Contagion Across Financial Markets: An Empirical Assessment*

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Abstract

Information transferred between financial markets can be important during a financial crisis. Using a latent factor model of returns we consider spillovers and contagion between currency and equity markets for a panel of countries in the East Asian cirsis of 1997-98. Financial returns are modelled as a linear combination of unobserved factors representing: shocks unique to the market and country, country-specific shocks, common market shocks, world shocks, spillovers between markets and contagion between markets. Using a definition adapted from Masson (1998,1999), contagion is modelled as the effects of the residual in one market on the other, after controlling for all other forms of shock. The results show that spillovers and contagion from currency markets accounted for the vast majority of equity market volatility. With the exception of Indonesia, contagion from equity markets had little effect on currency markets. Indonesian returns show strong evidence of contagion effects in both equity and currency markets.

Keywords: contagion, spillovers, indirect estimation, financial markets.

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1 Introduction

There is now a substantial literature on contagion in both equity and foreign exchange markets. However, these streams of literature have little common ground. Even the definitions of contagion employed in each differs. Considering that market practitioners and observers are widely agreed that there are transfers of information between these markets, particularly during times of crisis, it is appropriate to examine contagion in and between these markets in a unified manner. Using a model which has been proposed separately in each of these markets, a model of the interactions between the markets is developed and estimated.

The literature on contagion in equity markets largely focuses on contagion as evidenced by correlations between stock prices (for example Forbes and Rigobon (1999) and references therein). The existence of non-independent movements in prices is contrary to theoretical stock valuation and indicates common non-fundamental price changes. Much of the recent work on this topic was prompted by the 1987 stock market crash and the disturbances during the recent East Asian and Russian financial crises.

The currency market literature on contagion is less well-defined than that for equity prices. The literature is largely discursive (see for example Fane (2000), Goldstein (1998), Goldstein, Kaminsky and Reinhart (2000)) and there has been little agreement in the profession as to an appropriate definition of the term contagion. Research in this area has been growing rapidly in the past decade, prompted by each of the ERM crisis (1992), the Mexican peso crisis (1994) and the East Asian crisis (1997-8). The empirical literature is limited, with most work focussed on the exchange market pressure index approach of Eichengreen, Rose and Wyplosz (1996).

This paper takes a three variable latent factor model to examine movements in equity prices and foreign exchange returns. The model has been proposed separately by Forbes and Rigobon (1999) for the equity market, Mahieu and Schotman (1994) and Dungey (1999) for the currency market as well as by Edwards (2000) for interest rates, and Kose, Otrok and Whiteman (1999) to explain macroeconomic fundamentals. Here the arbitrage properties exploited in Dungey (1999) and Dungey and Martin (2000) for estimating the model in currency markets are applied to enable estimation of the equity market factors. The amalgamation of the two markets into one model is a natural extension of the separate work, and allows estimation of the previously unidentified models for equity returns.

A number of hypotheses raised in the existing literature are addressed with this model. Radelet and Sachs (1998) and Goldstein, Kaminsky and Reinhart (2000) speculated that Indonesia was the country most heavily affected by contagion, and our results support that. Further, our estimates confirm the findings of Bae, Karolyi and Stultz (2000) that contagion is more important among developing nations than developed. And, in line with our earlier results (Dungey and Martin (2000)) we support Krugman's (1998) claim that Malaysia, Indonesia and Thailand were affected differently to South Korea. Our model also provides some further evidence on the direction of contagion between financial markets put forward in Bae, Karolyi and Stultz (2000). We find that currency markets influence equity markets with little evidence of the reverse, apart from Indonesia. The linkages between Asia and the US are shown to be mainly in the form of spillovers, the unobserved but explainable component, rather than contagion.

The paper is organised as follows. Section 2 overviews the literature on contagion in equity and currency markets and the links between those markets to motivate the model developed in Section 3. Sections 4 and 5 outline the econometric method and the data. The results are presented in Section 6 and Section 7 concludes.

2 Contagion: An Overview

Financial market contagion is broadly discussed but poorly defined. Dornbusch et al (2000) provide an overview of the breadth of definitions existing in the academic literature. It seems likely that market players and observers may have even broader views. The definitions of contagion developed in the discursive and theoretical literature are largely divorced from the relatively small empirical literature on this topic. The most likely characterisation of contagion in the empirical literature sits well with the investigation of currency crisis events by Sachs, Tornell and Velasco (1996) where all unexplained turmoil (the residual) was denoted contagion. Similarly, Edwards (2000) considers contagion to be the information transfer between markets which exceeds ex ante expectations.

Contagion viewed as a residual process is consistent with the definition of Masson (1998,1999), one which has increasing importance due to its adoption by the IMF (see IMF 1999). Masson considers contagion in currency markets. He models movements in an exchange rate as a combination of country-specific events, common events which affect all markets (labelled 'monsoon effects'), and spillover effects, due to the known linkages between countries and economies. The remaining movement in exchange rates, unexplained by these three factors, is contagion.

Although a number of authors propose models of movements in asset prices which are consistent with the three factor model, empirical work generally proceeds without them. This is partly due to problems with identification (see for example Mahieu and Schotman (1994), Forbes and Rigobon (1999)) and partly due to estimation difficulties. Instead, contagion estimation has tended to take place in individual markets using a variety of techniques and observed data.

The literature on equity and currency markets has developed along different lines, although recently there have been moves to more consistent approaches across the markets. The following subsections examine the contagion literature and draw out the similarities across markets.

2.1 Equities

The equity markets have a relatively long history of examining high frequency comovements in returns (see for example, King, Sentana and Wadhwani (1995), Lin, Engle and Ito (1994)), a literature which gained popularity following the stock market crash of 1987.

Two dominant approaches exist in examining contagion in equity returns. The first approach is that of simple correlations (Baig and Goldfajn (1998) and Ellis and Lewis (2000)). This approach seems to have originated in the literature examining the promulgation of shocks in the equities markets, well before investigations began into contagion (cf Forbes and Rigobon (1999)). The correlations approach attempts to control for common sources of movements in returns before assessing changes in the information transfer process across periods. Any significant differences in correlations between periods is taken as evidence of contagion. In the existing literature the crisis periods are chosen ad hoc.

