in equation (2) are given by $v_{i,t}$, which represent shocks that are specific to each of the 10 equity markets with loading parameters given by ϕ_i . The first four factors (w_t, e_t, d_t, r_t) represent systematic factors whose risks are not diversifiable, whilst the country specific factors ($v_{i,t}$) represent idiosyncratic factors whose risks are diversifiable (Solnik (1974)).⁴ More compactly the system in equation (2) is written as

$$u_t = \begin{bmatrix} A; \Psi_1 \end{bmatrix} f_t = \Gamma_1 f_t \quad (3)$$

where f_t represents the full set of factors,

$$f_t = [w_t, e_t, d_t, r_t, v_{AR,t}, v_{BR,t}, \dots, v_{US,t}]. \quad (4)$$

To complete the specification of the model, the set of systematic and idiosyncratic factors are assumed to be independent with zero means and unit variances

$$f_t \sim (0, 1). \quad (5)$$

This choice of normalising the factors provides a convenient decomposition of equity volatility into the contributions of each of the underlying factors during the non-crisis period

$$Var(v_{i,t}) = \lambda_i^2 + \gamma_i^2 + \delta_i^2 + \psi_i^2 + \phi_i^2. \quad (6)$$

⁴The choice of factors is based on some preliminary empirical analysis. An alternative break down of the systematic factors would be in terms of regions (Glick and Rose (1999)), which could be achieved by a simple rotation of the proposed factor structure in equation (2). As the emphasis of the paper is on modelling contagion via the transmission of the nonsystematic factors, rotating the factors will not change the results, but simply change the interpretation of the systematic factors.

2.2 The Crisis Model

The crisis model of equity returns is characterized by the inclusion of additional transmission mechanisms linking global equity markets during the crisis periods, over and above the mechanisms identified by the non-crisis model in (2). The approach to modelling these additional linkages is to include the Russian ($v_{RU,t}$) and US ($v_{US,t}$) idiosyncratic shocks defined in (2), into the factor structure of the remaining countries during the crisis periods. Following Masson (1999), Forbes and Rigobon (2002), Pericoli and Sbracia (2003) and Dungey, Fry, González-Hermosillo, and Martin (2005a), these linkages are referred to as contagion as they represent shocks originating in an asset market which contribute to the volatility of other asset markets during periods of crisis.

$$u_t = \left[A; \Psi_2 \right] f_t = \Gamma_2 f_t \quad (8)$$

Contagion from Russia to international equity markets is modelled by the inclusion of the idiosyncratic Russian equity shock $v_{RU,t}$, into the factor structures of all other equity markets, with the strength of these connections governed by the parameter α_i . Equation (7) also allows for the effect of Russian idiosyncratic shocks to differ across regimes by allowing the parameter ϕ_{RU} in (2) to differ from α_{RU} in (7). Dungey, Fry, González-Hermosillo and Martin (2005b) interpret this as an idiosyncratic structural break.

Following the non-crisis period decomposition of the variance in (6), equity market volatility is decomposed during the Russian crisis as

$$Var(v_{i,t}) = \lambda_i^2 + \gamma_i^2 + \delta_i^2 + \psi_i^2 + \phi_i^2 + \alpha_i^2. \quad (9)$$

This suggests that the change in volatility between the non-crisis and Russian crisis periods arising from contagion for the i^{th} country is simply

$$\Delta Var(v_{i,t}) = \alpha_i^2. \quad (10)$$

This also suggests that a test of contagion emanating from the Russian equity market can be performed by testing the restriction

$$H_0 : \alpha_i = 0, \quad \forall i \neq RU. \quad (11)$$

Further, a test of a structural break in the Russian idiosyncratic factor is given by testing the restriction

$$H_0 : \phi_{RU} = \alpha_{RU}. \quad (12)$$

2.2.2 The LTCM Crisis Specification

An important feature of the LTCM crisis is that it occurs during the Russian crisis period, but is of shorter duration as the LTCM liquidity crisis is viewed to have ended at the time of the surprise inter-FOMC meeting to cut interest rates on October 15th. The implication of this characteristic of the twin-crisis periods, is that the contagious channel used to model the transmission of shocks during the Russian crisis, is still active during the LTCM crisis period. This feature of the problem imposes additional structure on the factors across the regimes.

or more compactly

$$u_t = \begin{bmatrix} A; \Psi_3 \end{bmatrix} f_t = \Gamma_3 f_t \quad (14)$$

The strength of contagion from LTCM to international equity markets is controlled by the parameter β_i . As in the case of the Russian crisis model, the specification of the LTCM crisis model also allows for a structural break in the idiosyncratic shock of the US, with the parameter β_{US} in (13) being allowed to differ from the parameter ϕ_{US} in (2). As the LTCM crisis coincides with the Russian crisis, the Russian idiosyncratic shock $v_{RU,t}$, is also included in the factor specification of the other equity markets to reflect the twin nature of the crises during the time of the LTCM crisis. A comparison of (7) and (13) shows that the parameters measuring the strength of contagion from Russia (α_i) are the same across the two regimes.

