

# Contagion, interdependence and U.S. monetary policy

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## **Abstract**

This paper examines the contribution of common external shocks and economic interdependence to stock market comovements among Central and Eastern European economies during the Russian crisis. It also investigates the extent to which country-specific shocks spread across these countries beyond the normal channels of interdependence during episodes of financial market turbulence. Different measures of U.S. monetary policy ranging from market-determined interest rates to policy interest rates and measures of monetary policy surprises show that the measurement of common external shocks is not innocuous. The results indicate that common external shocks affect Central and Eastern European economies to a significant extent. Moreover, the transmission mechanism of country-specific shocks changes in the face of abnormal high-volatility events. The latter result contradicts some existing empirical evidence.

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# 1 Introduction and motivation

The last decade has been one of occasional high turbulence in international financial markets. A number of currency and financial crises have largely dampened an unprecedented increase in international capital flows towards emerging market countries. Large capital outflows have constrained these countries to adjust policies in order to respond to the sudden stop of external financing. Furthermore, it is widely argued that these crises carry contagious effects in that they spread to other countries, either in the neighbourhood or around the globe.

Economic comovements across countries arise from the existence of common external shocks, as well as from economic interdependence. Contagion is defined as a change in the way that country-specific shocks are propagated across countries during financial crises. Consequently, any model of international comovements must take account of common external shocks, economic channels of interdependence, and potential changes in the latter channels in the face of financial turbulence. Focusing exclusively on the channels interdependence could lead to the conclusion that country-specific shocks are transmitted across countries when in fact the presence of common external shocks leads a group of countries to suffer from financial turbulence simultaneously.

There is accumulating evidence that economic policies in major industrialised countries affect economic conditions in emerging market economies. In a seminal paper on the determinants of capital flows to Latin America between the end of the "lost decade" and the early nineties, Calvo, Leiderman and Reinhart (1993) find that the large increase in capital inflows is partly due to external factors, such as lower international interest rates and the recession in the United States. They also argue that "some of the renewal of capital flows to Latin America results from external factors and can be considered an *external shock* common to the region"<sup>1</sup>. In the current context of rising international interest rates this question comes back to the forefront of the policy agenda. To the extent that many emerging market economies try to stabilise their exchange rates with respect to the U.S. dollar, U.S. monetary policy is crucial to the sustainability of the exchange rate regime in these countries.

The vast majority of studies makes use of some short-term U.S. market interest rate to capture the stance of U.S. monetary policy. However, there are many different short-term interest rates and these do not always move in a synchronous manner. What interest rate should be used to control for common external shocks? A three-month Treasury bill interest rate? A money market rate? A discount rate? Moreover, is it the stance of monetary policy or monetary policy surprises that affect emerging market economies?

This paper assesses this question and makes use of different measures of U.S. monetary policy, ranging from short-term interest rates to measures of policy surprises. The empirical specification extends the model of interdependence of Favero and Giavazzi (2002) by including common external shocks explicitly. This specification captures interdependence between stock market returns of three Central and Eastern European countries and Russia

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<sup>1</sup>Calvo, Leiderman and Reinhart (1993), p. 109

from July 1998 to December 1999. This sample is interesting in so far as financial market turbulence was highly significant, thereby allowing for the identification of contagion, and in so far as important changes in the stance of U.S. monetary policy, partly anticipated and partly unanticipated, took place at that time. In other words, the sample should allow for the empirical modelling of contagion, interdependence and common external shocks.

The results show that common external shocks were affecting stock market returns in Russia and Central European economies to a significant extent. The U.S. stock market and emerging market turbulence affected the region. Interestingly, we find that although U.S. market interest rates are not significant, the federal funds rate, which is a direct measure of U.S. monetary policy, has explanatory power for the Russian stock market return. This result indicates that the measurement of common external shocks is not innocuous. Finally, we uncover widespread evidence of contagion, in the sense that the transmission mechanism of country-specific shocks changes in the face of financial market turbulence.

The paper is organised as follows. Section 2 provides a selective review of the literature on the importance of common external shocks. Section 3 discusses the various measures of the stance of U.S. monetary policy. Section 4 introduces briefly the structural model of interdependence that has been proposed by Favero and Giavazzi (2002), while section 5 provides a short description of the data. Section 6 presents the empirical results and provides for some further interpretation. Section 7 concludes.

## **2 Common external shocks: what is the evidence?**

This section summarizes the evidence on the impact of common external shocks. Frankel and Roubini (2001) discuss the role of the policies of industrialised countries and their effects on emerging market economies. There are three main areas where these policies matter. Firstly, macroeconomic policies have an impact on emerging markets through interdependence. Secondly, developed countries respond to emerging market crises through various mechanisms, most notably rescue packages. Thirdly, the contributions to the debate on the reform of the international financial architecture have effects on the current and future economic conditions of emerging markets. This paper focuses exclusively on the impact of industrialised countries' macroeconomic policies on emerging market economies.

Which macroeconomic variables have a significant short-term impact on emerging markets? In general, changes in aggregate income in the developed world affect emerging markets through changes in traded quantities, namely exports and imports, and changes in prices on world markets. It is often argued that the quick recovery of Mexico after the 1994/95 Tequila crisis was partly due to strong economic growth in the United States. In contrast, when the Asian crisis in 1997/98 hit many south-East Asian countries, there was no growth in the leading regional economy as Japan was having a dismal economic performance.

Interest rates in industrialised countries are important for several reasons. Firstly, low rates of return in these countries would trigger capital flows to emerging markets

where rates of return are higher. In fact, Calvo, Leiderman and Reinhart (1993) have shown that capital inflows into Latin America can be partly explained by the low level of international interest rates, among other external variables. The expanding literature on early warning indicators also indicates a significant role of foreign interest rates. To this extent, abrupt reversals in the interest rates of industrial countries could cause sudden shifts in international capital flows, thereby increasing the probability of speculative attacks. Secondly, higher interest rates raise the cost of debt service for debtor countries. Thirdly, emerging markets that maintain currency pegs must set interest rates in accordance with that of the country to which they fix, given that capital mobility is sufficiently high for monetary policy to be largely ineffective domestically.