Forbes and Rigobon (1999) provide an overview of the literature and show how the presence of heteroskedasticity distorts the most common test. Their results indicate a dramatic decrease in the number of contagious events with this adjustment. However, the correlation coefficients are simply a reorganisation of a linear model of the information transfer between markets (a point taken up by Bae, Kayoli and Stultz (2000)) and as such there is an implicit assumption that the underlying moment conditions of the process are satisfied for simple regression.

The second approach to contagion in equity markets is the estimation of VAR models of returns across markets. In this approach various groups of financial market data are endogenously related through a simple VAR. This genre also has a relatively long history in the equity market literature, see, for example Eun and Shim (1989). In some studies ad hoc exogenous variables are chosen to associate particular events with the VAR results (Baig and Goldfajn(1998), Ellis and Lewis (2000)). The limitations of this approach are that it does not capture the known GARCH style properties of the observed data, as well as other problems standard to VAR analysis (see for example Hall (1995)).

One further branch of the literature is related to the Baig and Goldfajn and Ellis and Lewis approaches. Kaminsky and Schmulker (1999) adopt an event approach to the problem, a priori identifying 'good' and 'bad' news in several categories associated with excess returns. This 'news' style of study has a high profile in the exchange market literature.

2.2 Currencies

The literature on contagion in currency markets has exploded since the crises in Latin America and East Asia. There is some evidence of the correlations and the VAR approaches discussed above applied to exchange rate returns, (Ellis and Lewis (2000), Baig and Goldfajn (1998)) but in general a more diverse range of techniques has been employed.

The dominant approach to modelling contagion in currency markets is to examine the effect of the presence of crises in foreign markets on domestic markets. In the Eichengreen, Rose and Wyplosz (1995,1996) approach if foreign crises effect the probability of a domestic crisis this is taken as evidence of contagion. Lowell, Neu and Tong (1998) take evidence of contemporaneous crises in themselves as evidence of contagion (because the hypothesised probability of independent contemporaneous crises is very low). A particularly important aspect of this approach is the identification of crisis periods. Lowell, Neu and Tong do this through ad hoc examination of the data. Eichengreen et al construct an index of exchange market pressure (EMP) and apply a threshold criteria to that index to identify crisis periods.

Of particular issue with these approaches is the variety in the frequency of the effect under consideration. Eichengreen et al consider quarterly changes in exchange rates and fundamentals. This is a very different view of contagion to that investigated in the other markets which concentrate on high frequency data. More recently the Eichengreen et al methodology has been applied at higher frequencies, Cerra and Saxena (1999). Other approaches to the currency market problem have also focussed on the short run data, at least in part because the speed of the transmission is one of the major policy concerns. This aspect motivates the high frequency application in this paper.

In general, however, all of these studies have examined contagion in terms of testing for its existence. The relative size or contribution of contagion in the market is not quantified. Dungey and Martin (2000) develop a model for currency market returns based on the Masson definition to quantify the impact of contagion from the Thai currency crisis on three other East Asian economies. That model forms the basis for the extensions here to the other financial markets.

All streams of literature on contagion seem to agree on several important aspects. The first is that there are unobservable factors which affect the markets, and the second is to some extent the perceived structure of these unobservables. In each of the empirical literatures there is a recurrence of the theme found in Masson that movements in financial variables can or should be linked to changes in either country-specific events or common shocks (see for example Dooley (2000), Mahieu and Schotman (1994), for currency markets, Forbes and Rigobon (1999) for equity markets). This similarity provides the forum for the linkages between the markets. Once each return can be modelled in this manner spillovers can be incorporated by links between the markets and contagion becomes the unexplained residual component. Such a model is developed in section 3 and section 4 describes our process for estimating the system.

3 Contagion between markets

Latent factor models have been proposed for modelling returns in both equity and currency markets. The fundamental idea is that unobserved factors can be used to capture the 'news' or 'events' associated uniquely with the stock or currency of interest, and those factors which commonly affect all stocks or currencies, without a priori identification of the factors themselves.

3.1 Equity Market

In the equity market, a latent factor specification of equity movements involves a linear combination of country-specific factors and common factors. King and Wadhini (1990), Lin, Engle and Ito (1994) and references cited therein consider returns in stock market indices of country i at time t, $s_{i,t}$, to be represented as:

$$s_{i,t} = \phi_{si} C^s_{i,t} + \lambda_{si} M^s_t \qquad \text{for i=0,1,2....N.} \tag{1}$$

where $C^s_{i,t}$ is labelled the unique factor and represents the unique equity market country-specific factor, associated with returns in stock market index i at time t and M^s_t is the common market factor which affects all stock market returns at time t. The factor loadings ϕ_{si} and λ_{si} vary across stock markets, but not over time.[1]

3.2 Currency Market

A similar structure of latent factor model can be constructed for exchange rate returns, building on the work of Diebold and Nerlove (1989) and Mahieu and Schotman (1994). Returns in bilateral exchange rates are modelled as a linear combination of country-specific factors associated with the two cur-

[1] Edwards (2000) considers a similar model for short-term interest rates.

