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Unanticipated Shocks and Systemic Influences: The Impact of Contagion in Global Equity Markets in 1998

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Abstract

August to September 1998 has been characterized as one of the worst episodes of global financial distress in decades. This paper investigates the transmission of the Russian and the LTCM crises through global equity markets using a panel of 14 developing and industrial countries. The results show that contagion was systemic during the period, with industrial countries providing the dominant cross-country transmission linkages. Both crises reinforced each other, highlighting the importance of studying them jointly. An implication of the empirical results is that models of contagion that exclude industrial countries are potentially misspecified and may yield misleading outcomes.

JEL Classification Numbers: C33, E44, F34

Keywords: Financial Crises, Contagion, International Spillovers, Russia, LTCM, Equity Markets

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I. INTRODUCTION

Since the mid-1990s, international financial markets have experienced several episodes of crises. As a result, a number of studies have investigated the transmission of shocks across national borders and the impact of crises on the volatility of global financial markets. Some recent examples are Bae, Karyoli, and Stultz (2003); Forbes and Rigobon (2002); Corsetti, Pesenti, and Roubini (2002); and Kaminsky and Reinhart (2002). See Dornbusch, Park, and Claessens (2000) for a review.

This paper examines the transmission of shocks during the 1998 Russian crisis and the near-default of the U.S. hedge fund Long-Term Capital Management (LTCM) in global equity markets, including key emerging markets and industrial countries. The choice of this period is particularly interesting for three reasons. First, the period is characterized by extreme distress in global financial markets in *both* developing and industrial countries (Cohen and Shin (2002), Upper (2001)). Second, the events during this period are considered by some observers to represent the worst turbulence in international financial markets in the last few decades (Committee on the Global Financial System (1999)) and are therefore well suited for an inclusion in a study of the transmission of shocks across countries. Third, given the high exposure of banks and hedge funds to Russia (Jorion (1999), Van Rijckeghem and Weder (2000, 2001)) and the short interval between the two crises, there is a possibility that the two events are connected.

In identifying the channels through which crises are transmitted across global equity markets, it is necessary to distinguish those channels which arise from economic linkages and thus are anticipated, and those channels which are unanticipated. Potential anticipated channels are the spillover effects arising from trade linkages (Eichengreen, Rose, and Wyplosz (1996)) and financial linkages through the rebalancing of investors' portfolios including banks and hedge funds (Van Rijckeghem and Weder (2001), Hall and Taylor (2002), Kiyotaki and Moore (2002)).[2] Unanticipated shocks represent the impact of crises over and above mechanisms arising from economic linkages. These mechanisms are also referred to as contagion (Sachs, Tornell, and Velasco (1996) and Masson 1999 a,b,c). Contagion has often been considered an emerging market phenomenon (see, for example, Bae, Karyoli, and Stultz (2003)). However, given the potentially important interconnections between global financial markets as a channel of contagion, it is important in modelling contagion to include both industrial countries and emerging markets (Van Rijckeghem and Weder (2001) and Dungey, Fry, González-Hermosillo, and Martin (2002)).

The approach taken in this paper is to examine the daily behavior of equity returns for 14 countries among several regions of the world. The selection of the sample is representative of countries from key regions of the world: Argentina, Brazil, and Mexico

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[2] Given the low volume of trade between Russia and other countries, it is the financial linkages rather than the trade linkages which are dominant in the transmission mechanism in this period.

from Latin America; Hong Kong SAR, Indonesia, the Republic of Korea, and Thailand from Asia; Poland and Russia from Eastern Europe; and Germany, Japan, the Netherlands, the United Kingdom, and the United States as representative industrial countries. The period of study encompasses daily equity returns from January to December 1998. The focus on equity markets is to identify additional linkages in financial markets other than the direct linkages experienced in global bond markets from the Russian bond default identified by Dungey, Fry, González-Hermosillo, and Martin (2002). These additional linkages between asset markets during the turbulence that followed Russia's default arose through the impact on the price of government securities, which served as a basis for pricing other financial instruments and as a vehicle for hedging (Cohen and Shin (2002), Upper (2001)).

To identify the various shocks underlying volatility in equity markets, a latent factor model of equity returns is developed. The advantage of this approach is that it is possible to quantify the sources of volatility without a priori identification of the relevant fundamental variables, as is necessary in the approach of Eichengreen, Rose, and Wyplosz (1996) and Glick and Rose (1999), for example. The model identifies both global and regional shocks as well as idiosyncratic shocks unique to each market. Contagion is measured as the effects of unanticipated movements in the Russian and U.S. equity markets on other equity markets around the world.

The latent factors governing equity returns are specified to evolve according to autoregressive processes, with GARCH conditional variance structures to reconcile the model with the observed features of the data. The origins of the model can be found in papers such as Diebold and Nerlove (1989); King and Wadhwani (1990); Ng, Engle, and Rothschild (1992); 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.

Related work that also looks at the Russian crisis and the LTCM period is by Rigobon (2001), who uses the Determinant of the Change in Covariance (DCC) test to measure changes in the correlation structure of equity markets of emerging countries. Using a different approach, Kaminsky and Reinhart (2002) broaden the focus and look at a range of countries that includes both industrial and emerging markets. Dungey, Fry, González-Hermosillo, and Martin (2002) also look at a range of developing and industrial countries but focus on bond markets. Finally, Kho, Lee, and Stultz (2000) consider the effects of the LTCM crisis on the balance sheets of U.S. banks.

This study attempts to shed light on several issues concerning the importance of contagion in equity markets. First, it identifies the relative strengths of the transmission of shocks arising from the Russian and LTCM crises on global equity markets. Second, it looks at potential interconnections between the two crises and whether they reinforced each other. Third, it looks at whether there are differences between the effects of shocks on emerging and industrial equity markets of the two crises. This latter hypothesis is of interest given the views of the Committee on the Global Financial System (1999) which differentiate between the two crises, with the Russian crisis seeing as affecting developing markets and the LTCM crisis seeing as affecting developed markets; the latter presumption is also made by Schnabel and Shin (2002).

