ESSAYS ON FINANCIAL INTEGRATION, FINANCIAL MARKET DEPENDENCE, AND MONETARY POLICY TRANSMISSION

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ESSAYS ON FINANCIAL INTEGRATION, FINANCIAL MARKET DEPENDENCE, AND MONETARY POLICY TRANSMISSION

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This dissertation offers three essays addressing critical topics in financial market dependence and monetary policy transmission in an era of financial integration: 1) the domestic effects of monetary policy (MP) shocks on market interest rates in small open economies, 2) international transmission of U.S. MP shocks to other open financial markets, and 3) volatility spillovers among financial markets in emerging market (EM) economies.

The first chapter investigates the nature of monetary policy transmission in selected small open economies and the U.S. by estimating structural vector autoregressive (SVAR) models using the external instrument identification method. Differing from related studies on U.S. monetary policy, which mostly employ high-frequency futures rates to identify monetary policy shocks, the study proposes and tests alternative sets of external instruments for the focal open economies that do not yet have well-established futures markets in MP instruments.

The second chapter focuses on the international transmission of U.S. monetary shocks into a variety of financial markets in open economies. I again exploit the external instrument approach to identify the impact of U.S. and domestic MP shocks in a SVAR system. Utilizing the identified shocks for the event study analysis and the local projection estimation, I further test non-linear features of such transmission.

Empirical results from the first and second chapters provide a variety of meaningful insights. The results show that foreign exchange rates respond to monetary shocks flexibly, i.e., without generating puzzles raised by earlier studies and that the shocks strongly propagate into other types of open financial markets as well. The studies also confirm the significant transmission of domestic monetary shocks in open economies, but U.S. shocks appear to exhibit greater and more persistent influences over domestic asset prices than domestic shocks. Besides, the international propagation of U.S. shocks also demonstrate non-linear features.

The third chapter investigates the occurrence of dependency between foreign exchange markets and stock markets in EM countries by testing volatility spillovers of asset returns. I modify the classical BEKK GARCH (1,1) model to study the dynamics and origins of volatility spillovers. The empirical results are threefold. First, volatility spillovers between financial markets are significant in most EM countries. Second, such spillovers are found to be contingent on the sample period and market conditions, a result that is generally consistent with findings in the literature on time-varying, asymmetric, and contagion-shift spillovers. Finally, the results suggest that, under normal conditions, the relevant spillovers are explained mostly by comovement from common information about fundamentals; during crises, however, while common information plays a role, market contagion also becomes an important source of spillovers

BIOGRAPHICAL SKETCH

Jongrim Ha is a PhD student in the Department of Economics at Cornell University. Raised in Busan, Korea, he earned a BA degree in economics from Seoul National University. He worked for the Bank of Korea from 2004 to 2011 in three core departments. He then enrolled in Cornell University and earned an MA degree in 2014 and PhD degree in 2016. His research interests are open-economy macroeconomics and international finance, with a specific focus on monetary policy and financial stability issues.

This document is dedicated to my beloved mother. Thank you so much for the unconditional love and support you have always given me. I really miss and love you so much.

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CHAPTER 1

WHICH MONETARY SHOCKS MATTER IN SMALL OPEN ECONOMIES? EVIDENCE FROM SVARS

1.1 Introduction

The frictionless transmission of monetary policy (hereafter 'MP') shocks through financial markets is a key assumption in conventional macroeconomics as well as in practical policy discussions. The central banks in many advanced countries currently choose overnight interest rates as an MP operating instrument, based on the belief that short-term interest rates, among other candidate instruments, are the most directly related to their macroeconomic targets. They attempt to steer inflation and/or output gaps towards targets via market interest rates at all maturities. Transmission of policy effects to other financial market asset prices are, in this sense, a crucial prerequisite for successful MP implementation.[1]

It is, however, yet to be determined whether, in a world of open financial markets, MP decisions transmit through a variety of financial markets effectively and in a timely way. U.S. financial markets, for instance, confronted Greenspan's conundrum in the mid-2000s, during which a global savings glut kept long-term rates low even as the Federal Reserve raised short-term rates. This phenomenon is not confined to the U.S. To the extent that interest rate movements in small open economies (hereafter 'SOEs') are heavily influenced by international monetary and financial spillovers, their movements are more

[1] As we discuss in Section 1.2, conventional models of monetary policy transmission regard financial markets as frictionless, thereby predicting long-term rates which rely entirely on the expected path of short-term rates in reaction to MP actions.

likely to deviate from a central bank's policy stance (Turner [2013], Obstfeld [2015]).[2] As a result, central banks are faced with a dilemma in their efforts to achieve macroeconomic stability because focusing only on short-term rates can bias the assessment of a given policy stance.