rencies/countries[2] and a common factor effecting all exchange rate returns. The addition of an arbitrage assumption means that it is not necessary to estimate the loadings for cross-rates as they can be extracted from a panel of exchange rates against a common numeraire currency (Dungey (1999)). Exchange rate returns are expressed as:

$$e_{i,t} = \phi_{ei} C^e_{i,t} + \phi_{e0,t} C^e_{0,t} + \lambda_{ei} M^e_t \quad \text{for i=1,2,...N,} \tag{2}$$

where $e_{i,t}$ is the return in the exchange rate of currency i against the numeraire currency, currency 0, at time t. The factor $C^e_{i,t}$ represents the unique exchange market country-specific factor associated with country i and $C^e_{0,t}$, is the country 0 factor (or numeraire factor). The factor $C^e_{i,t}$ is labelled the unique factor in the currency market model. The parameter ϕ_{ei}, i=0,1...N, reflects the effects of the unique and numeraire shocks on $e_{i,t}$. In a panel of N exchange rates, expressed against the common numeraire currency 0, there will be N parameters ϕ_{ei}. However, the parameter ϕ_{e0}, remains constant for each exchange rate. Hence, we label the factor $C^e_{0,t}$, the fixed common factor. The final factor, M^e_t, represents common shocks to each exchange rate (consistent with Masson's (1998,1999) monsoonal effects) with a loading λ_{ei} which varies with each exchange rate. M^e_t is labelled the common currency market factor. Volatility in exchange rate returns can be examined from the variance-covariance matrix of a panel of exchange rate returns modelled as in equation (2). The necessary condition for identification is easily seen to be $N \geq 4$, see Dungey (1999).

3.3 A common model

Consider combining the models of these markets, so that for country i ($i \neq 0$) there will be two equations representing financial markets of the form of

[2] Strictly the interpretation of these factors should be as associated with individual currencies, but given that currencies are generally uniquely associated with a particular country we make the assumption that the two attributions are synonymous.

equations (1) and (2). This combination currently recognises that there is no necessity for the country-specific factors or common variable factors in each market to be the same. However, it is possible that there are common factors affecting both markets, and the model can be augmented to allow for this. We allow two possibilities. The first is that there are country-specific factors which affect all markets in a particular country, although with differing loadings and the second is that there may be factors which affect all markets across countries, again with differing parameters. These additions to the model are given in equations (3) to (4).

$$
\begin{aligned}
s_{i,t} &= \phi_{si} C^s_{i,t} + \lambda_{si} M^s_t + \omega_{si} Z_{i,t} + \delta_{si} W_t \qquad \text{for i=0,1,2....N} \qquad (3) \\
e_{i,t} &= \phi_{ei} C^e_{i,t} + \phi_{e0} C^e_{0,t} + \lambda_{ei} M^e_t + \omega_{ei} Z_{i,t} + \omega_{e0} Z_{0,t} \\
&\quad + \delta_{ei} W_t \qquad \text{for i=1,2,...N,} \qquad (4)
\end{aligned}
$$

where the addition of the common country-specific factor is represented by the term $Z_{i,t}$ with loadings ω_{si} in the equity returns and ω_{ei} in the currency market returns, and the common variable or 'world' factor to all markets by the term W_t, with loadings δ_{si} and δ_{ei} in the equity and currency markets respectively. Note that there will be N equations representing exchange market returns and $(N+1)$ representing equity returns accounting for the numeraire country. In addition, the exchange rate equation (4) also includes the term $Z_{0,t}$ to capture effects common to financial markets in the numeraire country.

It is by now well-established that financial markets data generally exhibits some form of hetroscedasticity. In order to capture the potential GARCH structure of the returns data we allow the unobserved factors a GARCH structure. Consider the set of all unobserved factors $f = \{C^s_i, M^s, C^e_i, M^e, Z_i, W$ for $i = 0, 1, 2..N\}$, the t subscript has been dropped for brevity. Allowing for some possible autoregression the GARCH structure of the factors can be expressed as:

$$\begin{aligned} f_{k,t} &= \rho_k f_{k,t-1} + u_{k,t}, \qquad k\text{=all elements of } f & (5)\\ u_{k,t} &= h_{k,t}^{0.5} v_{k,t} & (6)\\ h_{k,t} &= 1 - \alpha_k - \beta_k + \alpha_k u_{k,t-1}^2 + \beta_k h_{k,t-1} & (7)\\ v_{k,t} &\sim N(0,1). & (8) \end{aligned}$$

The intercept terms in equation (7) are specified as $1 - \alpha_k - \beta_k$ in order to normalise the unconditional variance of each factor to $1/(1 - \rho_k^2)$. Existing results have tended to find that the GARCH features of financial market data can be sufficiently captured by placing this structure on the common factors (Dungey, Martin and Pagan (2000)). In the model specified here we allow GARCH to apply to the market factors, M_t^s and M_t^e, the common world factor W_t and the common fixed factor in the currency markets, $C_{0,t}^e$.The remaining factors are specified as N(0,1).

Dungey and Martin (2000) demonstrate that the Masson definition of spillovers and contagion can be incorporated into a model such as given by equation (4) for currency markets. The complete system incorporating spillovers, contagion, AR and GARCH characteristics is shown in equations (9) to (18). Dungey and Martin (2000) represented spillovers as the lagged effects of other country-specific effects. This could be incorporated into the model by considering spillover effects from the common country effects into other countries, the $Z_{i,t}$.[3] However, here we are interested in both spillovers and contagion between markets. Hence, the appropriate spillover effect is the lagged impact of other markets on the market in question. This enters the model shown in equations (9) to (10) with parameters d_{jkl}, where the subscripts k and j refer to the impact of spillovers from market k onto market j, and the subscript l denotes the number of lags for that spillover effect. In

[3]It is also possible to identify country/market specific spillover effects from the $C_{i,t}^e$ and $C_{i,t}^s$, however that results in a significant increase in the parameterisation of the problem and is hence not done here.

this application we include spillover effects with one lag.