The empirical results show that there are significant and systemic linkages resulting from the Russian and LTCM crises that affect the countries investigated. In particular, the LTCM crisis is found to be very important in contributing to the volatility of global equity markets. There is also evidence that the Russian crisis was channeled through Germany and other industrial countries. The pivotal role of industrial countries and the widespread importance of the LTCM crisis are consistent with Kaminsky and Reinhart (2002), who argue that shocks need to affect financial centers in industrial countries to become systemic. These results are in contrast with the views of the Committee on the Global Financial System (1999) that the LTCM crisis concentrated on developed markets and that the Russian crisis mainly impacted emerging markets.

The remainder of this paper is organized as follows. Section II reviews the background of events, with a discussion of the data characteristics and the sample period provided in Section III. The factor model of contagion used in this paper is given in Section IV. In Section V, the estimation method is discussed, and Section VI details the empirical results. Section VII concludes with a summary and directions for future research.

II. Background of Events

After a period of relative calm in international financial markets during the first part of 1998, following the Asian crisis in 1997, a shock was felt on August 17, 1998 when Russia announced a de facto devaluation by widening the trading band of the ruble. Russia also declared its intention to restructure all official domestic currency debt obligations falling due to the end of 1999 and imposed a 90-day moratorium on the repayment of private external debt (Kharas, Pinto and Ulatov (2001)).

The Russian default appears to have led to a reassessment of credit and sovereign risks across global financial markets, evidenced by large jumps on liquidity spreads and risk premia (Cohen and Shin (2002)). For example Dungey, Fry, González-Hermosillo and Martin (2002) find that bond spreads for a range of countries more than doubled during 1998. During this period most equity markets across the globe accelerated their decline (see Figure 1) and became more volatile (see Figure 2). A few weeks after the Russian crisis was unveiled, news reached financial markets on September 23, 1998 about the financial scheme that was being put together to rescue the U.S. highly leveraged hedge fund LTCM. The investment strategies of LTCM had been largely based on betting on "normal" volatilities and credit and liquidity spreads between closely related securities, some of which seemed to have changed in the aftermath of the Russian crisis (Jorion (2000)). LTCM lost more than 50 percent of its end-December 1997 capital by the end of August 1998. With assets still at $126 billion, the leverage ratio (or the ratio of assets-to-capital) had increased from 28-to-1 to 55-to-1 during the same period. The potential effect of LTCM collapsing was such that the New York Federal Reserve organised a bailout of LTCM on September 23 by encouraging 14 banks to invest in the hedge fund.

During the period of the Russian and LTCM crises, the U.S. Federal Reserve cut interest rates aggressively in three steps between September 29 and November 17, 1998. One of these moves was announced between regular FOMC meetings on October 15 which, according to market participants (Committee on the Global Financial System (1999)), signaled the beginning of the abatement of financial constraints. This otherwise arbitrary "end" to the crisis of 1998, is also supported by other findings in the literature (see, for example, Kumar and Persaud (2001), Upper and Werner (2001)). The sharp easing in U.S. monetary policy was in part motivated by growing concerns that the U.S. economy was on the verge of experiencing a liquidity crash as bond spreads globally had risen to exceptionally high levels. The Federal Reserve actions may have staved off a far more dramatic crisis as suggested by the analysis in Schnabel and Shin (2002).