During the LTCM crisis the decomposition of equity market volatility is given by

$$Var(v_{i,t}) = \lambda_i^2 + \gamma_i^2 + \delta_i^2 + \psi_i^2 + \phi_i^2 + \alpha_i^2 + \beta_i^2. \quad (15)$$

The change in volatility between the non-crisis and LTCM crisis periods is

$$\Delta Var(v_{i,t}) = \alpha_i^2 + \beta_i^2, \quad (16)$$

which shows that the total contribution of contagion can be further decomposed into the respective elements of the two crises during the LTCM crisis period. A test of contagion emanating from the LTCM equity market can be performed by testing the restriction

$$H_0 : \beta_i = 0, \quad \forall i \neq US. \quad (17)$$

A joint test of contagion from both Russia and the US is given by

$$H_0 : \alpha_i = 0; \beta_j = 0, \quad \forall i \neq RU, \forall j \neq US. \quad (18)$$

A test of a structural break in the US idiosyncratic factor is given by testing the restriction

$$H_0 : \phi_{US} = \beta_{US}. \quad (19)$$

3 Empirical Issues

This section outlines a strategy based on generalised method of moments (GMM) to estimate the multi-regime factor model of financial crises. Also discussed are a number of data issues relating to time zones and the choice of the crisis dates.

3.1 Data

The sample consists of daily share prices ($P_{i,t}$) on 10 countries, beginning January 2, 1998 and ending December 31, 1998, a total of $T = 260$ observations. Local equity market data are used which are sourced from Bloomberg.⁵

Daily percentage equity returns of the i^{th} country are computed as

$$s_{i,t} = 100 (\ln (P_{i,t}) - \ln (P_{i,t-1})). \quad (20)$$

Missing observations are treated by using the lagged return.⁶ To capture differences in time zones of equity markets, a 2-day moving average is chosen following the approach of Forbes and Rigobon (2002), with the first observation of the moving average set equal to the realised returns on January 5th.⁷ The effective sample of returns data begins January 5, 1998 and ends December 31, 1998, a total of $T = 259$ observations.

A plot of the filtered equity returns is given in Figure 1. Some descriptive statistics of the data are presented in Table 1 for the total sample period and a sub-period that begins January 5 and ends August 14, corresponding to the period prior to the Russian bond default. The increase in the volatility of equity returns between the pre-default period and the total period is highlighted in Table 2 which contains the variances and covariances of daily percentage equity returns for the two sample periods.

⁵The particular stock market indices used are: Buenos Aires Stock Exchange, Brazil Bovespa Stock Exchange, Hang Seng Stock Index, Thai SET Index, Warsaw Stock Exchange Total Return Index, Russian RTS Index \$, Deutsche Borse AG German Stock Exchange, Nikkei 225 Index, FTSE 100, Dow Jones Industrial Index.

⁶Filling in missing observations by use of a linear interpolation between observed returns does not change the qualitative results of the estimated factor model.

⁷Another approach to addressing the problem of different time zones is to follow Dungey, Fry, González-Hermosillo, and Martin (2003) and treat time zones as a missing observation problem. However, estimation is more involved as it requires simulating a high frequency model to generate ‘hourly’ data which is converted into ‘daily’ data and then calibrated with the actual data.