Consistent with the Masson (1998, 1999) definition, contagion enters the system as the unexplained component of the model. In this instance, contagion from one market to another will be represented by the impact of the error terms from the market factor equations (given by equations (11) and (12)) in each of the market equations (9) and (10). The loadings on contagion are given by the parameters γ_{jkl}, where again the subscripts k and j, refer to contagion effects from market k onto market j, and l denotes the number of lags in the contagion effect. Contagion enters contemporaneously in this application, so that $l = 0$.

$$\begin{aligned} s_{i,t} &= \phi_{si} C^s_{i,t} + \lambda_{si} M^s_t + \omega_{si} Z_{i,t} + \delta_{si} W_t + d_{se1} M^e_{t-1} \\ &\quad + \gamma_{se0} u_{e,t} \qquad \text{for i=0,1,2....N} \qquad (9) \\ e_{i,t} &= \phi_{ei} C^e_{i,t} + \phi_{e0} C^e_{0,t} + \lambda_{ei} M^e_t + \omega_{ei} Z_{i,t} + \omega_{e0} Z_{0,t} + \delta_{ei} W_t \\ &\quad + d_{es1} M^s_{t-1} + \gamma_{es0} u_{s,t} \quad \text{for i=1,2,...N} \qquad (10) \end{aligned}$$

$$\begin{aligned} M^s_t &= \rho_s M^s_{t-1} + u_{s,t} && (11) \\ M^e_t &= \rho_e M^e_{t-1} + u_{e,t} && (12) \\ C^e_{0,t} &= \rho_0 C^e_{0,t-1} + u_{0,t} && (13) \\ W_t &= \rho_w W_{t-1} + u_{w,t} && (14) \\ u_{k,t} &= h^{0.5}_{k,t} v_{k,t} \qquad \text{for } k = s, e, 0, w && (15) \\ h_{k,t} &= 1 - \alpha_k - \beta_k + \alpha_k u^2_{k,t-1} + \beta_k h_{k,t-1} \quad \text{for } k = s, e, 0, w && (16) \\ v_{k,t} &\sim N(0,1) && (17) \\ \{C^s_{i,t}, C^e_{i,t}, Z_{i,t}, Z_{0,t}\} &\sim N(0,1). && (18) \end{aligned}$$

The model without AR or GARCH characteristics can be estimated with GMM using the second moment conditions, of which there are $(3N+2)(3N+3)/2$ to identify $12N + 10$ parameters if there are no spillovers or contagion and $12N(1+L)+10+8L$ parameters with spillovers and contagion, where L

is the total number of lags incorporated for spillovers and contagion. In this case the full model with spillovers and contagion (but no AR or GARCH) requires $N \geq 5$ for identification for the case of only one timing entry point for contagion and spillover effects; that is markets in 6 countries are required to identify the system, where one currency acts as the numeraire.

The independence of the factors results in the second moment conditions for the variances of $s_{i,t}$ and $e_{i,t}$ shown in equations (19) and (20) (where time subscripts have been dropped for ease of exposition). These conditions provide a convenient means of decomposing the contribution that contagion and spillovers make to volatility in each of the financial market series.

$$
\begin{aligned}
var(s_i) &= \phi_{si}^2 + \frac{\lambda_{si}^2}{1-\rho_s^2} + \omega_{si}^2 + \frac{\delta_{si}^2}{1-\rho_w^2} + \frac{d_{se1}^2}{1-\rho_e^2} + \gamma_{se0}^2 \qquad (19) \\
var(e_i) &= \phi_{ei}^2 + \frac{\phi_{e0}^2}{1-\rho_0^2} + \frac{\lambda_{ei}^2}{1-\rho_e^2} + \omega_{ei}^2 + \omega_{e0}^2 + \frac{\delta_{ei}^2}{1-\rho_w^2} \\
&\quad + \frac{d_{es1}^2}{1-\rho_s^2} + \gamma_{es0}^2. \qquad (20)
\end{aligned}
$$

The model of contagion in equations (9) to (18) is specified in terms of latent factors, and hence data on the factors are not available for estimation. Instead, we proceed with indirect estimation techniques for estimating latent factor models. This method effectively overcomes Weber's (1999) concerns about the difficulties in implementing the Masson definition of contagion. The next section describes the indirect estimation methodology.

4 Estimation Methodology

The model specified in Section 3 can be estimated for the case of no AR or GARCH in the factors ($\alpha_k = \beta_k = \rho_k = 0$, for all k) using GMM or the Kalman filter with the necessary identification condition of $N \geq 5$ in the model defined in equations (9) and (10). However, factor dependence eliminates the GMM approach and the introduction of GARCH structures on any of the unobserved factors violates the normality assumption of the Kalman filter errors and produces inconsistent estimates (Gourieoux and Monfort (1995)). One means of overcoming this restriction is to use indirect estimation techniques as developed by Gourieoux, Monfort and Renault (1993), Gallant and Tauchen (1996) and Duffie and Singleton (1993).[4] This technique produces consistent estimates, while their efficiency is a function of the auxiliary model used in estimation, as discussed below. In practice we use GMM estimates of the model without dependency or GARCH error structures as starting values in the indirect estimation.

The indirect estimator is a useful tool where the desired model is difficult to estimate with conventional methods, but relatively simple to simulate. The latent factor model specified here is a good example of this problem. Indirect estimation is implemented by repeatedly simulating the latent factor model and matching the characteristics of the simulated results with the characteristics of the observed data using an auxiliary model. The choice of auxiliary model is important in that it needs to mimic the desired properties of the data closely, but remain tractable. In practice we have found that more closely identified problems produce more stable results.

The indirect estimator is implemented by first simulating the model for returns in currency, and equity markets using a set of random numbers. Simulated factors are then used to construct simulated currency and equity returns.

The auxiliary model for this problem consists of variances and covariances of the demeaned returns series and the product of the squared return i at time t, with the squared return j at time $t-1$. Define

$$y_t = \{s_{i,t}, e_{it}\} \quad \forall i \tag{21}$$

where $s_{i,t}$ and $e_{i,t}$ are the demeaned equity and currency returns respectively.

[4] Lin, Engle and Ito (1994) use an alternative approach based on a full likelihood estimator. This is tractable in the problem they discuss, but not in the larger dimension problem addressed here.

The auxiliary model g_t is defined as:

$$g_t = \{g_{1t}, g_{2t}\}, \quad \forall i, j, \tag{22}$$

where

$$\begin{aligned} g_{1t} &= \{y_{i,t} y_{j,t}; i \geq j\} & (23) \\ g_{2t} &= \{(y_{i,t}^2 - \overline{y_{i,t}^2})(y_{j,t-1}^2 - \overline{y_{j,t}^2})\}. & (24) \end{aligned}$$

This auxiliary model is a subset of that specified in Dungey and Martin (2000), but contains more moment conditions as more asset market returns are involved. There are a total of 6 countries in the sample for 2 markets, a total of 5 exchange rates and 6 equities. Hence there are 66 moment conditions in g_{1t} and 121 in g_{2t}.