Exchange rates between the currencies of the main economies of the world also matter. The large appreciation of the U.S. dollar against the yen in 1995 and 1996 is often seen as one of the sources of the Asian crisis. The south-East Asian countries, pegging to the U.S. dollar, experienced a large loss of competitiveness, leading to wide current account deficits and significant losses of reserves. This argument has been debated and its explanatory power is not clear. However, it remains that exchange rate volatility among the largest economies is certainly detrimental to emerging markets.

Having identified channels of interdependence between industrialised countries and emerging market economies, what is the empirical evidence? Calvo, Leiderman and Reinhart (1993) show the importance of the level of U.S. interest rates and U.S. growth as determinants of capital inflows to emerging markets. Empirical studies dealing with emerging market financial crises indicate that common shocks are significant. Frankel and Rose (1996) find that currency crashes occur when domestic output growth is low, domestic credit growth is high, and the level of foreign interest rates is high. Milesi-Ferretti and Razin (1998) also show evidence that, notwithstanding the importance of domestic macroeconomic factors, external factors such as unfavourable terms of trade and high interest rates in industrial countries trigger current-account reversals and currency crises. Moreno and Trehan (2000) attempt to determine the extent to which common external shocks explain the simultaneous occurrence of currency crises and show that sixty to eighty percent of the variation in the total number of currency crises over the post-Bretton-Woods period is due common shocks.

Frankel, Schmukler and Serven (2002) find that emerging market economies exhibit high sensitivity to international interest rates, especially under fixed exchange rate regimes. Reinhart and Reinhart (2001) present stylized facts on the impact of economic conditions in the United States on emerging markets. They conclude that economic downturns in the United States have adverse consequences on emerging markets, in particular for those whose export share to the United States is large. Moreover, capital flows to emerging markets increase markedly in years when U.S. monetary policy is easing, thereby corroborating the results obtained by Calvo, Leiderman and Reinhart (1993). Arora and Cerisola (2000) examine the impact of U.S. monetary policy on the emerging market spreads and find that the U.S. federal funds target rate has a significant positive effect on emerging market spreads.

Hayo and Kutan (2002) assess to what extent world market developments have an

impact on the Russian bond and stock markets. The sample period extends from September 1995 until November 2001. The U.S. stock market index is found to Granger-cause Russian bond and stock market returns, showing that the Russian financial market has become more vulnerable to developments in global financial markets. Habib (2002) uses a vector autoregressive specification to look at the effect of changes in German interest rates and emerging market turbulence (measured as the spread on the EMBI+ index) on the nominal exchange rates and interest rates of the Czech Republic, Hungary and Poland. Data are at the daily frequency and run from January 1998 to May 2001. The evidence shows that interest rates and exchange rates in these three countries are not affected by German interest rates. However, emerging market risk premia shocks affect all three countries' exchange rates. The reaction of interest rates to such shocks differs across countries. Whereas the Polish interest rate does not react and that of the Czech Republic is affected only marginally, Hungary exhibits a highly significant effect. Habib (2002) attributes this result to the fixed exchange rate regime prevailing in the latter country, while both the Czech Republic and Poland had less rigid arrangements. For Hungary's exchange rate peg to survive, the authorities had to raise interest rates more than in the other countries which had more flexible exchange rates.

Mackowiak (2002) makes use of a structural VAR analysis to determine whether domestic or foreign factors are the dominant source of macroeconomic fluctuations in the Czech Republic, Hungary and Poland, over a period from 1992 to 2000. The central finding is that foreign factors, and notably German interest rates, account for a sizeable proportion of the variation in the price level, output, and interest rates in the three countries<sup>2</sup>.

Overall, what does this selective empirical evidence have to say about the appropriate choice of variables? When modelling common external shocks, we should take into account the U.S. stock market, U.S. monetary policy, the German stock market, German monetary policy and emerging market risk premia shocks. This paper controls for these variables and makes two important new contributions. Firstly, we use different measures of the stance of foreign monetary policy. In particular, we assess whether emerging market economies are mainly affected by the level of interest rates, either market-determined or set by the monetary authorities, or rather by monetary policy surprises. Secondly, to the extent that these countries are economically interdependent, a structural model of interdependence between the stock markets of the region is specified to test for the existence of nonlinearities in the transmission mechanism of country-specific shocks.

### 3 Measuring U.S. monetary policy

There is an important literature on the measurement and the identification of monetary policy. The leading methodology makes use of structural vector autoregression models to

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<sup>2</sup>At first sight, this conclusion about German interest rates seems to conflict with the evidence reported by Habib (2002) which relies on daily data. However, Mackowiak (2002) points out that the fraction of variation in each variable increases over time, with small short-run effects. Therefore, it is not surprising to reach opposite conclusions with respect to the impact of German interest rates.

obtain estimates of monetary policy and to assess the impact of monetary policy shocks on various macroeconomic variables such as price levels or output (Christiano, Eichenbaum and Evans, 1999). However, these models typically require monthly data. In the context of the analysis of the propagation of shocks across international financial markets, this frequency is clearly too large. This paper will focus on daily data, leading to alternative methods to measure monetary policy, and notably its unexpected component.

Many econometric specifications that look at the impact of common external interest rate shocks make use of yields on U.S. Treasury securities, in particular the three-month U.S. Treasury bill interest rate. However, this variable really measures the rate of return on some asset and it is an imperfect proxy for U.S. monetary policy. We will focus instead on the federal funds rate, the federal funds target rate, and the discount rate, as measures of the current stance of monetary policy<sup>3</sup>. We also pay attention to monetary policy surprises. These are measured as changes in the federal funds target rate which surprise bond markets. In the end, we should be able to determine whether investors mostly react to changes in the rates of return on U.S. Treasury securities, or more to changes in monetary policy as such. Again, these rates of return are correlated with changes in monetary policy, but not perfectly.