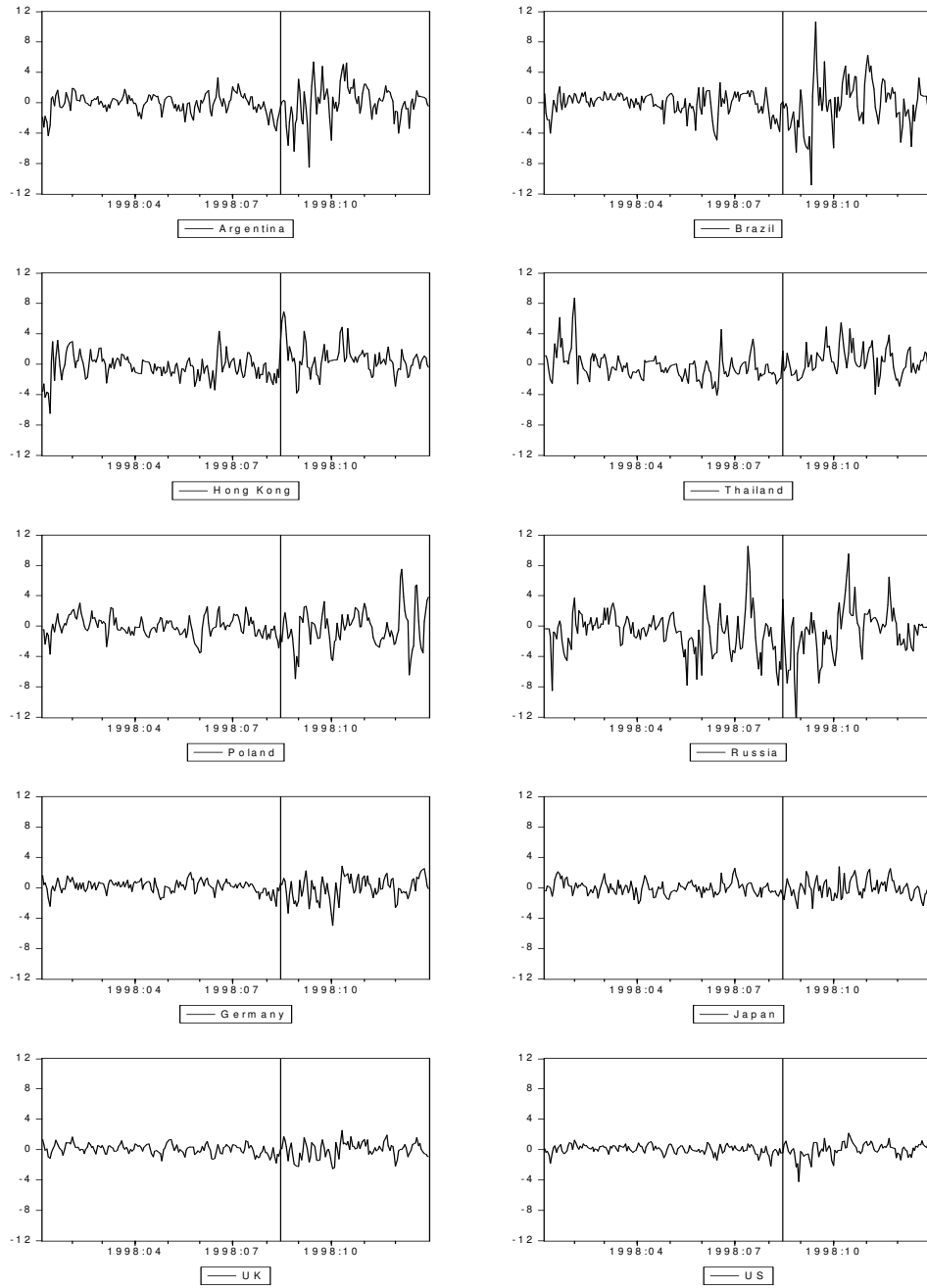


Figure 1: Equity market returns (2 day moving average), January 5, 1998 to December 31, 1998. The vertical line represents August 14, 1998, which corresponds to the end of the pre-default period.

Table 1:
Descriptive statistics of daily percentage equity returns for selected sample periods.^(a)

Country		Pre-default period Jan. 5 to Aug. 14			Total Period Jan. 5 to Dec. 31		
		Mean	Max	Min	Mean	Max	Min
Argentina	(AR)	-0.129	3.304	-4.359	-0.054	5.344	-8.522
Brazil	(BR)	-0.087	2.638	-4.909	-0.100	10.653	-10.844
Hong Kong SAR	(HK)	-0.342	4.320	-6.462	0.051	6.891	-6.462
Thailand	(TH)	-0.281	8.756	-4.108	-0.007	8.756	-4.108
Poland	(PO)	-0.055	3.040	-3.687	-0.110	7.496	-6.922
Russia	(RU)	-0.741	10.548	-8.476	-0.701	10.548	-12.828
Germany	(GE)	0.182	1.998	-2.485	0.105	2.841	-5.003
Japan	(JA)	-0.023	2.558	-2.119	-0.039	2.785	-2.734
United Kingdom	(UK)	0.076	1.664	-1.752	0.052	2.515	-2.517
United States	(US)	0.054	1.254	-2.150	0.043	2.174	-4.225

(a) Equity returns are based on a 2-day moving average, with missing observations replaced by the previous return value.

Table 2:
Variance-covariance matrices of daily percentage equity returns for selected sample periods.^(a)

	AR	BR	HK	TH	PO	RU	GE	JA	UK	US
<i>Pre-default period: January 5 - August 14</i>										
AR	1.471									
BR	1.126	1.899								
HK	0.987	0.940	2.392							
TH	0.748	0.992	1.656	3.090						
PO	0.719	0.604	1.086	1.016	1.535					
RU	1.378	1.808	1.492	1.706	1.522	6.951				
GE	0.281	0.402	0.592	0.476	0.281	0.719	0.584			
JA	0.214	0.282	0.501	0.494	0.280	0.216	0.162	0.666		
UK	0.313	0.470	0.423	0.525	0.333	0.828	0.312	0.124	0.400	
US	0.356	0.452	0.418	0.368	0.243	0.474	0.227	0.072	0.224	0.291
<i>Total period: January 5 - December 31</i>										
AR	2.930									
BR	2.973	4.947								
HK	0.998	0.725	2.981							
TH	0.987	1.088	1.646	3.187						
PO	0.951	0.880	1.161	0.982	3.353					
RU	2.227	2.619	1.129	1.556	1.467	8.063				
GE	0.890	0.945	0.752	0.518	0.667	1.369	1.199			
JA	0.536	0.648	0.517	0.533	0.634	0.616	0.309	0.925		
UK	0.672	0.760	0.654	0.543	0.653	1.097	0.660	0.295	0.658	
US	0.806	1.053	0.500	0.453	0.423	0.792	0.450	0.183	0.362	0.504

(a) Equity returns are based on a 2-day moving average, with missing observations replaced by the previous return value.

3.2 Regime Dating

The model consists of three regimes with the timing of the three regimes chosen as:

$$\begin{aligned} \text{Regime 1 (Pre-default)} & : \text{ Jan. 5 to Aug. 14} \quad (T_1 = 159) \\ \text{Regime 2 (Russian crisis)} & : \text{ Jan. 5 to Dec. 31} \quad (T_2 = 259) \\ \text{Regime 3 (LTCM crisis)} & : \text{ Aug. 28 to Oct. 15} \quad (T_3 = 35) \end{aligned} \quad (21)$$

with respective sample sizes given by T_1, T_2 and T_3 . The first regime is taken as the pre-default period which pertains from the start of the sample period to August 14, 1998. This is the trading day after the publication of a letter from George Soros recommending a substantial devaluation of the Russian rouble. It is also the day that Yeltsin declared that the rouble would not be floated, as well as the trading day before the rouble was floated and the Russian debt suspension was announced on August 17. This regime is used to identify the parameters of the non-crisis model. The second regime corresponds to the Russian crisis. Dating this crisis for equity markets is not entirely straightforward as Figure 1 shows that there is a substantial build-up of volatility in the Russian equity market well before the floating of the rouble on August 17. It is also not entirely clear when the Russian crisis ended, if it had ended at all by the end of 1998. For these reasons, the Russian crisis is taken to occur over the total sample period. The third regime is the LTCM crisis period which runs from August 28 to October 15, 1998. From the end of August the plight of LTCM gradually became more public, culminating in the public announcement of a recapitalization package in late September. The LTCM associated crisis is taken to end with the surprise cut in US interest rates between FOMC meetings on October 15, 1998.