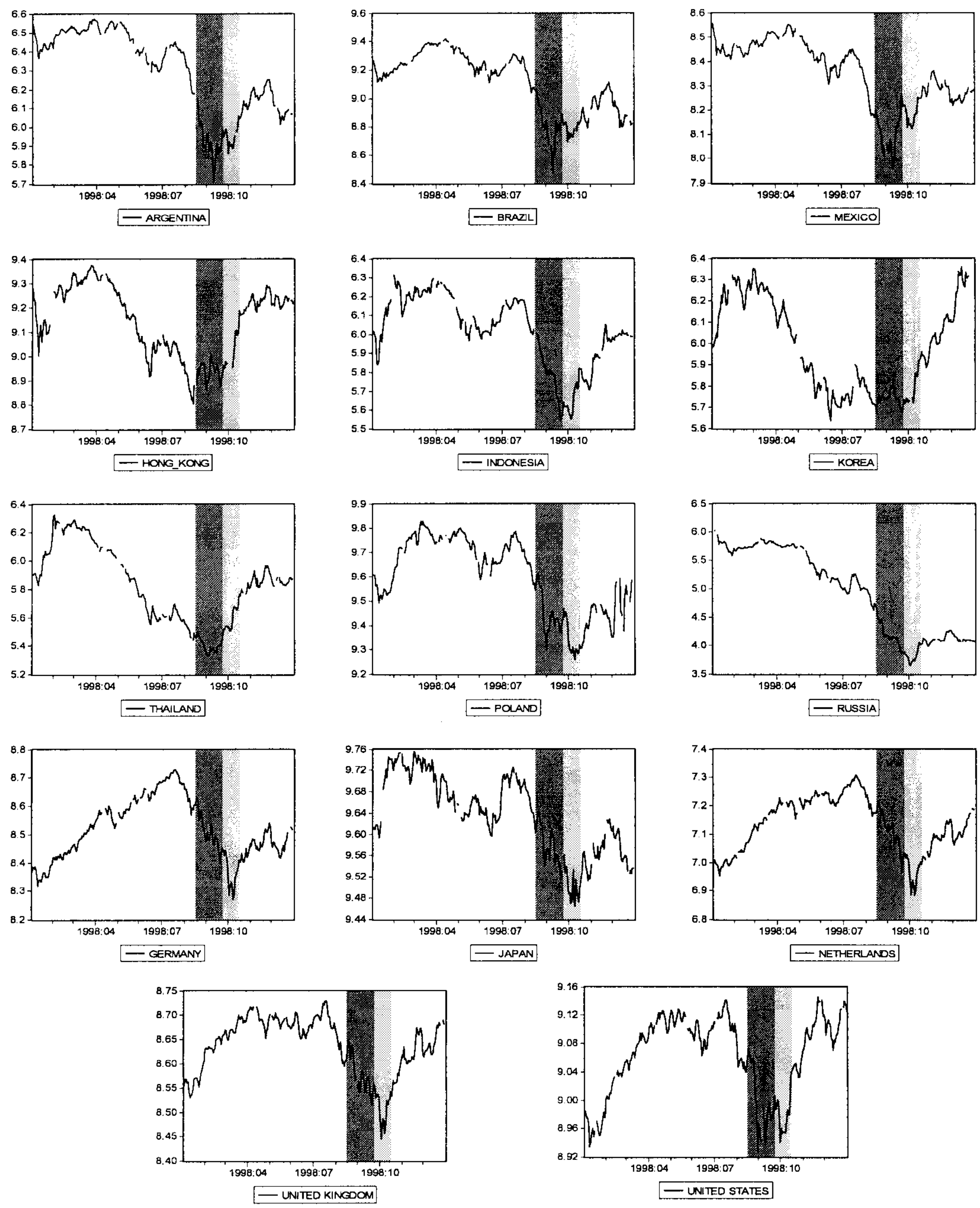
III. The Data and Sample

Daily stock market indices are collected from fourteen countries, which are chosen to be representative of a selection of industrialized and emerging economies. The markets are Argentina, Brazil and Mexico in Latin America; Hong Kong SAR, Indonesia, the Republic of Korea, and Thailand in Asia; Poland and Russia in Eastern Europe; and Germany, Japan, the Netherlands, the United Kingdom, and the United States among the industrial countries. The sample period is from January 2, 1998 to December 31, 1998, a total of 260 daily observations. Details of the data sources are found in Appendix I. The data are converted into equity market returns by taking the difference of the natural logarithms of the data, and are presented in percentage terms (see Figure 2).

Table II.1 in Appendix II presents the descriptive statistics of daily percentage equity market returns.[3] The table shows that two thirds of the emerging markets have negative average returns, with Russia displaying the largest negative daily return of -0.74 percent. This large fall is highlighted in Figure 1 which shows that the equity price in Russia continually fell over 1998 before leveling out after the LTCM crisis. With the exception of Japan, the industrial countries yielded small positive average returns. The table shows that equity returns over the period exhibited large movements with the emerging markets tending to experience greater absolute variability than the industrial countries. Some of the countries exhibit positive autocorrelation in returns, with the two Eastern European countries having values between 0.18 and 0.24. All returns display strong evidence of non-normalities.

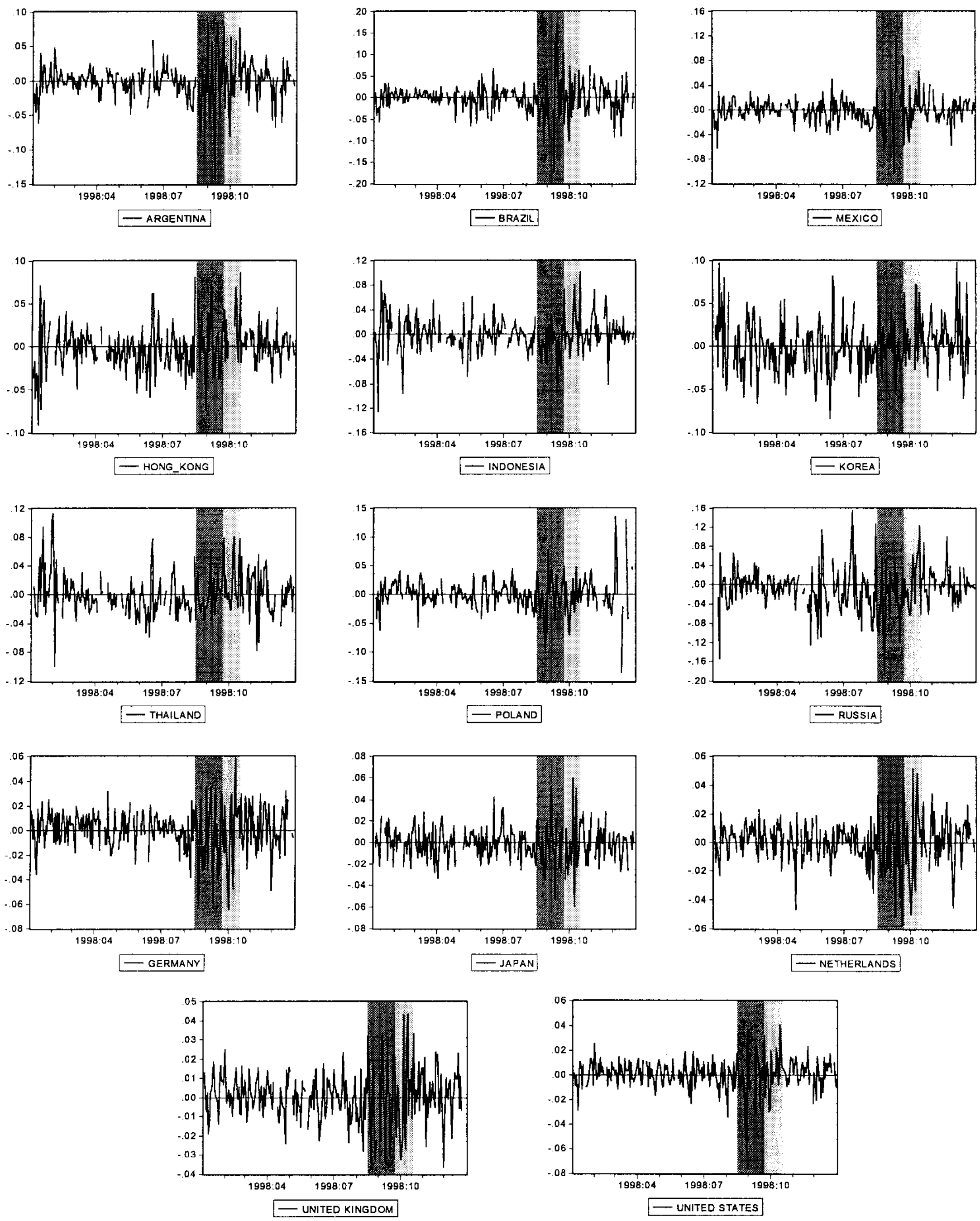
[3] Augmented Dickey Fuller and Phillips Perron tests indicate that all equity returns are stationary.

Figure 1. Stock Market Prices, January–December 1998 [4]
(natural logarithms)



[4] Shading shows the timing of the Russian and LTCM crises, respectively.