### 3.1 The expectation hypothesis and the Fisher relation

The use of short-term U.S. market interest rates to model the influence of U.S. monetary policy may not be fully adequate. Usually, changes in the federal funds target rate are followed by changes in market interest rates in the same direction. However, there are instances where this direction reverses. Pakko and Wheelock (1996) discuss episodes in which market interest rates responded in different ways to Federal Reserve policy changes. For example, on May 17th 1994 the Fed raised its objective for the federal funds rate by 50 basis points. The market response was a decline in bond yields, both shortly before the meeting and after the announcement of the interest rate increase. To this extent, using market interest rates to capture monetary policy poses difficulties.

What is the relationship between the Federal Reserve monetary policy and market interest rate behaviour? The *expectation hypothesis* states that long-term interest rates should reflect current and expected future yields on short-term securities. The yield on three-month Treasury bills reflects the current and expected future path of the federal funds rate over the next three months. As a result, changes in current or expected future short-term interest rates will tend to cause similar changes in long-term interest rates.

Because long-term rates are linked to the current expected future path of short-term interest rates, expectations of future policy changes are important to explain the movements

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<sup>3</sup>The Federal Open Market Committee (FOMC) determines a target for the federal funds rate. This interest rate clears the market for federal funds. Open market operations are conducted so that the federal funds rate corresponds to its target. Whenever the Fed aims to lower the federal funds rate, it purchases government securities to increase the amount of reserves available to the banking system. Although the intended funds rate may not be achieved on a daily basis, it does so on average. The discount rate is the interest rate that the Federal Reserve charges financial institutions for short-term loans of reserves.

of current interest rates. In fact, changes in the target for the federal funds rate tend to exhibit some smoothing. This persistence could explain why the yield on a given security may respond to a change in the federal funds target rate by more than the amount of the target change. The security yield would actually incorporate expectations of future changes in the target rate in the same direction.

The expectation hypothesis provides a theoretical argument for a relationship between monetary policy and market interest rates, and provides a rationale for deviations of market interest rates from the federal funds rate. But how could one explain a movement in the opposite direction? The *Fisher relationship* states that the nominal interest rate consists of two components, the real interest rate and expected inflation. If market participants expect higher inflation in the future, they will require a higher interest rate as a compensation. Changes in the current stance of monetary policy may provide information about future inflation and market interest rates should change accordingly. This could explain opposite movements in the federal funds target rate and market interest rates. To the extent that market participants interpret a more laxist monetary policy today as increasing inflation in the future, then market interest rates should rise to account for higher expected inflation. Conversely, lowering long-term interest rates may require an increase in short-term rates.

This explanation may be valid for horizons long enough for inflation to matter. At the three-month horizon, however, it is unlikely to be very important. An alternative interpretation is that opposite movements could be due to a change in market expectations. A lower than expected interest rate reduction today would imply more of an increase in the future. Through the expectations channel, current market interest rates would rise, although the policy rate is reduced.

The expectation hypothesis and the Fisher relationship are two theoretical arguments for a relationship between monetary policy and market interest rates. However, this link may reverse directions and its size may not exactly proportional. Thus, it is unclear whether attempting to use market rates as a proxy for monetary policy is fully adequate.

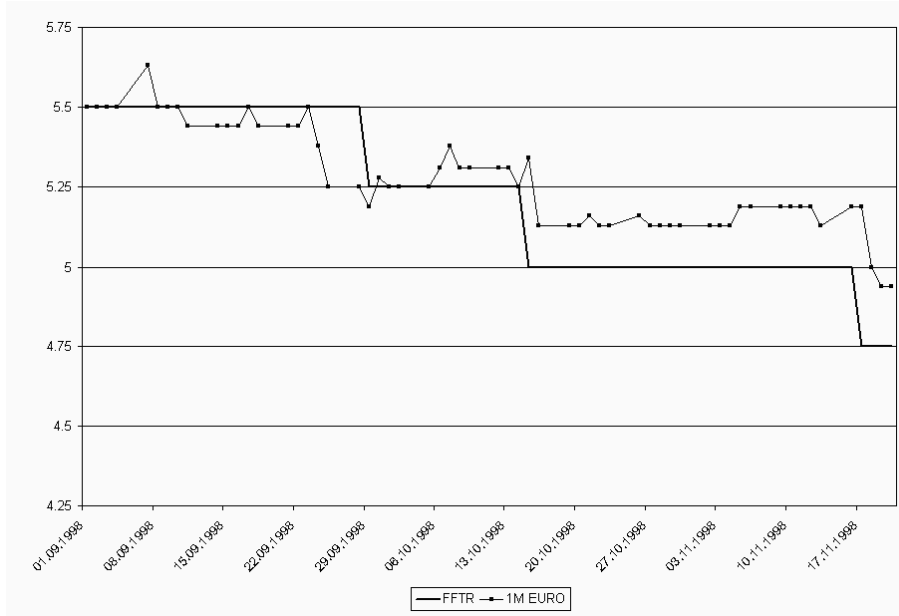
## 3.2 Monetary surprises

In the empirical part of this paper we also try to assess whether investors react to actual changes in monetary policy or only to unexpected policy shocks. Such a distinction requires a methodology to isolate the shocks from the expected component of monetary policy. A growing body of literature focuses on the federal funds futures rate<sup>4</sup>. In 1988 the Chicago Board of Trade started trading an interest rate futures contract based on the average monthly fed funds rate. Since the fed funds rate is the main policy instrument of the Federal Reserve, and given that it remains close to its intended level, efficient futures market should set prices to reflect the expected path of monetary policy. To the extent that these prices are publicly available, it should be relatively easy to extract market expectations about the future actions of the Federal Reserve.

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<sup>4</sup>Gürkaynak, Sack and Swanson (2002) provide a good survey on the use of market interest rates to extract expectations of the future stance of monetary policy.