As a preliminary test of the choice of the regime dates in (21), Table 4 contains estimates of the shocks in the three regimes for each of the 10 countries. These are obtained by estimating the 10-variate VAR in (1) with $p = 1$ lag, for the total period. The point estimates of the VAR are reported in Table 3 with standard errors in parentheses. The shocks are computed as the residual variances corresponding to each of the regime sub-periods in (21).⁸

Inspection of Table 4 shows that the variances progressively increase across the three regimes. This is consistent with the structure of the factor model which predicts that

⁸Strictly speaking the point estimates of the VAR are not asymptotically efficient as a result of the assumption that the disturbance variances are not constant across regimes.

Table 3:

Parameter estimates of the 10-variate VAR of daily percentage equity returns with $p = 1$ in (1). Based on the total sample period with standard errors in parentheses.

Lag	AR	BR	HK	TH	PO	RU	GE	JA	UK	US
AR	0.570 (-0.089)	-0.086 (-0.118)	0.128 (-0.082)	0.025 (-0.088)	0.163 (-0.087)	0.125 (-0.141)	0.165 (-0.055)	0.053 (-0.053)	0.053 (-0.040)	-0.005 (-0.038)
BR	0.024 (-0.068)	0.525 (-0.091)	-0.048 (-0.063)	0.091 (-0.068)	-0.094 (-0.067)	0.046 (-0.109)	-0.068 (-0.042)	0.020 (-0.041)	-0.038 (-0.031)	0.021 (-0.029)
HK	0.026 (-0.066)	-0.027 (-0.087)	0.624 (-0.061)	0.059 (-0.066)	-0.017 (-0.065)	-0.187 (-0.104)	-0.015 (-0.040)	0.026 (-0.039)	0.012 (-0.030)	0.003 (-0.028)
TH	0.074 (-0.060)	0.064 (-0.079)	-0.037 (-0.055)	0.523 (-0.060)	-0.107 (-0.059)	0.125 (-0.095)	-0.027 (-0.037)	-0.027 (-0.036)	-0.020 (-0.027)	0.025 (-0.026)
PO	-0.070 (-0.056)	-0.101 (-0.074)	-0.056 (-0.052)	0.002 (-0.056)	0.583 (-0.055)	-0.116 (-0.089)	-0.063 (-0.034)	-0.047 (-0.033)	-0.006 (-0.025)	-0.010 (-0.024)
RU	0.097 (-0.037)	0.105 (-0.049)	0.020 (-0.034)	0.008 (-0.037)	0.061 (-0.036)	0.606 (-0.058)	0.019 (-0.023)	-0.006 (-0.022)	0.031 (-0.017)	0.048 (-0.016)
GE	-0.207 (-0.123)	-0.156 (-0.163)	-0.381 (-0.114)	-0.136 (-0.122)	-0.034 (-0.120)	-0.142 (-0.195)	0.360 (-0.075)	-0.031 (-0.073)	-0.142 (-0.056)	-0.047 (-0.052)
JA	-0.155 (-0.103)	-0.010 (-0.136)	-0.200 (-0.095)	-0.089 (-0.102)	-0.012 (-0.101)	-0.142 (-0.163)	-0.148 (-0.063)	0.427 (-0.061)	-0.099 (-0.047)	-0.073 (-0.044)
UK	0.060 (-0.185)	0.141 (-0.245)	0.273 (-0.171)	0.423 (-0.184)	0.014 (-0.181)	0.137 (-0.293)	0.033 (-0.114)	0.152 (-0.110)	0.494 (-0.084)	0.079 (-0.079)
US	-0.091 (-0.201)	0.286 (-0.266)	0.488 (-0.186)	-0.052 (-0.200)	0.496 (-0.197)	0.196 (-0.318)	0.463 (-0.123)	0.130 (-0.119)	0.390 (-0.091)	0.426 (-0.086)
C	0.061 (-0.092)	0.002 (-0.121)	0.036 (-0.085)	-0.003 (-0.091)	-0.015 (-0.090)	-0.276 (-0.145)	0.040 (-0.056)	-0.039 (-0.054)	0.032 (-0.042)	0.055 (-0.039)

the volatility of equity returns in the pre-default increases during the Russian crisis, and increases even further during the LTCM crisis as a result of the assumption that the Russian crisis is still in existence during the LTCM crisis period. One important feature of the country volatilities across the three regimes is that the volatilities of the six emerging equity markets is of a higher order of magnitude than it is for the four industrial equity markets. This observation is discussed below in the context of measuring the size of contagious transmission mechanisms in the empirical results.

Table 4:
Variance of residuals from VAR(1) of returns for the pre-default, Russian crisis and LTCM crisis regimes.