Figure 2. Stock Market Returns, January–December 1998 [5]
(differences of natural logarithms).



[5] Shading shows the timing of the Russian and LTCM crises, respectively.

Table II.2 shows that there is in general strong evidence of correlation amongst equity returns of countries within each region, with the strongest correlations exhibited by the Latin American countries, with correlations ranging between 0.74 and 0.80. Outside of each region, there are also some significant correlations amongst equity returns. Some notable examples are the correlations between the United States and Latin American countries, with correlations between 0.57 and 0.64, and between the United States and Hong Kong (0.40). The German equity market also exhibits high correlations with a number of emerging equity markets, including Hong Kong (0.52), Argentina (0.46), Russia (0.43) and Poland (0.37). This correlation with Russia is particularly interesting given the high exposure of German banks to Russia during the period (Van Rijckeghem and Weder (2000)). Within the industrial block, there are also high correlations between the three European countries of Germany, the Netherlands and the United Kingdom with correlations between 0.81 and 0.84.

To identify the conditional volatility structure of equity returns, the results from estimating univariate GARCH(1,1) models are presented in Table II.3 of Appendix II. These results show that all countries with the exception of the Netherlands exhibit a degree of conformity amongst the point estimates thereby highlighting that the equity returns display similar GARCH structures. Most of the country GARCH models show long memory with the volatility structure of three of the countries exhibiting IGARCH. The GARCH features of the data are used in developing the factor model in the next section to provide a parsimonious parameterization of the multivariate GARCH structure of equity returns.

IV. A Factor Model of Equity Markets

The model of contagion specified in this paper is based on the factor model of Dungey, Fry, González-Hermosillo and Martin (2002) and earlier work by King, Sentana and Wadhini (1994). The equity market returns $s_{i,t}$, of each of the 14 countries investigated are assumed to be decomposed in terms of a range of independent factors. The factor model is specified as:

$$s_{i,t} = \theta_i + \lambda_i W_t + \gamma_i R_{k,t} + \phi_i f_{i,t} + \delta_i e_{RU,t} + \psi_i I_t e_{US,t}. \qquad (1)$$

The first factor is referred to as a world factor W_t, as it represents shocks that are common to all equity markets. Potential common shocks could include changes in monetary policy, as discussed in Section II, which in general impact upon global financial markets.[6] The second

[6] A range of variables have been used in empirical analyses to represent global factors (see, for example, Eichengreen, Rose and Wyplosz (1996)). However, most of the variables used are not available at a high frequency. In the case of interest rates, these are available daily and hence could be used as a candidate variable to measure global shocks, as in Forbes and Rigobon (2002). This approach is not adopted here. Instead, the global factor is identified implicitly through the comovements of equity returns. Issues of identification are discussed in Section V.

factor represents a regional factor $R_{k,t}$, which corresponds to shocks that are common just to countries in geographical groups. Three regional groups are considered *(k=1, 2. 3)*: Latin America (Argentina, Brazil and Mexico), Asia (Hong Kong, Indonesia, Korea and Thailand) and Eastern Europe (Poland and Russia). No common factor is specified for the five industrial countries, although one possibility would be to include a European factor associated with Germany, the U.K. and the Netherlands given the correlation structure amongst these countries presented in Table II.2. The third factor is $f_{i,t}$, and represents shocks that are idiosyncratic to the equity market of a particular country. Finally, the next two components, $e_{RU,t}$ and $e_{US,t}$, capture the effects of unanticipated shocks from Russia and the United States respectively. These components represent contagion with the strength of the transmission mechanisms determined by the parameters δ_i and ψ_i. The unanticipated shocks formally represent that part of time variation in the idiosyncratic shocks which is not predicted using information at time t-1.Given the statistical properties of equity returns identified in Section III, the idiosyncratic shocks from Russia and the United States are modeled as autoregressive processes with one lag and GARCH conditional variances:

$$\begin{aligned} f_{i,t} &= \rho_i f_{i,t-1} + e_{i,t} \quad i = RU, US \\ e_{i,t} &= \sqrt{h_{i,t}} u_{i,t} \\ h_{i,t} &= 1 - \alpha_i - \beta_i + \alpha_i e_{i,t}^2 + \beta_i h_{i,t-1} \\ u_{i,t} &\sim N(0,1). \end{aligned} \tag{2}$$

The restriction $1-\alpha_i-\beta_i$ in the GARCH equation normalizes the unconditional variance of $e_{i,t}$ to unity and is used for identification (Diebold and Nerlove (1989)).

The indicator variable I_t in equation (1) is a dummy variable which is designed to isolate the effects of contagion from the LTCM crisis from other unanticipated transmissions from the dominant U.S. economy. This variable takes the value of one during the LTCM crisis period, September 23, 1998 to October 15, 1998, and zero otherwise, a total of 17 observations:

$$I_t = \begin{cases} 0: \text{non LTCM period} \\ 1: \text{LTCM period.} \end{cases} \tag{3}$$

To complete the specification of the model, the world W_t and regional $R_{k,t}$ factors are also specified to have autoregressive processes and GARCH conditional variances:

$$
\begin{aligned}
&W_t = \rho_w W_{t-1} + e_{w,t} \\
&R_{k,t} = \rho_k R_{k,t-1} + e_{k,t} \quad k = \textit{Latin, Asia, E. Europe}, \\
&e_{j,t} = \sqrt{h_{j,t}} u_{j,t} \qquad j = w, \textit{Latin, Asia, E. Europe}, \\
&h_{j,t} = 1 - \alpha_j - \beta_j + \alpha_j e_{j,t}^2 + \beta_j h_{j,t-1} \\
&u_{j,t} \sim N(0,1).
\end{aligned} \tag{4}
$$

The specification of autoregressive and, somewhat more importantly, GARCH conditional variances on the factors provides a parsimonious representation of the time varying conditional moments of equity returns. It is the commonality in the characteristics of equity returns identified in Section III that makes the development of the factor model feasible. By construction, all factors have zero means. This implies that the mean of equity returns in equation (1) is given by the parameter θ_i.