Letting $y_{q,i,t}$ be the q^{th} set of simulations from the model we can also calculate moment conditions for the simulated data of the same form. This is denoted as v_t as follows:

$$v_t = \{v_{1t}, v_{2t}\} \quad \forall i, j, \tag{25}$$

where

$$\begin{aligned} v_{1t} &= \{y_{q,i,t} y_{q,j,t}; i \geq j\} & (26) \\ v_{2t} &= \{(y_{q,i,t}^2 - \overline{y_{q,i,t}^2})(y_{q,j,t-1}^2 - \overline{y_{q,j,t}^2})\}. & (27) \end{aligned}$$

Letting Ψ represent the estimates of the unknown parameters, the indirect estimator is the solution to:

$$\Psi = \arg\min_{\Psi} \left[\overline{g} - \overline{v}\right]' \Omega^{-1} \left[\overline{g} - \overline{v}\right], \tag{28}$$

where $\overline{g}$ and $\overline{v}$ are the vectors of sample means obtained from (22) and (25) respectively. Ω^{-1} is a weighting matrix computed as:

$$\Omega = \frac{1}{T} g_t' g_t + \frac{1}{T} \sum\nolimits_{l=1}^{L} \omega_l (g_t' g_{t-l} + g_{t-l}' g_t), \tag{29}$$

with

$$\omega_l = 1 - \frac{l}{L+1}, \tag{30}$$

representing the Newey-West weights (see Gourieroux, Monfort and Renault (1993)).

The objective function, (28), is minimised using the OPTMUM procedure in GAUSS with numerical gradients. The GAUSS procedure RNDN was used to obtain the random numbers to simulate the model.

5 Data

The data used in this study is a set of four economies involved in the East Asian currency crisis of 1997-98, plus Australia and the US as the numeraire. The four East Asian markets are Thailand, Indonesia, Malaysia and South Korea. The choice of countries is determined partly by a desire to address an interesting interlude in world financial markets. The selection of the four East Asian economies stems from Krugman's (1998) hypothesis that Malaysia, Indonesia and Thailand were somehow alike but that contagion to South Korea was more difficult to understand. The US is the obvious choice of numeraire or reference market for this problem. It also seems desirable to include the Australian markets as one of the more developed markets in the area. To support this inclusion we note that although the Singapore currency market turns over a greater volume of trade in total than Australia (BIS 1999), turnover in the Australian dollar itself is greater than the other potential East Asian inclusions (we do not include Japan in this list - an examination of contagion in the Japanese currency market is currently in progress). Further, the equities market in particular in Australia has greater depth than most of the East Asian markets, and there are clear trade linkages between Australia and the other countries in the region.

The sample period examined is designed to cover the crisis period in these markets. There is no clear guide to the start of the crisis period (see

Kaminsky and Schmulker (1999)), but we define the crisis period as running from 2 July, 1997 to 31 August, 1998. This period takes in the float of the Thai baht, on 2 July 1997 which is sometimes used to date the start of the crisis (for example Lowell et al (1998)), the float of the Indonesian rupiah on 14 August 1997 and the float of the South Korean won on 22 December 1997. It also encompasses the contagious period in stock markets identified by Forbes and Rigobon (1999) as the month beginning 17 October 1997, but ceases prior to the fixing of the Malaysian ringgitt in September 1998. The data on demeaned returns for equity markets and exchange rates are presented in Figures 1 to 6 for the sample period.

Financial markets data have long been known to contain GARCH properties. In the most general version of the model specified in equations (9) to (18) GARCH could be specified for each latent factor. However, a number of studies have now determined that the GARCH properties observed in the data can be appropriately captured by imposing GARCH structures on a common latent factor (see Dungey, Martin and Pagan (2000), Kose, Otrok and Whiteman (1999)). Hence, our proposal is to impose GARCH characteristics on the common factors in the model. The common factors include the common market factors M_t^s, M_t^e, the fixed currency factor, $C_{0,t}^e$ and the world factor, W_t. We also impose the restriction that $\rho_w = 0$, that is there is no autoregressive component to the world factor.[5] In support of this structure Tables 1 and 2 present the univariate $GARCH(1,1)$ characteristics of equity and exchange rate returns for the sample. The characteristics are

[5] We expect that the autoregressive structures of the equity and currency market returns will be quite different and are better picked up with the common market factors.

estimated from a model of the form of equation (31) for each of the markets.

$$\begin{aligned} y_{i,t} &= \rho_0 + \rho_1 y_{i,t-1} + u_{i,t} \\ u_{i,t} &= h_{i,t}^{0.5} v_{i,t} \\ h_{i,t} &= \alpha_0 + \alpha_1 u_{i,t}^2 + \beta_1 h_{i,t-1} \\ v_{i,t} &\sim N(0,1), \end{aligned} \tag{31}$$

where $y_{i,t}$ refers to returns in equity or exchange rate markets for country i at time t.

An important issue in the application of the model to cross market contagion is that of timing. To justify the use of the no-arbitrage condition for the currency market component (Dungey (1999)) the exchange rates must be observed at the same point in time. Engle, Ito and Lin (1990) have shown timing effects in the currency markets. However, equity markets are typically domestically located - 24 hour trading in equities is possible, but for developing economies this market is likely to be extremely thin. The evidence for equity markets is mixed. Hamao, Masulis and Ng (1990) find that information flows into Asia from other markets but little in reverse and Lin, Engle and Ito (1994) find results in both directions.