Country	Pre-default Jan 5 - Aug 14	Russian crisis Jan 5 - Dec 31	LTCM crisis Aug 28 - Oct 15
AR	0.872	1.183	6.085
BR	1.412	2.009	11.192
HK	1.509	1.532	1.833
TH	1.655	1.774	1.922
PO	0.800	1.727	2.046
RU	3.939	4.338	6.446
GE	0.394	0.528	1.734
JA	0.460	0.506	1.575
UK	0.240	0.306	0.850
US	0.219	0.230	1.005

3.3 GMM Estimator

The model is estimated using generalised method of moments (GMM). This has the advantage of not having to specify the distribution of the factors in (5). Let the sample periods for the three regimes be respectively T_1 (pre-default), T_2 (Russian crisis) and T_3 (LTCM crisis). Associated with each regime is the empirical variance-covariance matrix

$$\Omega_1 = \frac{1}{T_1} \sum_{t=1}^{T_1} u_t u_t', \quad \Omega_2 = \frac{1}{T_2} \sum_{t=1}^{T_2} u_t u_t', \quad \Omega_3 = \frac{1}{T_3} \sum_{t=1}^{T_3} u_t u_t', \quad (22)$$

where u_t is the (10×1) vector of shocks from the VAR in (1).

The factor model is compactly written as

$$u_t = \Gamma_k f_t, \quad k = 1, 2, 3 \quad (23)$$

where Γ_1 , Γ_2 and Γ_3 are defined in equations (3), (8) and (14) respectively and f_t is the set of all factors defined in equation (4).

Using the property that the factors are independent with zero means and unit variances, the theoretical variance-covariance matrices for the three regimes are conve-

niently given by

$$E_k [u_t u_t'] = \Gamma_k \Gamma_k', \quad k = 1, 2, 3. \quad (24)$$

The total number of unknown parameters in Γ_1, Γ_2 and Γ_3 is 53. The GMM estimator is obtained by choosing the parameters of the factor model, Γ_1, Γ_2 and Γ_3 , by matching the empirical moments in (22) with the theoretical moments in (24). Associated with each empirical variance-covariance matrix are $10 \times 11/2 = 55$ unique moments. In total there are $3 \times 55 = 165$ moments across all three regimes. To control for the number of moments specified in the GMM procedure, the full set of unique empirical moments are used from the non-crisis regime, 55 in total, whilst just the empirical variances are used for the remaining two regimes, 20 in total. This means that there are 75 empirical moments. Defining the set of excess (empirical less theoretical) moment matrices for the three regimes as

$$\begin{aligned} M_1 &= \text{vech}(\Omega_1) - \text{vech}(\Gamma_1 \Gamma_1') \\ M_2 &= \text{diag}(\Omega_2) - \text{diag}(\Gamma_2 \Gamma_2') \\ M_3 &= \text{diag}(\Omega_3) - \text{diag}(\Gamma_3 \Gamma_3'), \end{aligned} \quad (25)$$

the GMM estimator is obtained by choosing the parameters of the factor model to minimise the following objective function

$$Q = M_1' W_1^{-1} M_1 + M_2' W_2^{-1} M_2 + M_3' W_3^{-1} M_3, \quad (26)$$

where W_1, W_2 and W_3 are the optimal weighting matrices (Hamilton, (1994)). Equation (26) is minimised with u_t in (22) replaced by the residuals of the estimated VAR in (1) with $p = 1$ lags. The computations are performed using the BFGS algorithm in GAUSS Version 6 with a convergence criterion of 0.00001.

4 Empirical Results

4.1 Parameter Estimates

The GMM point estimates of the factor model are given in Table 5 with standard errors based on the optimal weighting matrix reported in parentheses. A test of the model is

given by testing the number of over-identifying restrictions, $75 - 53 = 22$. Under the null hypothesis that the restrictions are satisfied, the value of the objective function in (26) is asymptotically distributed as χ^2 with 22 degrees of freedom. The reported value of the test statistic is 26.041. The p-value is 0.250, showing that the restrictions are not rejected at conventional significance levels.

Given that the shocks are normalized to unity from the restrictions of the model, it is informative to compare the size of each of the shocks on international equity markets. The parameter estimates of the common factor (λ_i) show that all markets react in the same direction to world shocks. A comparison of the point estimates on the world factor show that world shocks have a greater absolute impact on emerging markets than industrial markets with Russia experiencing the greatest impact.

Inspection of the parameter estimates of the emerging markets factor (γ_i), show that the Latin American and Asian economies respond in the same direction, whereas within the Eastern European bloc, Poland and Russia move in opposite directions. The parameter estimates of the industrial countries (δ_i), show that Germany, the UK and the US all respond in the same way by a similar amount. In contrast, Japan moves in the opposite direction ($\delta_{JA} = 0.038$), although this parameter is statistically insignificant with a standard error of 0.050. The parameter estimates of the regional Americas effect (ψ_i), show that the Latin American countries experience almost double the impact of shocks to this factor compared with the US.

A comparison of the Russian contagion parameter estimates (α_i), shows that the absolute impact of contagion on emerging markets is larger than it is on industrial markets, with the exception of Thailand which is smaller than the size of the shock on the UK and the US, but nonetheless larger than the effect of contagion on Germany and Japan.