Figure 1: Federal funds target rate and one-month Eurodollar rate



Despite the attractiveness of the federal funds futures rate, there is still no consensus whether this rate is an unbiased predictor of the federal funds rate or of the federal funds target rate. Carlson, McIntire and Thomson (1995), Owens and Webb (2001) find no bias, whereas Robertson and Thornton (1997) and Söderström (2001) conclude that the futures rate features a systematic bias. More generally, this approach relies on the expectation hypothesis, so that the futures rate should be equal to the expected future spot rate on average. However, this type of proposition usually fails empirically. The forward-spot spread is generally not a good forecast of interest rate changes.

With these results in mind, we follow Cochrane and Piazzesi (2002). They measure monetary policy shocks as changes in the federal funds target rate that surprise bond markets. An attractive feature of their methodology is the reliance on daily data, which is most desirable for the ultimate goal of this paper, testing for a breakdown in the way that shocks are transmitted in international financial markets. Monetary policy shocks are obtained as the change in the one-month Eurodollar deposit rate from just before to just after the target change. Importantly, this measure relies on the fact that there is a change in the target rate, thereby eliminating from the shocks all dates on which the target rate may have been expected to change, but it did not.

Figure 1 shows the one-month Eurodollar rate and the federal funds target rate between 1st September 1998 and 20th November 1998. During this period the Federal Reserve decreased its target by a quarter percentage point three times, on 29th September, 15th October and 17th November.

Both series of data are retrieved from the Federal Reserve Bank of New York's web site. One-month Eurodollar rates are measured at 9.30 a.m. every day, Eastern time. Changes

in the target for the federal funds rate are always announced later on during the day. Therefore, the monetary surprise is measured as the difference between the one-month Eurodollar rate prevailing the next day minus that prevailing on the day of the policy change.

Figure 1 illustrates which federal funds target rate changes were expected and unexpected. The change on 29th September was largely expected as the one-month Eurodollar rate had been declining gradually to 5.19. Indeed, market participants expected a slightly larger decrease in the target than was announced. In contrast, the changes on 15th October and 17th November were completely unexpected by the markets. For example, focusing on 17th November, although the Federal Reserve lowered its target to 4.75, the one-month Eurodollar rate was back to 5.19! Market participants expected that the target would be raised. In what follows, we shall use a series of monetary policy shocks as a measure for the unexpected component of monetary policy.

## 4 A structural model of interdependence

Favero and Giavazzi (2002) propose a three-step procedure to study the propagation of devaluation expectations among ERM members. The first step is to estimate a reduced-form vector autoregression model to identify with dummy variables residuals corresponding to observations which represent market turbulence. The second step is to estimate a structural model of interdependence and the third step consists of a test for the existence of contagion.

Suppose two countries, 1 and 2, with corresponding stock market returns denoted by  $s_1$  and  $s_2$ . The dynamic structural model of interdependence, allowing for all contemporaneous feedbacks and one-lagged endogenous responses, is given by

$$s_{1,t} = \beta_{12}s_{2,t} + \gamma_{11}s_{1,t-1} + \gamma_{12}s_{2,t-1} + \varepsilon_{1,t} \quad (1)$$

$$s_{2,t} = \beta_{21}s_{1,t} + \gamma_{21}s_{1,t-1} + \gamma_{22}s_{2,t-1} + \varepsilon_{2,t} \quad (2)$$

or, in matrix form,

$$BS = \Gamma(L)S + E \quad (3)$$

The conditional distribution of  $s_1$  and  $s_2$  is described by a reduced-form vector autoregressive specification given by

$$S = \Pi(L)S + B^{-1}E \quad (4)$$

In the usual form, the reduced-form model is given by

$$\begin{pmatrix} s_{1,t} \\ s_{2,t} \end{pmatrix} = \begin{pmatrix} \pi_{11} & \pi_{12} \\ \pi_{21} & \pi_{22} \end{pmatrix} \begin{pmatrix} s_{1,t-1} \\ s_{2,t-1} \end{pmatrix} + B^{-1} \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix} \quad (5)$$

$$B^{-1}E = \begin{pmatrix} u_{1,t} \\ u_{2,t} \end{pmatrix} | I_{t-1} \sim \left[ \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma_t \right] \quad (6)$$

where the residuals in (5) are heteroscedastic and non-normal. This implies that the sample contains episodes of high market turbulence to be identified with dummy variables, thereby filtering out heteroscedasticity and non-normality.

$$\begin{pmatrix} s_{1,t} \\ s_{2,t} \end{pmatrix} = \begin{pmatrix} \pi_{11} & \pi_{12} \\ \pi_{21} & \pi_{22} \end{pmatrix} \begin{pmatrix} s_{1,t-1} \\ s_{2,t-1} \end{pmatrix} + B^{-1} \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix} \quad (7)$$

$$\begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix} = \left( I + \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} d_{1,t} & 0 \\ 0 & d_{2,t} \end{pmatrix} \right) \begin{pmatrix} \varepsilon_{1,t}^l \\ \varepsilon_{2,t}^l \end{pmatrix} \quad (8)$$

$$\begin{pmatrix} \varepsilon_{1,t}^l \\ \varepsilon_{2,t}^l \end{pmatrix} \sim N \left[ \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma \right] \quad (9)$$

The partitioning of the matrix containing the dummy variables is conditional on the country in which the shock originates.  $\varepsilon_{1,t}^l$  and  $\varepsilon_{2,t}^l$  are the structural shocks in periods of low volatility, that is, they are homoscedastic and normally distributed. The off-diagonal blocks in the matrix of  $a_{ij}$ 's allow for nonlinearities in the propagation of shocks between countries. Therefore, a simple test for the absence of nonlinearities<sup>5</sup> specifies the following null hypothesis:

$$H_0 : a_{ij} = 0, \forall i \neq j \quad (10)$$

The estimation of the reduced-form model (5) is the first step of the methodology. Large residuals are defined as events and represented by dummy variables. Again, this allows to filter out heteroscedasticity and non-normality. The second step is to estimate the structural model of interdependence. Unfortunately, this system of simultaneous equations is not identified. Restrictions on the lag structure of the model are imposed, assuming that the own lagged dependent variable is assumed to be sufficient to capture the structural dynamics, i.e.  $\gamma_{ij} = 0, \forall i \neq j$ . In this way, the system of equations is exactly identified as each equation in the system is itself identified.