The data for this study is exchange rates at some point in time and domestic equity market domestic closing values. There are obvious timing difficulties. However, following the zonal approach of Eun and Shim (1989) and Bae, Karolyi and Stultz (2000) we use data dated on the same calendar day. The timing implications are that the Asian markets data is determined before the US data. Hence, Asian markets cannot react to US events on that day, but instead react to the previous day's information. The US market, however, can react contemporaneously to Asian market events as they occur earlier in the same trading day. The choice of timing for the exchange rate observations is either to take an observation in the Asian time zone or to take an observation at the end of the trading day (that is in US time). In this paper we choose the latter; in this way all events for the calendar day should be incorporated into the exchange rate observations.

The timing issues do not in fact materially effect our estimation of the system in equations (9) to (18) but do create some difficulties in interpreting the common factors. The market factor for currency markets is estimated from data which contains the same information set. However, the market factor for equities may not. There may be some instances where a common effect will be spread over two calendar days, because it occurs after the Asian market closes but before the US market closure. A similar problem occurs with the definition of the country-specific factors, the $Z_{i,t}$ in equations (9) and (10). This factor relates to events which relate to a particular country but effect all financial markets in that country. Because the exchange rates are observed outside the Asian time zone there is potential here again that the country-specific information incorporated in the exchange rate returns is different to that in the equity market. This should be a relatively minor problem, if we think that the majority of country-specific news is likely to be related to the particular country itself. Some information on the extent of this problem is evident from the estimation process - dramatic changes in the own market/country components will reflect problems of this nature. We found little evidence of this.

6 Results

The estimation of equations (9) to (18) was carried out with a simulation path of Q=20, with T=303 observations and 11 data series, giving a sample size for the simulated data of QT=6060 observations.[6] The parameter estimates in themselves are not particularly interesting, so instead we present the variance decompositions in Tables 3 and 4. The results are clear cut. With the

[6] This simulation was built up from smaller runs, Q=2 and Q=10 which took respectively 10.7 and 24.6 hours to converge on a dual processor Pentium 800 with 512 meg of RAM. The Q=20 simulation converged in 56.9 hours.

Table 1:

Maximum likelihood parameter estimates of univariate GARCH(1,1) models in equation (31) for equity market returns in alternative countries over the period, 2-July-1997 to 31-August-1998: QMLE t-statistics in brackets.

Parameter	Country					
	S. Korea	Indonesia	Thailand	Malaysia	Australia	US
ρ_0	-0.191	-0.210	-0.407	-0.355	-0.030	0.112
	(-1.480)	(-1.316)	(-2.940)	(-2.218)	(-0.629)	(1.734)
ρ_1	0.143	0.207	0.176	0.151	0.106	0.041
	(2.206)	(3.645)	(2.508)	(2.255)	(1.607)	(0.492)
α_0	0.033	0.131	0.860	0.165	0.364	0.149
	(0.932)	(2.294)	(2.604)	(1.971)	(2.455)	(1.540)
α_1	0.109	0.081	0.176	0.090	0.348	0.223
	(3.216)	(5.106)	(2.961)	(3.580)	(4.176)	(5.504)
β_1	0.900	0.912	0.677	0.910	0.273	0.706
	(33.600)	(68.807)	(7.965)	(67.092)	(1.285)	(7.974)
$\ln L$	-741.744	-719.295	-691.690	-748.607	-403.989	-462.742

Table 2:

Maximum likelihood parameter estimates of univariate GARCH(1,1) models in equation (31) for exchange rate returns in alternative countries over the crisis period, 2-July-1997 to 31-August-1998: QMLE t-statistics in brackets.

Parameter	Country				
	S. Korea	Indonesia	Thailand	Malaysia	Australia
ρ_0	0.027	0.196	0.210	0.186	0.098
	(1.031)	(0.865)	(2.214)	(2.371)	(2.282)
ρ_1	0.401	0.151	0.092	0.107	-0.020
	(4.660)	(1.970)	(1.193)	(1.701)	(-0.316)
α_0	0.004	0.841	1.477	0.042	0.020
	(5.305)	(5.155)	(5.781)	(2.237)	(1.640)
α_1	0.323	0.236	0.394	0.042	0.064
	(6.383)	(7.361)	(4.080)	(4.584)	(2.422)
β_1	0.761	0.780	0.131	0.908	0.908
	(27.878)	(29.434)	(1.233)	(60.064)	(22.755)
$\ln L$	-431.090	-872.920	-578.980	-550.851	-335.170

exception of Indonesia, there is little evidence of contagion or spillovers from equity markets to currency markets, but substantial contagion from currency markets to equity markets. The observed direction is consistent with general interpretation of the East Asian financial crisis as originating in the currency markets, and spreading from there.

In the equity markets over 90 percent of volatility in all countries except Thailand, is attributable to either contagion or spillovers from the currency markets. The exception of Thailand may be important here. The other dominant factor for Thailand is the common equity market effect, and this may support the argument made by McKibbin and Martin (1998) that equity markets in Thailand were in crisis far earlier than the currency crisis period represents.

The breakdown between the contribution of spillovers and contagion in equity markets is interesting. Recall that spillovers refer to the impact of explained common currency market effects on the equity market returns. This is akin to feedback effects between the markets. The markets where this is dominant are the developed markets of Australia and the US, and Thailand and Malaysia. The developed market results are not unexpected as they generally have better information processing capacity, and the Thai result may be reflecting its role as a crisis originator. The Malaysian result is more difficult to understand.

South Korean and Indonesian equity markets were the most heavily affected by contagion from currency markets. The South Korean result is consistent with the argument of Krugman (1998) that one can understand the transmission of the crisis between the export competing economies of Malaysia, Thailand and Indonesia but not to South Korea. This is exactly what is being demonstrated here, contagion is the impact of the unexplainable component.

Contagion and spillovers from equity markets to currency markets are quite limited. The exception is the relatively large contagion (50 percent of total volatility) to Indonesia. Several authors (Radelet and Sachs (1998), Goldstein et al (2000)) have argued that Indonesia has been the economy most severely impacted by contagion effects, and our results support that hypothesis in both currency and equity markets.