In contrast to the Russian crisis results, the absolute effect of contagion from the LTCM crisis (β_i) on emerging and industrial countries is more mixed. The greatest impact of contagion during the LTCM crisis is on Latin America, followed by Russia. The other industrial countries, namely Germany, Japan and the UK, experience contagion levels less than these countries, but more than the two Asian markets and Poland. Inspection of the standard errors reveals that Thailand is not affected by contagion in a statistical sense from either the LTCM crisis or the Russian crisis.

An interesting feature of the estimates of the idiosyncratic parameters (ϕ_i) is that ϕ_{BR} is statistically insignificant. This suggests that the Brazilian equity market was primarily determined by external influences during the sample period: a point which is consistent with the findings of Baig and Goldfajn (1998) who argue that Brazil was heavily influenced by contagion from the Russian crisis, leading into Brazil's own crisis in early 1999.

4.2 Volatility Decompositions

4.2.1 Pre-default

Table 6 gives the volatility decompositions of equity returns in terms of the underlying factors during the pre-default period based on (6) using the parameter estimates of the 3-regime factor model reported in Table 5. The percentage contribution of idiosyncratic shocks to equity market volatility is over 65% in the case of Japan (78.44%), and the two East European countries, Russia (66.33%) and Poland (65.02%). Idiosyncratic shocks are also important in the case of Thailand (54.97%) and Germany (47.01%). These results suggest that there is potential for portfolio diversification amongst these countries to minimise portfolio risk.

For the remaining five countries the results in Table 6 show that the systematic risk factors contribute over 50% to equity market volatility. For the two Latin American countries the contributions to equity market volatility are over 65% for Argentina (World plus Regional factor shocks) and Brazil (World plus Emerging factor shocks). Just over 60% of Hong Kong's equity volatility comes from the world factor, whereas for the UK the contribution is over 70% from world factor shocks (35.75%) and industrial market factor shocks (37.78%). Just under 50% of (American) regional factor shocks contribute to US equity market volatility with a further important contribution from the industrial market factor shocks (27.09%).

4.2.2 Russian Crisis

Table 7 gives the volatility decompositions of equity returns in terms of the underlying factors during the Russian crisis based on (9) in terms of the various factors. The variance decompositions reveal the relative important contribution of contagion emanating from Russia on most international equity market volatility. The dominant channel in a

Table 5:
GMM parameter estimates of the multi regime factor model in equations (2), (7) and (13), with standard errors based on the optimal weighting matrix in parentheses. The (unconstrained) estimate of the objective function in (26) is $\widehat{Q}_u = 26.041$.

Country	Common Factors				Idiosyncratic Factors ϕ_i	Contagion from Russia LTCM	
	World λ_i	Emerging γ_i	industrial δ_i	Regional ψ_i		Russia α_i	LTCM β_i
AR	0.568 (0.077)	0.227 (0.103)	-	0.516 (0.139)	0.494 (0.083)	0.514 (0.141)	2.176 (0.237)
BR	0.721 (0.105)	0.651 (0.193)	-	0.520 (0.143)	0.408 (0.251)	0.787 (0.138)	2.979 (0.320)
HK	0.866 (0.080)	-0.335 (0.097)	-	-	0.595 (0.069)	0.556 (0.169)	0.506 (0.398)
TH	0.842 (0.096)	-0.197 (0.098)	-	-	0.955 (0.068)	0.324 (0.459)	0.318 (0.621)
PO	0.454 (0.068)	-0.277 (0.073)	-	-	0.725 (0.034)	0.954 (0.144)	0.518 (0.416)
RU	1.023 (0.147)	0.417 (0.243)	-	-	1.551 (0.125)	1.760 (0.165)	1.394 (0.390)
GE	0.304 (0.036)	-	-0.285 (0.041)	-	0.392 (0.024)	0.446 (0.055)	1.076 (0.093)
JA	0.286 (0.042)	-	0.038 (0.050)	-	0.551 (0.029)	0.341 (0.073)	1.013 (0.126)
UK	0.286 (0.033)	-	-0.294 (0.030)	-	0.246 (0.035)	0.274 (0.056)	0.722 (0.087)
US	0.187 (0.030)	-	-0.233 (0.031)	0.297 (0.086)	0.150 (0.166)	0.172 (0.088)	-0.877 (0.136)

proportionate sense, is from Russia to Poland (46.08%), supporting the hypothesis that regional proximity is important, as in Glick and Rose (1999). Another major recipient of contagion during the Russian crisis is Germany (37.76%), which is consistent with the heavy banking exposure of Germany to Russia (Van Rijckhem and Weder (2003)). Thailand experiences almost no contagion from Russia during the crisis (5.95%) and the US relatively little (12.89%). The remaining countries, Argentina, Brazil, Hong Kong, Japan and the UK, all experience contagion effects between 20% and 31% of volatility. This group contains both emerging and industrial markets. In general there is no clear evidence that contagion effects are greater or lesser in either group of markets during the Russian crisis. Another way to view the relative size of contagion is to observe that in six of the nine non-Russian countries, the relative contribution of contagion to equity market volatility is greater than the contribution of the country idiosyncratic factors.

4.2.3 LTCM Crisis

Table 8 gives the volatility decompositions of equity returns in terms of the underlying factors during the LTCM crisis based on (15). The breakdown of the total contagion effect during this period (last two columns of the Table) reveals that the LTCM crisis dominated the Russian crisis in terms of the contribution to equity market volatility for all industrial countries and the two Latin American countries. The contribution to equity market volatility due to contagion emanating from the LTCM crisis is between 63% and 69% for Germany, Japan and the UK, whereas the contribution of contagion emanating from Russia is under 10% for these countries. The contribution of contagion from the US is even higher for Argentina and Brazil where it is just over 80% during the LTCM crisis. This empirical result provides strong support for the importance of regional proximity in transmitting crises.