Existing empirical studies on MP transmission in SOEs nevertheless have paid less attention to transmission through financial markets, focusing mainly on the direct relationship between MP shocks and macroeconomic variables, typically assuming there are no frictions in capital and financial markets (e.g., Obstfeld et al. [2005], Frankel et al. [2004]). Specifically, few studies explicitly deal with how well market interest rates, e.g., long-term bond yields, respond to local MP shocks, assuming that the traditional interest rate channel performs well as theory predicts.[3, 4] Moreover, there is still no conclusive consensus on the dynamic relationship between MP and foreign exchange (FX) rates in the literature. Despite many prior results on the puzzling movements of exchange rates in response to MP shocks, e.g., foreign exchange rate and forward premium puzzles,[5] several recent studies reconcile the empirical results with theory by adopting new identification strategies.[6] Moreover, to the extent that foreign MP shocks play an important role in explaining movements of domestic financial asset prices under financial integration, the transmission mechanism of foreign

[2]South Korea, for example, has experienced such a conundrum, with long-lasting, low levels of long-term rates despite consecutive MP tightening in 2010-11, and this was attributed to the influence of a strong surge in foreign investments into national bond markets.

[3]Studies on the U.S. market have progressed well. For instance, seminal studies, including Cochrane and Piazessi (2002) and Gürkaynak et al. (2005), provide evidence that unanticipated MP shocks significantly influence long-term bond yields and other financial asset prices in the U.S. Another group of studies, including Evans and Marshall (1998) and Rudebush et al. (2006), do not, however, find strong evidence of a close relationship, attributing the relationship to other factors, including appetite for risk.

[4]As we discuss in Section 1.2, however, the capacity of SOEs to influence movements of long-term rates can be limited in a world of large capital flow across border and financial integration.

[5]See Christiano and Eichenbaum (1995) for the puzzles.

[6]See Kim and Roubini (2000) and Bjørnland (2009), for example.

MP shocks must be equally considered in studies on domestic MP transmission.

Taking these issues into account, we seek to investigate the channels of MP transmission in SOEs within and across borders. To this end, we use an open-economy SVAR model—a main workhorse in the field of empirical MP transmission studies—with various financial market variables as well as macroeconomic variables. Identification of structural monetary policy shocks in SVAR can be problematic, however, especially in a model with multiple financial variables, because of simultaneity issues. Most studies in an open-economy setting impose arbitrary relationships on endogenous variables (e.g., a recursive structure or Cholesky restriction), which specify that some structural shock has no contemporaneous effect on one or more financial variables, thereby facing difficulties in sorting out the contemporaneous movements of MP shocks, exchange rates, long-term yields, etc. (Faust et al. [2003], Gertler and Karadi [2015]). In addition, identified monetary structural shocks in such a model can be quite different from each other depending on assumptions regarding the identification of such shocks (Rudebush 1998). This may work as a critical limitation when interpreting empirical results pertaining to the dynamic relationship between structural shocks and endogenous variables, e.g., impulse response functions (IRFs) and decomposition of forecast error variances.

The identification scheme proposed by Stock and Watson (2012) and Mertens and Ravn (2013), to which we refer as the external instrument identification scheme, has considerable appeal because it exploits the attractive features of SVARs while addressing the identification issues raised above by using information from external instruments. In the area of MP transmission studies, Gertler and Karadi (2015) combine a SVAR set-up with such an identification scheme, exploiting high-frequency external instrument variables, federal funds, and euro dollar futures rates. Contrary to findings in the literature on U.S. markets, this identification method has not yet been applied to related studies of other economies. One critical reason for this omission may be that there are no futures markets with active trading in such monetary policy operating targets in those countries, and thus external data for MP shocks are not easily obtainable.