The majority of exchange rate volatility in this sample is explained by the common currency market effect and strong common factor effects were also observed in Dungey and Martin (2000). Somewhat surprisingly the exception to this was the Australian dollar/US dollar rate. This was the only bilateral rate in the sample not containing an Asian currency. It seems likely that in this case the common currency market effect is proxying for an Asian crisis latent factor. The volatility for the Australian dollar seems to have been transmitted through the US dollar, rather than by a direct linkage of the Australian currency with the Asian currencies.

There are a number of similarities between these results and those in Bae, Karolyi and Stultz (2000). First, they find that contagion in the East Asian crisis runs from currency to equity markets. Second, they find that developed nations are less exposed to contagion than developing economies, although our evidence is more mixed in this regard. In currency markets this result is true in that the total contribution from spillovers and contagion is lower for the US and Australia than the Asian markets. However, in the equity markets, over 90 percent of volatility in markets other than Thailand can be attributed to either contagion or spillovers. Bae, Karolyi and Stultz also find that the US is almost entirely insulated from Asian contagion - a result we do not support in the equity markets. However, we do find that market spillover effects can account for most of the linkages from Asia to the US. That is the relationship is explainable rather than random. These findings can be augmented by our findings here. The evidence suggests that contagion is more important for developing nations than developed. But, this does not mean that the developed nations are insulated, rather that they absorb information from the unobservable, but explainable, relationships between

Table 3:
Equity Market Volatility Decompositions: $(s_{i,t})$

Components & parameter		S.Kor.	Indon.	Thai.	Malay.	Aust.	US
Unique	ϕ_{si}	2.177	0.570	10.175	1.028	0.479	1.164
Equity Mkt.	λ_{si}	1.544	0.739	35.855	0.049	1.035	0.177
Country	ω_{si}	0.121	0.796	1.011	0.000	0.019	0.439
World	δ_{si}	0.355	0.762	8.413	1.539	0.128	0.022
Spillovers	d_{se1}	7.325	30.297	37.464	87.022	85.545	55.631
Contagion	γ_{se0}	88.478	66.834	7.082	10.362	12.795	42.566
Total		100.000	100.000	100.000	100.000	100.000	100.000

currency markets, rather than through unobserved information. This may be akin to saying that the 'irrational' and herd type behaviour often associated with financial crises does not extend to the developed markets, but rather they are subject to a 'flight to quality'.

7 Conclusions

Empirical work on contagion is relatively limited, and the techniques and definitions applied in different financial markets tend to vary widely. We have proposed and estimated an integrated model of contagion for equity and currency markets. The definition of contagion used here is adapted from Masson (1998,1999). Contagion is the effects of residual movements in one market on another after accounting for unique country and market-specific

Table 4:

Currency Market Volatility Decompositions: $(e_{i,t})$

Components & parameter		Country				
		S.Kor.	Indon.	Thai.	Malay.	Aust.
Unique	ϕ_{ei}	0.041	6.396	0.160	1.012	4.678
Numeraire	ϕ_{0i}	0.965	2.762	7.276	9.377	83.213
Currency Mkt	λ_{ei}	98.183	33.327	83.777	80.698	7.800
Country	ω_{ei}	0.715	0.099	1.048	0.288	0.279
Numeraire Ctry	ω_{0i}	0.003	0.007	0.019	0.024	0.217
World	δ_{ei}	0.014	2.325	1.174	2.075	1.575
Spillovers	d_{es1}	0.017	4.932	2.511	1.899	0.481
Contagion	γ_{es0}	0.062	50.153	4.033	4.626	1.757
Total		100.000	100.000	100.000	100.000	100.000

and common ('monsoonal') shocks and the impact of spillovers between markets. A latent factor model of currency and equity movements is developed which reflects this definition, and is used to assess the extent of spillovers and contagion between currency and equity markets in the East Asian crisis of 1997-98. The results provide a decomposition of the total volatility in both equity and currency returns into components associated with unique country and market specific shocks, common market shocks, country-specific shocks, world shocks and spillover and contagion effects. We also account for the known GARCH properties of financial market returns.

The results indicate that, with the exception of Indonesia, contagion from equity markets to currency markets was relatively small, although contagion from currency markets to equities was substantial for some countries (between 43 and 88 percent for the US, Indonesia and South Korea). In other countries, the effect of spillovers from currency markets to equity markets were more important: spillovers accounted for over 85 percent of volatility for Malaysian and Australian equities, and around 56 percent for the US. In the currency market the majority of volatility in each exchange rate was explained by the common currency market factor.

There is an important exception to these general results in both equity and currency returns. In the case of Indonesia, the contribution of contagion is relatively high, 67 percent for equities and 50 percent for currencies. These results are consistent with the claims of Goldstein et al (2000) and Radelet and Sachs (1998) that Indonesia was the country most clearly affected by contagion.

Bae, Karolyi and Stultz (2000) have found that there is some directionality in the linkages between the geographic markets. They find that although the US events affect the Asian markets there is little evidence of the reverse. Our results expand this finding to show that there are relatively limited contagion effects from developing to developed markets, but that the spillover effects can be substantial. That is, although the linkages are unobserved, they are explainable, and hence do not represent contagion.

The next step in this line of research is to incorporate the role of money markets in this integrated approach. An extension of the model proposed in equations (9) to (17) is feasible, although it involves a substantial increase in the number of parameters to be estimated, and further thought as to an appropriate auxiliary model.