As a further example of the importance of regional effects, the dominant source of contagion for Poland during the LTCM crisis period is still from Russia (45.80%) compared to contagion from the US (13.51%).

Thailand experiences relatively small levels of contagion from either source during the LTCM crisis, with contributions of less than 6%. The contributions of contagion to volatility in Hong Kong are also modest. This result raises the question of whether Thailand and Hong Kong's roles during the Asian crisis led to some form of acquired

Table 6:
Variance decomposition in proportions (%): Pre-default period, January 5 - August 14. Row totals sum to 100%. Based on (6).^(a)

Country	Common Factors				Idiosyncratic Factors
	World	Emerging	Industrial	Regional	
AR	36.40	5.84	-	30.14	27.62
BR	37.63	30.70	-	19.61	12.06
HK	61.68	9.21	-	-	29.11
TH	42.70	2.33	-	-	54.97
PO	25.52	9.47	-	-	65.02
RU	28.88	4.80	-	-	66.33
GE	28.23	-	24.76	-	47.01
JA	21.18	-	0.38	-	78.44
UK	35.75	-	37.78	-	26.46
US	17.60	-	27.09	44.10	11.21

(a) The decompositions are constructed as follows: Define $z = 1/(\lambda_i^2 + \gamma_i^2 + \delta_i^2 + \psi_i^2 + \phi_i^2)$
World: $100z\lambda_i^2$, Emerging: $100z\gamma_i^2$, Industrial: $100z\delta_i^2$, Regional: $100z\psi_i^2$.

immunity to the Russian and LTCM crises. Whether this result is generalisable to other recent crisis sufferers is an interesting avenue for future research.

4.3 Structural Break and Contagion Tests

The strength of the contagious linkages identified in the variance decompositions is examined more formally in Table 9 where a number of tests of contagion and structural breaks are performed. The first panel of the table presents the hypotheses of no structural breaks in the idiosyncratic factors of Russia and the US based on equations (12) and (19) respectively. These hypotheses are both clearly rejected with p -values of 0.000 in both cases, thereby signifying that both countries underwent a significant structural break during the crisis period.

The second and third panels of Table 9 present joint tests of contagion during the Russian and LTCM crises respectively. These tests address the hypotheses raised earlier, that contagion from Russia affected emerging markets, and contagion from

Table 7:
Variance decomposition in proportions (%): Russian crisis, January 5 - December 31.
Row totals sum to 100%. Based on (9).^(a)

Country	Common Factors				Idiosyncratic Factors	Contagion from Russia
	World	Emerging	Industrial	Regional		
AR	27.36	4.39	-	22.67	20.76	28.85
BR	25.96	21.18	-	13.53	8.32	31.01
HK	49.19	7.35	-	-	23.21	20.26
TH	40.16	2.19	-	-	51.70	5.95
PO	12.00	4.46	-	-	30.59	52.95
RU	15.57	2.59	-	-	35.77	46.08
GE	17.57	-	15.41	-	29.26	37.76
JA	16.30	-	0.29	-	60.36	23.05
UK	26.93	-	28.56	-	19.93	24.68
US	15.33	-	23.60	38.42	9.77	12.89

(a) The decompositions are constructed as follows: Define $z = 1/(\lambda_i^2 + \gamma_i^2 + \delta_i^2 + \psi_i^2 + \phi_i^2 + \alpha_i^2)$
World: $100z\lambda_i^2$, Emerging: $100z\gamma_i^2$, Industrial: $100z\delta_i^2$, Regional: $100z\psi_i^2$, Contagion from
Russia: $100z\alpha_i^2$.

Table 8:
Variance decomposition in proportions (%) : LTCM crisis, August 28 - October 15.
Row totals sum to 100%. Based on (15).^(a)

Country	Common Factors				Idiosyncratic Factors	Contagion from Russia LTCM	
	World	Emerging	Industrial	Regional		Russia	LTCM
AR	5.45	0.87	-	4.51	4.14	4.95	80.08
BR	4.78	3.90	-	2.49	1.53	5.70	81.61
HK	42.10	6.29	-	-	19.86	17.34	14.40
TH	37.98	2.07	-	-	58.90	5.62	5.42
PO	10.38	3.85	-	-	26.46	45.80	13.51
RU	12.08	2.01	-	-	27.75	35.75	22.42
GE	5.49	-	4.81	-	9.14	11.79	68.78
JA	5.36	-	0.10	-	19.85	7.58	67.11
UK	9.93	-	10.49	-	7.35	9.10	63.13
US	3.52	-	5.42	8.82	2.24	2.96	77.05

(a) The decompositions are constructed as follows: Define $z = 1/(\lambda_i^2 + \gamma_i^2 + \delta_i^2 + \psi_i^2 + \phi_i^2 + \alpha_i^2 + \beta_i^2)$ World: $100z\lambda_i^2$, Emerging: $100z\gamma_i^2$, Industrial: $100z\delta_i^2$, Regional: $100z\psi_i^2$, Contagion from Russia: $100z\alpha_i^2$, Contagion from LTCM: $100z\beta_i^2$.