Identification of the factors is achieved implicitly through the decomposition of movements and comovements of equity returns. An informative method of presenting the results of the model is as a variance decomposition, setting out the relative contributions of each of the factors to total variance (or volatility) in the returns. The unconditional variance of the returns modelled in equation (1) is given by:

$$
\begin{aligned}
&\operatorname{var}(s_{i,t}) = \frac{\lambda_i^2}{1-\rho_w^2} + \frac{\gamma_i^2}{1-\rho_k^2} + \phi_i^2 + \frac{\delta_i^2}{1-\rho_{RU}^2} + \frac{\psi_i^2}{1-\rho_{US}^2} I_t \quad i \neq RU, US \\
&\operatorname{var}(s_{i,t}) = \frac{\lambda_i^2}{1-\rho_w^2} + \frac{\gamma_i^2}{1-\rho_k^2} + \frac{\phi_i^2}{1-\rho_{RU}^2} + \frac{\psi_i^2}{1-\rho_{US}^2} I_t \quad i = RU \\
&\operatorname{var}(s_{i,t}) = \frac{\lambda_i^2}{1-\rho_w^2} + \frac{\phi_i^2}{1-\rho_{US}^2} + \frac{\delta_i^2}{1-\rho_{RU}^2} \quad i = US
\end{aligned} \tag{5}
$$

The corresponding contributions of each factor to total volatility where the total volatility $\text{var}(s_{i,t})$, depends upon the country, are computed as:

(i) contribution of the world factor $\dfrac{\lambda_i^2}{(1-\rho_w^2)\,\text{var}(s_{i,t})}$

(ii) contribution of the regional factor $\dfrac{\gamma_i^2}{(1-\rho_k^2)\,\text{var}(s_{i,t})}$

(iii) contribution of the idiosyncratic factor

countries other than Russia and the U.S. $\dfrac{\phi_i^2}{\text{var}(s_{i,t})}$

Russia $\dfrac{\phi_{RU}^2}{(1-\rho_{RU}^2)\,\text{var}(s_{RU,t})}$

U.S. $\dfrac{\phi_{US}^2}{(1-\rho_{US}^2)\,\text{var}(s_{US,t})}$

(iv) contribution of contagion from Russia $\dfrac{\delta_i^2}{(1-\rho_{RU}^2)\,\text{var}(s_{i,t})}$

(v) contribution of contagion from the US (LTCM) $\dfrac{\psi_i^2}{(1-\rho_{US}^2)\,\text{var}(s_{i,t})}$

V. Estimation Issues

The factor model in (1) is estimated using simulated generalized method of moments (GMM) by comparing the theoretical moments of the model with the empirical moments obtained from the data. The theoretical moments are obtained from simulating the factors in equations (2) and (4) to generate simulated equity returns. This estimator is referred to as simulated GMM by Duffie and Singleton (1993), indirect inference by Gourieroux, Monfort and Renault (1993), and efficient method of moments by Gallant and Tauchen (1996). The estimator yields consistent parameter estimates and under certain conditions achieves the same efficiency as maximum likelihood (Gallant and Tauchen (1996)).

Let Ψ represent the K=95 unknown parameters in equations (1) to (4), the GMM estimator is the solution of

$$\hat{\psi} = \arg\min G'\Omega^{-1}G, \qquad (6)$$

where G is a $(M \times 1)$ vector or moment conditions and Ω is a $(M \times M)$ weighting matrix, defined below. The moment conditions used to construct G in (6) can be categorized into four components. The first set of moments are designed to identify the $N = 14$ parameters which control the levels of the equity returns (θ_i) by comparing the $N = 14$ sample means obtained from the actual equity returns with the $N = 14$ sample means obtained from the simulated equity returns.

The second set of moments are designed to identify the loadings of the factor model $(\lambda_i, \gamma_i, \phi_i, \delta_i, \psi_i)$ and consists of comparing the $N(N \times 1)/2 = 105$ unique variances and covariances obtained from the $N = 14$ actual equity returns and the $N = 14$ simulated equity returns. The third set of moments are designed to identify the 6 autoregressive parameters in the model: the four autoregressive parameters associated with the world and three regional factors in equation (4), and the two autoregressive parameters associated with Russia and the United States in equation (2). This set of moments is obtained in two parts. The first part consists of selecting the first four principal components from an eigen decomposition of the correlation matrix of actual returns and using these four series to estimate a VAR with one lag.[7] This four variate system is augmented with two univariate autoregressions each with one lag corresponding to the actual U.S. and Russian equity returns. This yields 18 moment conditions corresponding to the sample covariances between the residuals and the pertinent explanatory variables of the VAR. Each of the dynamic equations includes an intercept term which produces a further 6 moment conditions. The moments are evaluated using the simulated returns, but with the parameter estimates obtained from the actual returns.

The fourth and last set of moment conditions are designed to identify the GARCH parameters (α_i, β_i) in equations (2) and (4) associated with the world and three regional factors as well as the U.S. and Russian idiosyncratic factors. The strategy is to select the 6 residual series obtained from the previous set of moment conditions, and estimate 6 autoregressive models in the squares of these residual series containing two lags and an intercept. This results in 18 extra moment conditions. As with the moment conditions used to identify the autoregressive parameters, these moments are evaluated using the simulated returns, but with the parameter estimates obtained from the actual equity returns.

The total number of moment conditions is M=14+105+24+18=161, which are designed to identify the K=95 parameters. Finally, the weighting matrix in (6) is chosen as the outer product of the gradients based on actual returns with an adjustment for

[7] The eigen decomposition using the correlation matrix is an inappropriate direct estimation strategy as a result of the conditional heteroskedastic structure of the factor model making the correlation matrix time-varying. However, it does provide a suitable set of moment conditions in which to approximate the true likelihood function and thereby obtain consistent parameter estimates via the GMM estimation procedure.

autocorrelation of L=5 lags, calculated using Newey-West weights (Gallant and Tauchen (1996)).

The parameter estimates are obtained by using the gradient iterative algorithms in the OPTMUM library of GAUSS to minimize the function (6). All gradients are computed numerically. The simulated equity returns are obtained from using the GAUSS procedure RNDN to generate the normal random numbers. The length of the simulated excess returns is set at N=27000, where the first 100 observations are discarded to overcome start-up problems in initializing the six time-dependent factors containing autoregressive conditional variance components.