Figure 1: South Korean Returns

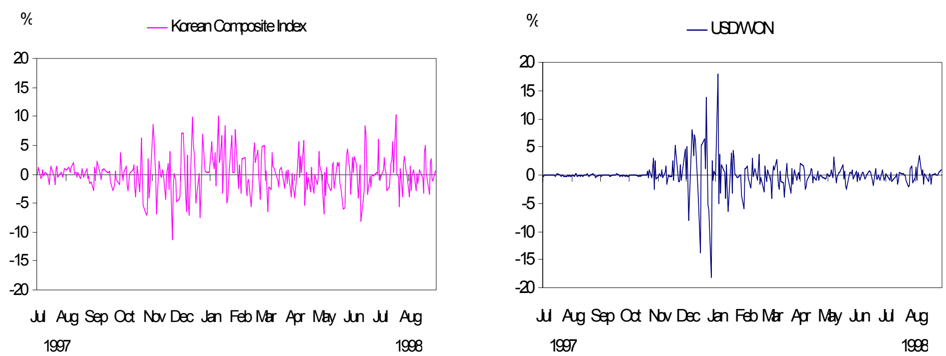


Figure 2: Indonesian Returns

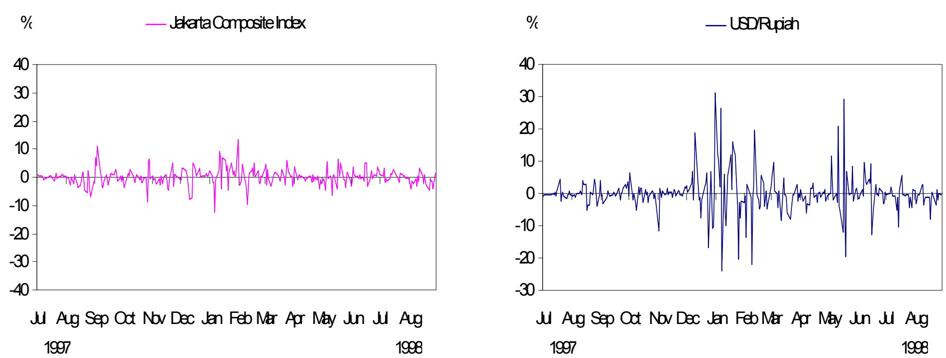


Figure 3: Thai Returns

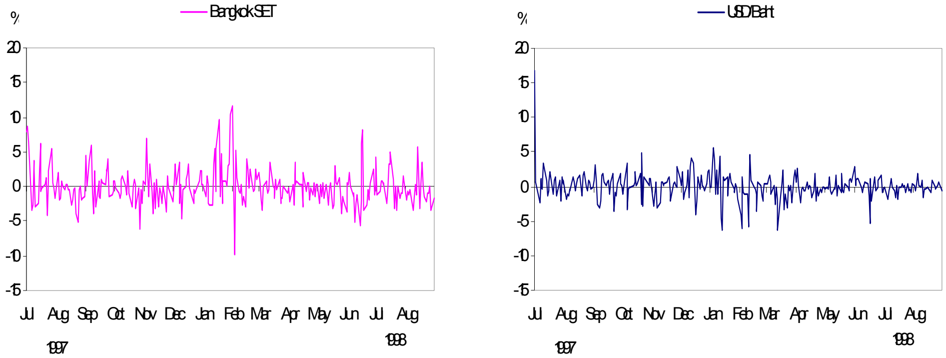


Figure 4: Malaysian Returns

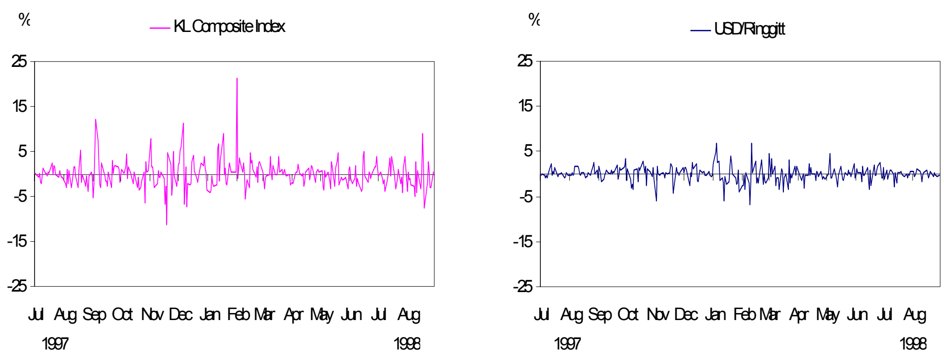


Figure 5: Australian Returns

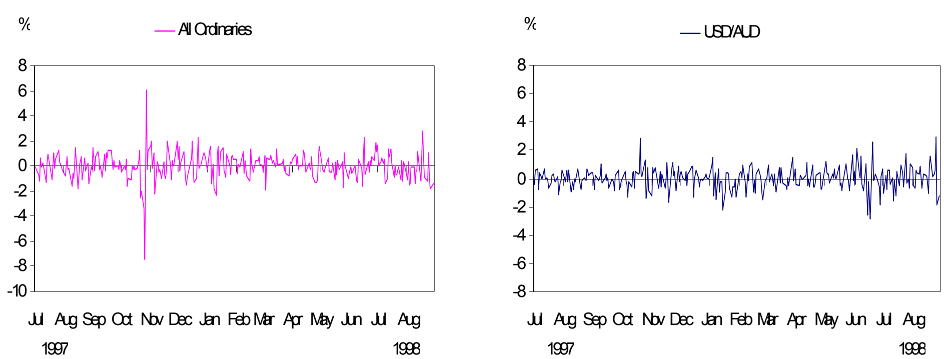
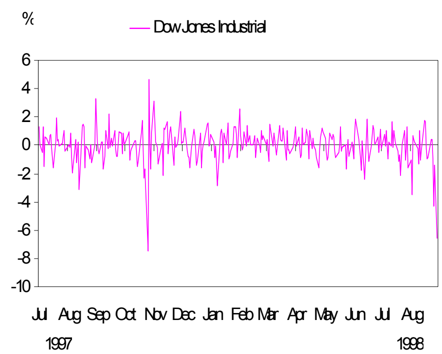


Figure 6: US Returns



A Data Sources

Data are daily sourced from Thomson Financial Datastream with the following codes (correct as at September 2000).

	Exchange Rate against USD	Equity Index
US	-	DJINDUS
South Korea	KOUSDSP	KORCOMP
Indonesia	USINDON	JAKCOMP
Thailand	USTHAIB	BNGKSET
Malaysia	MYUSDSP	KLPCOMP
Australia	AUSTRUS	ALLORDS

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