Given these circumstances, we contribute to the literature in the following respects. This chapter revisits the conventional topic of MP transmission in SOEs, but focuses on how well domestic MP shocks propagate through financial markets and on whether such transmission is distorted by international monetary spillovers. To that end, the SVAR models in this chapter explicitly test and compare the impact of domestic as well as foreign (U.S.) MP shocks on multiple market interest rates at a variety of maturities. Furthermore, we test MP transmission in national currency markets, in light of prior theoretical and empirical findings that foreign exchange rates play an important role in domestic and foreign MP transmission in open countries.

In addition, we avoid a simultaneity problem involving MP actions and other macroeconomic or financial variables by identifying monetary shocks using external instruments identification instead of making direct arbitrary assumptions about contemporaneous interaction between variables. Specifically, we exploit a variety of high-frequency financial data in the focal SOE countries as well as other measures obtained from econometric methods as external instruments to identify domestic and foreign MP shocks, and we provide a parsimonious characterization of MP shock transmission mechanisms in SOEs.[7]

[7]Recent studies, including Rogers et al. (2015) and Passary and Rey (2015), adopt a similar identification strategy. This study, however, is differentiated with other related studies in several aspects. We focus, for instance, focuses on the identification of local MP shocks in selected SOEs

Our empirical findings are as follows. First, medium- and long-term interest rates in the SOEs under study respond quite weakly to domestic MP shocks, and these effects are short-lived, which represents a more readily discernible response than estimates for the U.S. suggest. Meanwhile, foreign MP shocks have significant and persistent effects on domestic financial and macroeconomic variables, indicating that MP implementations in our sample SOEs may have been either hampered or strengthened by international monetary spillovers. Considering that overnight and short-term interest rates are monetary policy instruments in SOEs, any significant response of those variables to foreign MP shocks may indicate some sort of policy interdependence among central banks, e.g., policy coordination. Second, foreign exchange rates in this process are seen to respond significantly to MP shocks, as Dornbusch (1976) predicted. Contrary to the findings of existing studies that have reported counter-evidence for the overshooting hypothesis (e.g., Eichenbaum and Evans [1995], Grilli and Roubini [1995], Cushman and Zha [1997]), we find that an increase in policy rates causes the nominal exchange rate to appreciate instantaneously and then to depreciate gradually in line with uncovered interest parity (UIP), with few exceptions. Finally, a group of external instrument variables for the identification are tested and selected, among which movements of overnight spot rates on MP decision dates turn out to be the most suitable instrument for such identifications.

The remainder of this chapter is organized as follows. In Section 1.2 we provide an overview of theoretical relationships between endogenous variables in the context of open-economy structural models. In Section 1.3 we specify SVAR models and identifying restrictions. Section 1.4 summarizes the empirical

by testing a variety of economic variables in selected SOEs as instrumental variables for MP shocks. In so doing, we observe IRF results of macroeconomic variables in SOEs following U.S. and local MP shocks and furthermore compare the overall influence of the two structural MP shocks in the dynamic movements of variables in the SOEs.

results and Section 1.5 concludes.

1.2 Theoretical motivation and hypotheses

Standard New-Keynesian models with sticky prices and frictionless financial markets indicate that transmission of MP shocks to credit costs and thus to aggregate spending operates via yield curves assuming price rigidity. Given the expectation hypothesis of the term structure, the effect of MP decisions on the paths of current and expected short-term interest rates is summarized in (1.1):

$$R_t^m = m^{-1} E_t \left[\sum_{i=0}^{m-1} R_{t+i} \right] + \xi_t^m \tag{1.1}$$

where R_t^m is an m-period zero-coupon government bond yield at time t, R_t is a short-term interest rate (e.g., a central bank policy rate), and ξ_t^m is an m-period term premium. The term premium captures additional compensation for the interest rate (duration) risk inherent in medium- or long-term bond positions as well as residual effects of idiosyncratic market factors. If the premium is assumed to be constant over time, changes in the path of short-term policy rates will dominate changes in long-term rates, allowing central banks to influence movements of output and inflation (Gertler and Karadi [2015]).

The extent of a central bank's control, especially in SOEs, over macroeconomic developments is, however, controversial because policy and other monetary shocks migrate from other countries under international financial integration, possibly causing monetary spillovers even when exchange rates float freely (Obstfeld [2015]). The international monetary transmission mechanism can be considered as operating with the following, direct and indirect, channels through the short- and long- term yield structure.