One feature of the data mentioned in Appendix II is that the equity returns of each country contain missing observations. By simply deleting observations that are missing, and estimating the model with the reduced data set may introduce biases into the parameter estimates. To correct for these potential biases, the following steps are adopted. First, the factor model is simulated as if the full data set is known. Second, the simulated equity returns data set is reduced by extracting those simulated observations corresponding to when all observations in the actual returns series exist. This reduces the length of the simulated equity returns series to 17,300 observations when evaluating the theoretical moment conditions. As it is the parameters of the true model that are used in generating the simulated equity returns to be used in computing the theoretical moments, the simulated GMM estimator in essence automatically corrects any biases from missing observations.[8]

VI. Empirical Results

In this section the empirical results from estimating the factor model in equations (1) to (4) are presented. The results are given in terms of the volatility decompositions given in (5) as this provides a more informative measure to identify the relative contributions of the various factors and contagion to the volatility in equity returns of each country.[9] The results are presented initially for the non-LTCM period (I_t=0 in equation (3)) followed by the LTCM period (I_t=1 in (3)).

A. The Non-LTCM Period

Table 1 gives the volatility decompositions in terms of the various factors during the non-LTCM period. The results show that common factors arising from both world and regional shocks contribute more than 50 percent for most of the emerging markets. The exceptions are Indonesia, Thailand, and Poland which have a large idiosyncratic component.

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[8] A similar approach is used by Gourieroux, Monfort, and Renault (1993) to estimate continuous time models with discrete data.

[9] Point estimates of the parameters are not presented, but are available from *http://rspas.anu.edu.au/economics/staff/dungey*.

The world shocks are relatively small for the five industrial countries with the greatest weight given to the United States (37 percent). Of the industrial countries, Japan has up to 72 percent of volatility due to idiosyncratic factors, followed by the Netherlands (51 percent) and Germany (42 percent).

An important feature of the volatility decompositions in Table 1 is the strength of contagion from Russia to all industrial countries. The United Kingdom (61 percent) and Germany (50 percent) have the highest proportionate weight followed by the Netherlands (44 percent), the United States (40 percent) and Japan (28 percent). This result is consistent with the fact that European (especially German) and U.S. banks had large exposures to Russia, with expected losses of about 90 cents on the dollar (Van Rijckeghem and Weder (2001), Upper (2002)). Furthermore, a number of European and U.S. banks were put on negative watch or downgraded as a direct result of the Russian crisis (Van Rijckeghem and Weder (2000)).

The relatively large strength of contagion from Russia for industrial countries contrasts the proportionate role of contagion in the developing economies which tend to be smaller. The largest being Indonesia (18 percent) followed by Poland (17 percent), Argentina (15 percent) and Thailand (12 percent), with the remaining contributions for the other emerging markets being less than 6 percent. This finding does not support the view that contagion from Russia concentrated on other emerging markets (Committee on the Global Financial System (1999)).

B. The LTCM Period

The factor decompositions during the LTCM period are given in Table 2. These results highlight the importance of the United States in influencing global equity markets. All three Latin American countries experience high levels of contagion from the United States (between 63 percent and 87 percent).

Of the Asian region, Hong Kong SAR experiences the highest amount of contagion from the United States (75 percent) followed by Korea (46 percent), Thailand (36 percent) and Indonesia (32 percent). Interestingly, the factor structure for Thailand and Indonesia is similar across both factor groupings and sample periods (compare Tables 1 and 2 for the two countries). During 1998, both of these countries were still in the initial stages of resolving their banking crises.

Contagion from the United States to the two Eastern European countries varies, with Russia experiencing quite high levels (33 percent), possibly reflecting its vulnerability soon after having experienced its own crisis, and Poland experiencing low levels (5 percent). The latter result is somewhat puzzling and may reflect the early stages of financial market development in Poland whereby shocks are not freely transmitted from the rest of the world.

Table 1. Unconditional Volatility Decomposition of Equity Returns: Contagion from Russia and the United States During the Non-LTCM Period
(contribution to total volatility, in percent)

	World	Regional	Country	Contagion from Russia
Latin America				
Argentina	38.047	25.526	21.225	15.202
Brazil	56.113	38.166	0.238	5.483
México	21.913	63.011	14.978	0.099
Asia				
Hong Kong SAR	54.633	16.478	28.301	0.588
Indonesia	8.221	17.313	56.200	18.265
Korea	3.342	95.835	0.480	0.343
Thailand	3.005	20.306	64.230	12.460
Eastern Europe				
Poland	2.578	0.195	80.434	16.793
Russia	8.833	43.173	47.994	-
Industrial Countries				
Germany	7.791	-	41.752	50.457
Japan	0.008	-	72.442	27.550
Netherlands	4.523	-	50.773	44.703
United Kingdom	10.027	-	28.599	61.374
United States	36.546	-	23.817	39.637

Table 2 shows that there is also contagion from the United States to the other industrial countries during the LTCM crisis, with the exception of Germany, where the contagious transmission channel is dominated still by Russia. This continual importance of the Russian crisis on the German equity market may reflect the direct exposure of German investors to Russia, and the subsequent effects of the declining value of German bank stocks (Van Rijckeghem and Weder (2000)). Given the high degree of correlation between Germany and the European countries (Table II.2 in Appendix II) this also suggests a strong potential channel for transmitting the crisis from Russia to Europe, with Germany providing a conduit role. Part of the reason of this transmission could be attributed to a common bank lender (Van Rijckeghem and Weder (2001)) or more generally due to the rebalancing of investors portfolios (Kodres and Pritsker (2002), Schnabel and Shin (2002)).