Common external shocks will be exogenous variables. The structural model of interdependence is augmented by a matrix  $C$  of common shocks:

$$BS = \Gamma(L)S + \Psi C + E \quad (11)$$

and the resulting reduced-form model is obtained as

$$S = \Pi(L)S + \Phi C + B^{-1}E \quad (12)$$

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<sup>5</sup>Favero and Giavazzi (2002) refer to nonlinearities for the phenomenon of contagion. The reason is to avoid the implicit meaning of contagion as a significant increase in cross-market relationships during crisis episodes. In fact, it is also possible that there is a significant decrease in cross-market relationships, which is also interpreted as contagion.

This extended specification captures common external shocks separately. Therefore, when constructing the dummy variables which capture events, we retain only purely country-specific events.

## 5 Data

We study the propagation of country-specific shocks across stock markets and the impact of common external shocks for a sample of four countries, namely Russia, the Czech Republic, Hungary and Poland. The sample period extends from 1st July 1998 until 31st December 1999. Stock market returns are obtained as percentage changes in corresponding stock market indices expressed in U.S. dollars and retrieved from Datastream. Common external shocks include the U.S. stock market return, the German stock market return and German and U.S. interest rates. Data on the German and U.S. stock market indices, as well as the German three-month interbank interest rate, are also retrieved from Datastream. Data on various U.S. interest rates are taken from the Board of Governors of the Federal Reserve's web site. Since the sample period includes the 1999 Brazilian crisis, we control for the effects of Brazilian market turbulence by including the EMBI+ index for Brazil in our regressions.

U.S. market interest rates are the three-month Treasury bill interest rate and the three-month interbank interest rate. The choice for this maturity is made for two complementary reasons. On the one hand, we need a horizon long enough to capture expectations of exchange rates changes, in which case interest rates do not reflect money intervention by central banks. On the other hand, we need a horizon short enough so that spreads do not average expectations of exchange rate changes over a long period of time. To measure monetary policy as such, we make use of the federal funds rate, the federal funds target rate and the discount rate.

Finally, we construct measures of the unexpected component of monetary policy following Cochrane and Piazzesi (2002). When there is a change in the federal funds target rate on day  $t$ , we measure a shock as the difference between the one-month Eurodollar rate on that day  $t$  and the day  $t + 1$ . Then, we construct a variable which observations are zero except at the dates of changes in the federal funds target rate where this variable equals the size of the surprise.

## 6 Empirical results

Since the empirical approach relies upon three steps, this section presents the results in three sub-sections. Firstly, we estimate the reduced form of the model and identify idiosyncratic shocks with dummy variables. Secondly, we reintroduce the shocks into the structural model and we make use of three-stage least squares to obtain parameter estimates of the exactly identified model. Then, we conduct a simplification search which yields an simpler overidentified model. Finally, we can test for the existence of nonlinearities in

the international transmission of country-specific shocks.

## 6.1 The reduced-form model

The reduced form of the model is a vector autoregressive specification. The optimal lag length is determined by the Schwarz criterion which selects a unit lag length. Other information criterion such as the sequential modified likelihood ratio test or the Akaike criterion remain highly sensitive to the hypothesized maximum lag length, whereas the Schwarz criterion systematically selects the same unit lag length<sup>6</sup>.

Standard tests indicate that the null hypothesis of homoscedasticity of the residuals is largely rejected. Therefore, the sample includes abnormal events. We identify country-specific shocks with dummy variables. Such shocks correspond to residuals which are greater than 2.5 times their standard deviation. Table 1 describes the number of shocks in each country in our sample, depending on which U.S. interest rate is used. The left-hand column features U.S. interest rates. Therefore, we estimate six different specifications. TB3M is the three-month Treasury bill interest rate, IBK the three-month interbank interest rate, FFR the federal funds rate, FFTR the federal funds target rate, DISC the discount rate, and SH is our measure of the unexpected component of monetary policy.

	Russia	Czech Rep	Hungary	Poland
TB3M	13	7	13	6
IBK	13	8	14	6
FFR	14	8	13	5
FFTR	13	7	14	6
DISC	13	7	14	6
SH	13	6	14	6

Several comments are noteworthy. Firstly, the computed number of shocks in each country is remarkably stable across the different measures of U.S. interest rates. *Prima facie*, we could conclude that whichever interest rate is used does not change the results markedly. However, such an inference is wrong, as we shall see. Secondly, excluding all common external shocks from our baseline specification would increase the number of country-specific shocks. Typically, such an exclusion restriction yields three or four more shocks. To this extent, we would identify shocks as being idiosyncratic while these are actually common to the four countries under study. Hence, it remains very important to control for common external shocks explicitly, by introducing such variables into the structural model. Thirdly, it seems that countries with relatively flexible exchange rate regimes such as the Czech Republic and Poland exhibit less shocks than a country like

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<sup>6</sup>This result should not come as a surprise. Information criteria yield a number which represents the trade-off between goodness-of-fit and parsimony. Since the Schwarz criterion penalizes more the addition of lags relative to other criteria, it should be expected that it selects a lower optimal lag length.

Hungary with its more rigid exchange rate peg<sup>7</sup>. The relatively high number of Russian shocks stems from the fact that the sample period includes the 1998 Russian currency and financial crisis.

Turning to common external shocks, the initial specification includes the U.S. and German stock market returns and interest rates. Interestingly, whereas the coefficient on the German stock market return is significant, that on the U.S. stock market return is not. However, if we exclude the German interest rate from our regression, then the U.S. stock market return becomes significant with the expected positive sign. This result raises the issue of collinearity among these explanatory variables. The correlation among these is quite high, 0.4 in changes and 0.7 in levels. We use Granger-causality tests to assess how returns in the United States and Germany affect each other. We find that the U.S. return Granger causes the German return while the reverse is not true. Therefore, it looks like when both variables are introduced, the effect of the United States on Central and Eastern European stock markets works is captured by the German stock market return. On the basis of our Granger-causality tests, and given that German interest rates are never significant, we exclude the German stock market return and the German interest rate.