In integrated capital markets, a country's manipulation of short-term rates (R_t^*), especially if it is a large open economy such as the U.S., inevitably directly affects short-term rates (R_t^m) in other open countries following the interest-parity relationship represented in (1.2):

$$R_t = R_t^* + E_t \Delta (e_t) + \rho_t \tag{1.2}$$

where e_t is a nominal FX rate vis-á-vis the U.S. dollar and ρ_t is a currency risk premium in open economies at time t.

Although changes in the interest rate difference between two countries are absorbed mainly by adjustments in exchange rates, market interest rates in an open country are significantly influenced by foreign MP shocks, depending on the behavior of the exchange rate and the risk premium. If the Federal Reserve cuts its policy rates but SOEs maintain the path of the short-term interest rate constant in response, for instance, the resulting decrease in the foreign short-term rate causes the nominal exchange rate and, accordingly, macroeconomic variables in SOEs, to fluctuate.[8] In order to avoid sharp exchange rate movements, SOE central banks are likely to enhance the correlation between the domestic policy rate and the federal fund rate (FFR).

MP actions abroad can also influence domestic market interest rates indirectly through the combination of domestic MP transmission and international

[8]Dornbusch's (1976) exchange rate overshooting hypothesis predicts that an increase in the interest rate should make the nominal exchange rate appreciate sharply at first and then depreciate. An initial sharp exchange rate adjustment may have a negative effect on the economy.

spillovers. Equations (1.1) and (1.2) are combined to show the linkage between international long-term rates of the form (1.3):

$$R_t^m = R_t^{*m} + m^{-1} E_t \left[\sum_{i=0}^{m-1} \left(\Delta e_{t+j} + \rho_{t+j} \right) \right] + \xi_t^m - \xi_t^{*m} \tag{1.3}$$

where R_t^{*m} and ξ_t^{*m} are an m-period zero-coupon bond yield and an m-period term premium in the U.S. at time t, respectively. The other notations are the same as those used in equation (1.1).

Equation (1.3) implies that unexpected MP shocks in a foreign country at first adjust movements of market interest rates for a variety of maturities in the country and then lead to the correlated movement of market rates in SOEs as long as the change in the expected exchange rates tends to be slow over time and term premiums are internationally correlated across countries (e.g., Turner [2014], Hellerstein [2011]).[9]

Overall, these theoretical channels of international monetary transmission through integrated financial markets indicate that foreign MP adjustment can directly and/or indirectly have a significant impact on the movement of market interest rates in SOEs, and thereby influence the effectiveness of their domestic MP. Our empirical analysis leads to three implications of the MP transmission in SOEs that we can test. First, domestic MP shocks transmit through bond yields

[9]Foreign as well as domestic MP shocks also operate through the term premium and the currency risk premium. For example, consider first the case discussed above, an SOE central bank's effort to mitigate a sharp change in the exchange rate following a U.S. MP contractionary shock. Even when there is no monetary intervention such as synchronizing MP actions, consequential capital flows may occur, and thus affect the term premiums in SOE asset markets. Variations in term premiums on long-term assets caused by capital flow at times offset the impact of changes in short-term rates. In addition, SOE bond and currency risk premiums may fluctuate with changes in U.S. monetary policy. Tighter U.S. MP may, for example, raise perceived risk and uncertainty, which will compress capital inflows and boost risk premiums, thereby leading to potential unintended pro-cyclical dynamics in SOE bond markets (Bruno and Shin [2015]).

of multiple maturities instantaneously, with little response reflected in the term premium, based on the expectation hypothesis. we then investigate the role of U.S. MP shocks, as secondary MP shocks in the focal SOEs, by testing the second and third hypotheses: U.S. MP shocks transmit into overnight rates (MP instruments) in SOEs (direct international transmission), and U.S. MP shocks influence other market interest rates, e.g., medium- and long-term rates in non-U.S. open countries (indirect international transmission).