Table 2. Unconditional Volatility Decomposition of Equity Returns: Contagion from Russia and the United States During the LTCM Period
(contribution to total volatility, in percent)

	World	Regional	Country	Contagion from Russia	Contagion from United States
Latin America					
Argentina	13.918	9.338	7.764	5.561	63.418
Brazil	7.528	5.120	0.032	0.736	86.585
México	7.870	22.630	5.379	0.036	64.085
Asia					
Hong Kong SAR	13.792	4.160	7.144	0.149	74.756
Indonesia	5.595	11.782	38.244	12.429	31.950
Korea	1.811	51.916	0.260	0.186	45.830
Thailand	1.935	13.076	41.361	8.023	35.605
Eastern Europe					
Poland	2.449	0.185	76.410	15.953	5.003
Russia	5.939	29.027	32.269	-	32.765
Industrial Countries					
Germany	7.531	-	40.354	48.768	3.347
Japan	0.003	-	24.303	9.243	66.451
Netherlands	2.667	-	29.941	26.362	41.029
United Kingdom	4.613	-	13.156	28.234	53.997
United States	36.546	-	23.817	39.637	-

Examining the Non-LTCM and the LTCM periods together provides insights into the way crises are transmitted and reinforce each other. In particular, the results show that the two crises examined tended to reinforce each other given the strong contagious transmission mechanism from Russia to the United States (40 percent) and the reverse from LTCM to Russia (33 percent), possibly since U.S. hedge funds had high exposures to Russia (Van Rijckeghem and Weder (2001)). These transmission channels are further strengthened given the strong levels of contagion from Russia to Germany and the subsequent connection between Germany and other industrial countries excluding Japan, who was experiencing its own financial sector problems at this time. This property is reflected in the high proportion of volatility due to idiosyncratic factors for Japan.

VII. CONCLUSION AND SUGGESTIONS FOR FUTURE RESEARCH

This paper has provided an empirical analysis of the transmission of contagion in equity markets during the Russian bond default and LTCM crises in 1998. Contagion was identified as the effects of unanticipated shocks from either Russia or the United States on other global equity markets, having conditioned on both world and regional factors, as well as idiosyncratic shocks in individual countries' equity markets. Fourteen equity markets were studied consisting of industrial countries, and developing countries from three regions: Latin America, Asia, and Eastern Europe. The decomposition of shocks into world, regional, idiosyncratic, and contagion factors was performed using a factor model developed by Dungey and Martin (2002) and recently applied to bond markets during the Russian and LTCM crises by Dungey, Fry, González-Hermosillo, and Martin (2002).

An important outcome of the empirical results was the dominance of contagion from the United States arising from the LTCM crisis in September 1998. Contagion from the Russian bond default in August 1998 was found to be important, but quantitatively smaller than contagion from the LTCM crisis, and mostly affected industrial countries. There were two possible channels. One was through the direct exposure of U.S. banks and hedge funds, and European (especially German) banks to Russia. The second is an indirect channel arising from the interconnections between German and European financial markets, as well as the United States. The results also show that there was a reinforcing effect between the Russian and the LTCM crises, with significant contagion from Russia to the United States, and from the United States to Russia. An implication of the empirical results is that models of contagion that exclude industrial countries are potentially misspecified and may yield misleading outcomes.

While the results tend to be consistent with the other studies of contagion in equity markets, they do, however, contrast in some ways with other studies of contagion conducted on other financial markets. For example, in Dungey, Fry, González-Hermosillo, and Martin (2002) in studying the transmission of contagion during the Russian and LTCM crises in bond markets over the same period, we found that the contribution of contagion from the LTCM crisiswas relatively smaller than that of contagion from the Russian crisis. Further, we found that the transmission of contagion from Russia to other industrial countries was quantitatively small. In the equity markets, the empirical results reported showed that the transmission mechanism from the Russian shock was relatively stronger in equity markets for industrial countries than in those for developing countries.

An interesting aspect of the results concerns Brazil, which was the next country to experience a financial crisis in January 1999. In the current paper, contagion in equity markets from the United States was relatively important to understanding volatility in the Brazilian equity market in the run-up to that country's crisis. In the bond markets for the same period (Dungey, Fry, González-Hermosillo, and Martin (2002)), we found that contagion from Russia dominated volatility in Brazilian bond markets. This suggests that the onset of the crisis in Brazil was associated with the prior effects of international crises across several financial markets and several sources: Russia in the bond market and the United States in the equity market. This finding is consistent with the analysis of Kaminsky and Reinhart (2002) where similar shocks are expected to impact differently across markets and asset classes owing at least in part to structural differences between those markets. This also highlights the need for constructing a model which integrates both markets in order to identify contagion across both regions' financial markets and asset classes. Such a model provides a framework in which to study the possible domino effects of crisis transmissions through a broader class of financial assets.

I. Data Definitions and Sources

All data are from Bloomberg:

Argentina: Buenos Aires Stock Exchange

Brazil: Brazil Bovespa Stock Exchange

Mexico: IPC Mexico Bolsa Index

Hong Kong SAR: Hang Seng Stock Index Hong Kong

Indonesia: Jakarta SE Index

Korea: KOSPI Index

Thailand: Thai Stock Exchange of Thai Set Index

Poland: Warsaw Stock Exchange Total Return Index

Russia: Russian RTS Index $

Germany: Deutsche Borse AG German Stock Exchange

Japan: Nikkei 225 Index Tokyo SE

Netherlands: Cbs general index

United Kingdom: FTSE 100 Index

United States: Dow Jones Industrial Index

II. Preliminary Data Analysis

This Appendix contains descriptive statistics in Table II.1, correlations in Table II.2 and conditional volatility estimates in Table II.3 of equity returns. The full data set consists of 260 daily equity prices from January 2, 1998 to December 31, 1998, on fourteen countries. Returns are computed as the difference of the natural logs of stock prices and multiplied by 100 to express returns as a percentage, reducing the dataset to 259 daily observations. In computing the descriptive statistics in Table II.1 and the conditional volatility estimates in Table II.3, the equity returns for each country are based on all available data points for each country having excluded missing observations. The number of sample points used for each country are given in Table II.1. In computing the correlations in Table II.2, the total dataset is further reduced to 172 daily observations, which represents the complete dataset having extracted missing observations for each country. Issues of missing observations and how they are handled in the estimation of the factor model, are discussed in Section V.