## 6.2 Measuring interdependence and common external shocks

The second step of the methodology requires the estimation of the structural model. Initially, this specification is exactly identified by the restriction that the own lagged variable is sufficient to capture the structural dynamics. We carry out a simplification procedure by introducing zero restrictions on parameters, thereby obtaining an overidentified model. This new specification is estimated by three-stage least squares.

Tables 2 to 5 in the appendix summarize the results. Each table contains a p-value corresponding to a test for overidentifying restrictions. The null hypothesis is that the restrictions which narrow down the initial exactly identified model are not rejected by the data. We focus only on three different cases because the results are highly similar across different measures of U.S. monetary policy. In particular, we present estimations making use of the three-month Treasury bill interest rate, the federal funds rate and our measure of monetary policy surprises. To this extent, we can determine whether investors react to market rates, monetary policy as such, or to monetary policy surprises.

In general, the results are very similar across the three specifications. Two noticeable differences occur in the case of the federal funds rate. Firstly, the constant term is significantly positive for Russia. Secondly, Hungary is negatively related to Poland through interdependence. Otherwise, the magnitudes of the coefficients do not change too much depending on the measure of U.S. monetary policy. The model exhibits almost no interdependence between the three Central and Eastern European economies and Russia, except for a contemporaneous effect of Russia on Poland. Otherwise, as expected, we find

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<sup>7</sup>Overall our sample period, the Czech Republic had a floating exchange rate whereas Hungary had a crawling parity with narrow bands of fluctuation. Poland also had a crawling peg with bands which were enlarged after successive shocks, thereby signalling that the authorities were not ready to defend the parity at any cost.

interdependence among the Czech Republic, Hungary and Poland. For example, in the case of the three-month Treasury bill rate, an increase of one percent in the Hungarian stock market triggers an increase of 0.27 percent in the Czech stock market. Importantly, this result does not imply that large shocks are transmitted across stock markets in the region, but that these markets are permanently related. Hence, we refer to this evidence as interdependence, in contrast with contagion which is discussed in the next sub-section.

Turning to common external shocks, we find strong evidence that U.S. stock market returns and the Brazilian crisis affect Russia, Hungary and Poland, but never the Czech Republic. The magnitude of the coefficients on these two variables are especially high in the case of Russia. One possible interpretation for the lack of effects on the Czech Republic is that the exchange rate regime was more flexible in this country during our sample period, thereby allowing the exchange rate to absorb external shocks and reducing their impact on the economy.

The results on U.S. interest rates are particularly interesting. Many studies control for external monetary policy shocks using the three-month Treasury bill rate. In our specification, this interest rate is highly insignificant (p-value: 0.86 in the Russian equation) for all countries<sup>8</sup>. However, in the case of Russia the coefficient on the federal funds rate is highly significant (p-value: 0.0018 in the Russian equation) with the expected sign. Monetary easing in the United States brings about an increase in the Russian stock market. Finally, we also find that monetary surprises have an impact on the Czech Republic. This result was largely unexpected and we could not find any good economic interpretation. In any case, it may imply that further research should make use of alternative measures of monetary policy surprises to determine whether our result is robust.

Overall, our evidence points to the fact that investors react more to monetary policy changes and not to changes in market-determined interest rates. The generality of this conclusion should not be overstated, however. Our sample period spans over times of high turbulence in emerging markets. It may be that in normal times investors respond mostly to relative rates of return, whereas they would be highly sensitive to policy responses in times of heightened market volatility. Such an interpretation could explain why in our specification only the federal funds rate is significant, and why it is so only for Russia which was going through a currency and financial crisis.

### 6.3 Evidence of contagion

Tables 5 to 7 in the appendix present the results regarding the existence of contagion. We interpret as evidence of nonlinearities coefficients on country-specific shocks in three other countries which are significant in a given country equation. The null hypothesis of no nonlinearities can be interpreted as the complete absence of bold coefficients in our tables. Clearly, the null hypothesis is rejected for our three specifications. Therefore, we can conclude that the transmission mechanism of shocks among the four countries is not stable, that is, it changes in periods of unusual market turbulence.

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<sup>8</sup>Three-month interbank bank interest rates yield the same conclusion.

This result contrasts with earlier findings by Gelos and Sahay (2001). These authors analyze changes in correlations among stock market returns between tranquil and crisis periods. In this context, contagion is defined as a significant increase in the adjusted correlation coefficient between two stock market returns<sup>9</sup>. Clearly, contagion should be interpreted as a change in cross-market linkages, and not exclusively an increase. Gelos and Sahay (2001) conclude in favour of the absence of structural breaks, contrasting with our results.

Although correlation analysis has been used in numerous studies, it is subject to important drawbacks which imply that we should take such results with caution. Firstly, the adjustment procedure for the correlation coefficient relies upon an assumption of exogeneity in the underlying model. Relaxing this assumption indicates that the bias may be positive or negative and that it is sensitive to the parameters of the underlying model, making the adjustment problematic. Secondly, Corsetti, Pericoli and Sbracia (2002) show that the adjustment procedure is rooted on an arbitrary assumption about the variance of the shocks specific to the country where the crisis originates.

Gelos and Sahay (2001) also study the interesting question of the asymmetry of transmission between positive and negative shocks. They find that "around the Russian crisis the difference between the impact of positive and negative shocks is larger, and there is no significant effect of positive Russian stock returns on the other markets"<sup>10</sup>. The full-information methodology that we follow yields very different results. For example, irrespective of the measure of U.S. monetary policy, we find that the Russian shock on 6th October 1998 is transmitted beyond the normal channels of interdependence, positively to Hungary and negatively to the Czech Republic.