LTCM was confined to industrial markets. In each panel, three tests of joint contagion are conducted from the source country (Russia or the US) to: (i) all other countries; (ii) the industrial countries; and (iii) the emerging countries. A test of joint contagion from both Russia and the US is conducted in the final panel of the table.

Contagion is significant at the 5% level for all cases considered, except for the test of the hypothesis of no contagion from Russia to the emerging markets, which is rejected at the 10% level of significance but not at the 5% level. The proposition that Russia is associated with the emerging markets and the LTCM crisis just with the industrials is not supported. Both crises are systemic, with emerging and industrial countries impacting significantly during both crises. The tests of Table 9 are supported by the volatility decomposition results which show that individual industrial countries such as Germany were quite affected by Russia, and that most emerging and industrial countries were affected by the LTCM crisis.

5 Conclusions and Suggestions for Future Research

This paper has provided a framework for modelling the transmission of contagion in international equity markets during the complex period of the Russian bond default and the LTCM crisis in 1998. The model was based on extending the existing class of latent factor models commonly adopted in finance by allowing for additional transmission mechanisms between global equity markets during periods of financial crises arising from contagion. Contagion was identified as the impact of shocks from either Russia or the US on global equity markets, having conditioned on both world and regional factors, as well as country specific shocks in equity markets. A property of the model was that the volatility of equity returns could be decomposed in terms of the underlying factors, thereby providing a measure of the relative strength of contagion. A number of hypothesis tests of contagion and structural breaks were also carried out. The model was applied to ten equity markets consisting of 4 developed markets, and 6 emerging markets from three regions (Latin America, Asia, and Eastern Europe), using daily equity returns over 1998. A GMM estimator which matched the theoretical moments of the factor model with the empirical moments of the data across regimes, was presented.

The key results of the paper were that contagion is widespread to a variety of international equity markets from both the Russian and LTCM crises. The contagion

Table 9:

Alternative tests of contagion and structural breaks. The test statistics are reported in the third last column and are computed as the difference in the constrained estimate of the objective function \widehat{Q}_c and the unconstrained estimate of the objective function $\widehat{Q}_u = 26.041$, from Table 5. In computing \widehat{Q}_c , the weighting matrices corresponding to each of the regimes equal the unconstrained estimates used to evaluate \widehat{Q}_u .

Test		\widehat{Q}_c	Statistic	DOF	p-value
<i>No structural break in idiosyncratic factor of</i>					
Russia :	$\phi_{RU} = \alpha_{RU}$	57.289	31.248	1	0.000
US :	$\phi_{US} = \beta_{US}$	65.813	39.772	1	0.000
<i>No contagion from Russia to</i>					
All other :	$\alpha_i = 0, \forall i, i \neq RU$	49.346	23.304	9	0.006
Industrial :	$\alpha_i = 0, i = GE, JA, UK, US$	39.703	13.662	4	0.008
Emerging :	$\alpha_i = 0,$ $i = AR, BR, HK, TH, PO$	36.285	10.244	5	0.069
<i>No contagion from LTCM to</i>					
All other :	$\beta_i = 0, \forall i, i \neq US$	65.990	39.949	9	0.000
Industrial :	$\beta_i = 0, i = GE, JA, UK$	56.395	30.354	3	0.000
Emerging :	$\beta_i = 0,$ $i = AR, BR, HK, TH, PO, RU$	40.188	14.147	6	0.028
<i>Joint test of</i>					
No contagion	$\alpha_i = \beta_j = 0, \forall i, i \neq RU, j \neq US$	101.767	75.726	18	0.000

emanating from the emerging market of Russia affected a wide variety of both emerging and industrial countries. Rather than being seen as an emerging market phenomenon, as suggested by the Committee on the Global Financial System (1999: p7-8), contagion from the Russian crisis was found to be more statistically significant in industrial countries than emerging markets. The effects of contagion from the LTCM crisis period were found to be strongest on the other industrial nations, and the geographically close Latin American countries. Consistent with other research, regional effects were found to be important, with Polish equity markets dominated by contagion from Russia during both the Russian and LTCM crisis periods, and the LTCM crisis emanating from the US having strong effects in Latin America. One interesting result worthy of further research was the relatively low contagion effects experienced by the Asian economies in the sample. One possibility is that a consequence of the East Asian crisis was an acquired immunity for Asian countries during the Russian and LTCM crises.

Other work on contagion during the Russian and LTCM crises finds that contagion in bond markets also affected a wide variety of economies; Dungey, Fry, González-Hermosillo and Martin (2005a). The combination of these two results suggest that it would be informative to construct a more general model of asset markets combining both bonds and equities to test the importance of cross flows between markets across international borders. A step in this direction has been recently undertaken in Erhmann, Fratzscher and Rigobon (2005).⁹ A further interesting aspect of the results concerns Brazil, which was the next country to experience a financial crisis in January 1999. Brazilian financial markets seem to have experienced several hits from these crises. The Brazilian bond market was impacted by the Russian crisis (Dungey, Fry, González-Hermosillo, and Martin (2005a), and Baig and Goldfajn (2001)) and the equity market by the LTCM near collapse as shown here. An integrated model of the impacts on Brazil would be a fruitful line of future research.

⁹Some papers consider bivariate relationships across international borders or cross market relationships within borders; for example Granger, Huang and Yang (2000) and Hartmann, Straetmans and de Vries (2004).

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