Table II.1. Descriptive Statistics of Daily Percentage Equity Returns

	Latin America			Asia				Europe		Industrial Countries				
Statistic	Argentina	Brazil	Mexico	Hong Kong	Indonesia	Korea	Thailand	Poland	Russia	Germany	Japan	Netherlands	United Kingdom	United States
Mean	-0.13	-0.18	-0.13	-0.09	-0.07	0.10	0.03	0.03	-0.74	0.03	-0.09	0.02	0.05	0.03
Maximum	8.53	17.12	12.15	8.61	10.20	9.83	11.35	13.53	15.55	5.89	5.99	5.19	4.35	4.06
Minimum	-14.30	-17.23	-10.34	-9.10	-12.73	-8.44	-10.03	-13.53	-18.78	-6.44	-5.96	-5.77	-3.66	-6.58
Std. Dev.	2.96	3.66	2.29	2.67	3.00	3.14	2.96	2.90	4.56	1.85	1.65	1.64	1.33	1.23
AR(1)	0.08	-0.04	0.07	0.09	0.183	0.10	0.17	0.24	0.18	0.09	-0.06	0.11	0.14	0.04
AR(2)	-0.09	-0.05	0.00	-0.10	0.024	-0.03	0.01	-0.01	0.03	-0.19	-0.11	-0.09	-0.14	0.01
Skewness	-0.60	0.04	0.39	0.24	-0.046	0.40	0.73	0.26	-0.12	-0.59	0.15	-0.42	-0.03	-0.80
Kurtosis	6.84	7.11	8.16	4.26	5.299	3.46	4.90	8.32	5.16	4.18	4.38	4.33	3.77	7.04
Jacque-Bera	159.72	165.11	272.88	18.05	51.848	8.47	55.14	274.65	47.82	28.14	19.70	24.84	6.09	191.49
(p value)	(0.00)	(0.00)	(0.00)	(0.00)	(0.000)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.05)	(0.0)
# obs.	237	235	240	237	235	238	231	231	243	244	236	243	246	243

Table II.2: Correlation Matrix of Daily Equity Returns

	AR	BR	MX	HK	ID	KR	TH	PL	RU	DM	JP	NT	UK	US
AR	1.00													
BR	0.80	1.00												
MX	0.76	0.74	1.00											
HK	0.28	0.16	0.28	1.00										
ID	0.19	0.15	0.14	0.52	1.00									
KR	0.19	0.16	0.25	0.35	0.34	1.00								
TH	0.26	0.17	0.26	0.64	0.53	0.46	1.00							
PL	0.32	0.22	0.33	0.44	0.31	0.36	0.38	1.00						
RU	0.37	0.27	0.17	0.35	0.25	0.14	0.18	0.18	1.00					
DM	0.46	0.33	0.31	0.52	0.25	0.09	0.22	0.37	0.43	1.00				
JP	0.21	0.18	0.16	0.30	0.29	0.31	0.24	0.34	0.21	0.29	1.00			
NT	0.48	0.35	0.34	0.44	0.27	0.16	0.19	0.40	0.41	0.84	0.33	1.00		
UK	0.47	0.33	0.36	0.49	0.29	0.19	0.33	0.44	0.42	0.81	0.32	0.82	1.00	
US	0.64	0.59	0.57	0.40	0.23	0.19	0.38	0.32	0.29	0.51	0.18	0.43	0.55	1.00

Note: Abbreviations are as follows: Argentina (AR), Brazil (BR), Mexico (MX), Hong Kong SAR (HK), Indonesia (ID), Korea (KR), Thailand (TH), Poland (PL), Russia (RU), Germany (DM), Japan (JP), Netherlands (NT), United Kingdom (UK), and United States (US).

Table II.3. Univariate GARCH (1,1) Parameter Estimates of Equity Returns.
(QMLE standard errors in brackets)

The GARCH(1,1) model is specified as:

$$s_{i,t} = \rho_0 + \rho_1 s_{i,t-1} + e_{i,t},$$
$$e_{i,t} = \sqrt{h_{i,t}}\, u_{i,t}$$
$$h_{i,t} = \alpha_0 + \alpha_1 e_{i,t-1}^2 + \beta_1 h_{i,t-1}$$
$$u_{i,t} \sim N(0,1).$$

where $s_{i,t}$ is the equity market return for country *i* recorded at time *t*. All returns are scaled by a factor of 10 for numerical stability.

Country	Parameter					
	ρ_0	ρ_1	α_0	α_1	β_1	ln L
Latin America						
Argentina	1.844	0.106	21.044	0.245	0.782	-834.679
	(2.422)	(0.084)	(22.623)	(0.074)	(0.036)	
Brazil	2.080	0.025	7.425	0.115	0.878	-754.083
	(1.395)	(0.075)	(6.631)	(0.044)	(0.037)	
Mexico	-1.806	0.172	40.223	0.133	0.801	-778.061
	(1.641)	(0.094)	(31.136)	(0.063)	(0.088)	
Asia						
Hong Kong	-0.889	0.226	47.137	0.164	0.794	-812.382
	(1.906)	(0.090)	(37.380)	(0.063)	(0.054)	
Indonesia	-0.551	-0.085	38.001	0.104	0.803	-748.238
	(1.435)	(0.082)	(30.709)	(0.118)	(0.143)	
Korea	-7.288	-0.004	77.016	0.250	0.770	-858.906
	(4.361)	(0.181)	(80.239)	(0.189)	(0.031)	
Thailand	-1.402	0.088	105.067	0.043	0.884	-869.491
	(2.842)	(0.084)	(69.336)	(0.035)	(0.082)	
Eastern Europe						
Poland	-6.520	0.124	85.587	0.076	0.895	-913.918
	(3.887)	(0.090)	(103.290)	(0.046)	(0.060)	
Russia	-0.399	0.064	51.369	0.102	0.845	-831.151
	(2.275)	(0.077)	(42.314)	(0.048)	(0.032)	
Industrial Countries						
Germany	1.111	0.037	11.727	0.030	0.908	-688.190
	(1.175)	(0.078)	(10.582)	(0.028)	(0.059)	
Japan	1.755	0.025	14.522	0.102	0.863	-736.085
	(1.333)	(0.087)	(11.813)	(0.039)	(0.047)	
Netherlands	-0.347	0.224	783.919	0.428	0.165	-862.598
	(2.676)	0.108	(194.941)	(0.421)	(0.167)	
United	-0.067	0.152	21.089	0.117	0.889	-830.911
Kigdom	(1.682)	(0.087)	(44.752)	(0.068)	(0.092)	
United States	0.714	0.071	13.290	0.022	0.927	-715.221
	(1.246)	(0.079)	(9.754)	(0.027)	(0.046)	

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