In general, the methodology allows to study how shocks propagate across stock markets. Focusing on the estimations with the federal funds rate, we have thirty instances of contagion<sup>11</sup>. These correspond to positive shocks in 21 cases, and by definition to negative shocks in 9 cases. Among the positive country-specific shocks, twelve out of twenty-one yield a positive effect and nine yield a negative effect on other markets. Among the negative shocks, seven out of nine shocks trigger a fall in other markets, whereas the remaining two shocks lead to an increase in other markets. Therefore, negative shocks to one market imply adverse consequences in other markets in almost all cases, whereas positive shocks can lead to increases or decreases in other markets with a probability close to half. This asymmetry would mean that when markets are hit by negative shocks, investors sell in all markets indiscriminately, while their reaction to positive shocks exhibits more country discrimination. We interpret such discriminating behaviour as evidence of rebalancing effects in the sense that investors reshuffle their portfolios among the four stock markets in our sample.

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<sup>9</sup>Forbes and Rigobon (2002) show that the correlation coefficient can increase in the crisis period not because of a change in cross-market linkages but simply because of the higher variance in the high-volatility sub-sample. To this extent, the correlation coefficient is biased upwards, hence requiring an adjustment procedure.

<sup>10</sup>Gelos and Sahay (2001), p. 73.

<sup>11</sup>In other words, we count thirty bold coefficients.

## 7 Concluding remarks

This paper studies the relative contribution of common external shocks and economic interdependence to stock market comovements among four Central and Eastern European economies. The full-information approach proposed by Favero and Giavazzi (2002) is used to test for the existence of contagion, defined as a change in the way that country-specific shocks are transmitted internationally. Given the importance of common external shocks for emerging stock markets we control for the U.S. stock market, U.S. monetary policy and the impact of the 1999 Brazilian crisis.

We find that the U.S. stock market and turbulence in Brazil affect significantly Russia, Hungary and Poland, whereas these have no effect on the Czech Republic. We interpret this result as evidence that countries with more flexible exchange rate arrangements are better able to offset external shocks. Interestingly, our different controls for U.S. monetary policy perform differently. Although the three-month Treasury bill interest rate is never significant, the federal funds rate affects Russia. We also find that monetary policy surprises do not matter, except for the Czech Republic. We cannot provide a strong explanation for this surprising result. In general, our results point to the important fact that the measurement of common external shocks is not innocuous.

The propagation mechanism of country-specific shocks changes in the face of large abnormal events, thereby contrasting with earlier empirical evidence. Whereas positive shocks can trigger positive or negative effects on neighbouring stock markets, with a nearly equal probability, negative shocks are almost always having negative effects on other stock markets. This asymmetry could reflect the fact that investors do not discriminate among countries when facing bad news, while they do when news are good.

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## Appendix

This appendix contains the results from our econometric computations. Tables 2 to 4 present the parameter estimates of the overidentified structural model of interdependence, respectively using the three-month Treasury bill interest rate, the federal funds rate, and our measure of monetary policy surprises. The left-hand column lists the explanatory variables for our four equations. Coefficients in normal font are significant at the 5 percent level. Blank cells correspond to coefficients which are not significantly different from zero and are not reported.

Tables 5 and to 7 list the country-specific shocks which are obtained, explicitly specifying the type of shock (positive or negative). All unstarred coefficients are significant at the 5 percent level, starred coefficients are significant at the 10 percent level. Coefficients which are not significant are not reported for clarity. Finally, coefficients in normal font deal with own-country dummy variables, whereas coefficients in bold format measure nonlinearities.

Table 2: Three-month Treasury bill interest rate				
Test for overidentifying restrictions: p-value = 0.9280				
	$s_{RU}$	$s_{CZ}$	$s_{HU}$	$s_{PO}$
Constant				
$s_{RU}$	X			0.0699
$s_{CZ}$		X	0.7400	0.8405
$s_{HU}$		0.2657	X	
$s_{PO}$				X
Lagged dep. var.	0.1357	0.1276	-0.0865	
U.S. int. rate				
U.S. stock market	0.5783		0.1851	0.6283
Brazilian EMBI+	0.5611		0.2352	0.2167

Table 3: Federal funds rate				
Test for overidentifying restrictions: p-value = 0.3637				
	$s_{RU}$	$s_{CZ}$	$s_{HU}$	$s_{PO}$
Constant	0.0800			
$s_{RU}$	X			0.1734
$s_{CZ}$		X	0.4741	0.7793
$s_{HU}$		0.3284	X	-0.4027
$s_{PO}$				X
Lagged dep. var.	0.1039	0.1325	-0.0874	
U.S. int. rate	-0.0158			
U.S. stock market	0.5632		0.2452	0.6344
Brazilian EMBI+	0.5748		0.2215	0.2614

Table 4: Monetary policy surprises				
Test for overidentifying restrictions: p-value = 0.5647				
	$s_{RU}$	$s_{CZ}$	$s_{HU}$	$s_{PO}$
Constant				
$s_{RU}$	X			0.0932
$s_{CZ}$		X	0.8184	0.7507
$s_{HU}$		0.3808	X	
$s_{PO}$				X
Lagged dep. var.	0.1415	0.1146	-0.0763	
U.S. int. rate		-0.0786		
U.S. stock market	0.6006		0.1911	0.6306
Brazilian EMBI+	0.5552		0.1990	0.2190

Table 5: Contagion with TB3M						
Date	Country	Type	$s_{RU}$	$s_{CZ}$	$s_{HU}$	$s_{PO}$
03/07/98	RU	+	0.1137	<b>0.0214</b>		
11/08/98	CZ, HU	-, -	<b>-0.1053</b>		-0.0557	
13/08/98	CZ, PO	-, -	<b>-0.1337</b>	-0.0338		
14/08/98	RU	+	0.1499			
26/08/98	RU, CZ, HU	-, -, -	-0.1525		-0.0452	
27/08/98	RU, HU	-, -	-0.1623		-0.0814	
02/09/98	PO	+		<b>0.0213</b>		0.0434
07/09/98	PO	+	<b>-0.0845</b>			0.0624
10/09/98	RU	+	0.2343			
11/09/98	HU	-			-0.0649	
16/09/98	RU	-	-0.2049			
21/09/98	HU	-			-0.0511	
24/09/98	HU	+			0.0766	<b>0.0443</b>
06/10/98	RU	+	0.1307	<b>-0.0388</b>	<b>0.0492</b>	
14/10/98	RU	+	0.1435			<b>-0.0297*</b>
21/10/98	RU	+	0.1194		<b>-0.0357</b>	
02/11/98	HU	+			0.0645	
16/11/98	PO	+				0.0557
04/01/99	PO	+				0.0502
07/01/99	HU	+		<b>-0.0372</b>	0.0930	<b>0.0517</b>
13/01/99	CZ, HU	-, -			-0.0516	
15/01/99	HU	-	<b>-0.1096</b>		-0.0499	
25/01/99	HU	+			0.0420	
26/01/99	PO	+				0.0629
23/02/99	CZ	-		-0.0291		
08/03/99	HU	+		<b>-0.0318</b>	0.0819	<b>0.0372*</b>
05/05/99	RU	+	0.1339			
06/05/99	HU	+			0.0422	
12/05/99	RU, CZ	-, -	-0.1771	-0.0296		<b>0.0299*</b>
17/05/99	RU	+	0.1508			
20/07/99	CZ	+		0.0266		
31/12/99	RU	+	0.1558			

Table 6: Contagion with FFR						
Date	Country	Type	$s_{RU}$	$s_{CZ}$	$s_{HU}$	$s_{PO}$
03/07/98	RU	+	0.1143	<b>0.0226</b>		
14/07/98	RU	+	0.1199		<b>0.0279*</b>	<b>0.0315*</b>
11/08/98	CZ, HU	-, -	<b>-0.1023</b>		-0.0651	
13/08/98	CZ	-	<b>-0.1318</b>	-0.0255	<b>-0.0619</b>	
14/08/98	RU	+	0.1541		<b>0.0253*</b>	
26/08/98	RU, CZ, HU	-, -, -	-0.1454		-0.0556	
27/08/98	RU, HU	-, -	-0.1625		-0.0853	
02/09/98	PO	+		<b>0.0239</b>		0.0443
07/09/98	PO	+	<b>-0.0671*</b>			0.0820
10/09/98	RU	+	0.2402			<b>-0.0372*</b>
11/09/98	HU	-		<b>0.0239*</b>	-0.0801	<b>-0.0544</b>
16/09/98	RU	-	-0.1880	<b>-0.0244*</b>		
21/09/98	HU	-			-0.0570	
24/09/98	HU	+		<b>-0.0243*</b>	0.0905	<b>0.0719</b>
06/10/98	RU	+	0.1363	<b>-0.0367</b>	<b>0.0386</b>	
14/10/98	RU	+	0.1518			<b>-0.0475</b>
21/10/98	RU	+	0.1221		<b>-0.0418</b>	
26/10/98	HU	+			0.0484	<b>0.0433</b>
02/11/98	HU	+			0.0726	<b>0.0364*</b>
16/11/98	PO	+		<b>0.0185*</b>		0.0532
04/01/99	PO	+				0.0531
07/01/99	HU	+		<b>-0.0437</b>	0.0906	<b>0.0688</b>
13/01/99	CZ, HU	-, -				<b>-0.0365*</b>
15/01/99	HU	-	<b>-0.1165</b>		-0.0520	
25/01/99	HU	+			0.0420	
26/01/99	PO	+				0.0615
23/02/99	CZ	-		-0.0235		
08/03/99	HU	+		<b>-0.0370</b>	0.0789	<b>0.0536</b>
05/05/99	RU	+	0.1305			<b>-0.0291*</b>
12/05/99	RU, CZ	-, -	-0.1816	-0.0327		<b>0.0476</b>
17/05/99	RU	+	0.1470			
26/05/99	CZ	-		-0.0305		
20/07/99	CZ	+		0.0306		
31/12/99	RU	+	0.1552			

Table 7: Contagion with SH						
Date	Country	Type	$s_{RU}$	$s_{CZ}$	$s_{HU}$	$s_{PO}$
03/07/98	RU	+	0.1140	<b>0.0173*</b>		
11/08/98	CZ, HU	-, -	<b>-0.1053</b>		-0.0508	
13/08/98	CZ, PO	-, -	<b>-0.1344</b>	-0.0289		
14/08/98	RU	+	0.1498		<b>0.0270*</b>	
26/08/98	RU, CZ, HU	-, -, -	-0.1574		-0.0418	
27/08/98	RU, HU	-, -	-0.1640		-0.0685	
02/09/98	PO	+		<b>0.0169*</b>		0.0481
07/09/98	PO	+	<b>-0.0844</b>			0.0657
10/09/98	RU	+	0.2319			
11/09/98	HU	-		<b>0.0274</b>	-0.0775	<b>-0.0392*</b>
16/09/98	RU	-	-0.1983	<b>-0.0266</b>	<b>0.0298*</b>	
21/09/98	HU	-			-0.0465	
24/09/98	HU	+		<b>-0.0305</b>	0.0894	<b>0.0570</b>
06/10/98	RU	+	0.1331	<b>-0.0359</b>	<b>0.0452</b>	
14/10/98	RU	+	0.1489			<b>-0.0359</b>
21/10/98	RU	+	0.1238		<b>-0.0443</b>	
26/10/98	HU	+			0.0389	<b>0.0331*</b>
02/11/98	HU	+			0.0591	
16/11/98	PO	+				0.0559
04/01/99	PO	+				0.0498
07/01/99	HU	+		<b>-0.0459</b>	0.0935	<b>0.0533</b>
13/01/99	HU	-			-0.0544	
15/01/99	HU	-	<b>-0.1123</b>		-0.0427	
25/01/99	HU	+			0.0352	
26/01/99	PO	+				0.0610
23/02/99	CZ	-		-0.0259		
08/03/99	HU	+		<b>-0.0399</b>	0.0830	<b>0.0384*</b>
05/05/99	RU	+	0.1353			
06/05/99	HU	+			0.0367	
12/05/99	RU, CZ	-, -	-0.1772	-0.0242		
17/05/99	RU	+	0.1493			
20/07/99	CZ	+		0.0227		
31/12/99	RU	+	0.1542			