1.3 Estimation of SVAR model

1.3.1 SVAR modeling

We assume the economy is described by a structural form equation (1.4):

$$AX_t = \sum_{i=1}^{p} B_i X_{t-i} + \varepsilon_t \tag{1.4}$$

where X_t is an $n \times 1$ vector of financial variables, A and $B_i (\forall i \geq 1)$ are non-singular coefficient matrices, and ε_t is an $n \times 1$ structural disturbances vector. ε_t is serially uncorrelated and $E(\varepsilon_t \varepsilon_t^{'}) = I$, an identity matrix. For notational brevity, the specification in (1.4) omits deterministic terms and exogenous regressors. By pre-multiplying the inverse of the A matrix on both sides of the equation, the reduced-form representation is obtained as (1.5):

$$X_t = \sum_{i=1}^{p} \alpha_i X_{t-i} + e_t \tag{1.5}$$

where $\alpha_i = A^{-1}B_i$, and e_t are the reduced-form residuals. The residuals are related to structural shocks, as seen in (1.6):

$$e_t = \begin{bmatrix} e_t^p \\ e_t^q \end{bmatrix} = S\,\varepsilon_t = [s^p \;\; s^q] \begin{bmatrix} \varepsilon_t^p \\ \varepsilon_t^q \end{bmatrix} \tag{1.6}$$

where S = A^{-1}. e_t^p denotes a vector for the residuals of domestic and foreign MP instruments (i.e., $e_t^p = \left[e_t^{MP*}\, e_t^{MP}\right]'$), e_t^q is a vector for the residuals of the other variables, and the analogous definition applies to structural shocks ε_t^p and ε_t^q. s^p and s^q denote the columns in matrix S that correspond to the impact structural policy shocks ε_t^p and ε_t^q, on each element of the vector of reduced-form residuals e_t. The variance-covariance matrix of the reduced-form VAR is $\Sigma = E[e_t e_t'] = E\,[S\,S']$.

Next, the Wold representation as a function of the structural shocks is given as (1.7):

$$X_t = \sum_{j=0}^{\infty} C_j S\,\varepsilon_{t-j} = \sum_{j=0}^{\infty} C_j s^p \varepsilon_{t-j}^p + \sum_{j=0}^{\infty} C_j s^q \varepsilon_{t-j}^q \tag{1.7}$$

where C_j denotes the coefficients of the structural moving average (MA) form. Accordingly, if the financial variables respond to MP innovations, the IRFs of the k-th element of vector X (X_k) to a unit shock of ε_t^p at time $t + j$ is obtained by (1.8):

$$IRF_{k,j} = \frac{\partial X_{k,t+j}}{\partial \varepsilon_{k,t}^p} = C_{k,j} s^p \tag{1.8}$$

where $C_{k,j}$ is the k-th row of C_j.

Forecast error variance decomposition (FEVD) at time $t+j$ can also be calculated from the structural MA representation by (1.9):

$$FEVD_{k,j} = \frac{\mathrm{var}\left(\sum_{l=0}^{j} C_{k,l} s^p \varepsilon_{t-l}^p\right)}{\mathrm{var}\left(\sum_{l=0}^{j} C_{k,l} e_{t-l}\right)} \tag{1.9}$$

1.3.2 Identification scheme in SVAR analyses

The identification strategy should be deliberately chosen since it considerably affects model specification results, most importantly the identification of structural shocks.[10] In the monetary VAR literature, exogenous MP shocks are typically obtained by a surprise component from the regression of a policy rate on suggested explanatory variables, e.g., its lags and/or other financial and macroeconomic variables. Dynamic responses of endogenous variables in the VAR to the identified structural shocks, i.e., IRF and FEVD results, therefore vary depending on the assumptions imposed on relationships between endogenous variables.[11]

In addition, if identification restrictions are assumed without modeling the relationships between variables correctly, the model may generate biased results. For purposes of ease and convenience, for instance, short-run zero restrictions on the impact matrix are conventionally assumed, which orthogonalize reduced-form disturbances by Cholesky decomposition. In the literature on MP

[10]Obtaining identified 'exogenous' MP shocks is crucial in monetary VAR analyses because the response of variables to endogenous policy actions cannot distinguish the movement of the economy due to the policy action itself and to the variable that spurred that action.

[11]In this respect, Rudebusch (1998) criticizes the limitations of applying VAR methodology in MP analyses. He showed that structural shocks stemming from a recursively identified VAR may not be identical to MP shocks identified outside the VAR.

transmission as well, the short-run zero restriction has been widely used on the assumption that MP transmission is occasionally uni-directional, i.e., MP shocks do not affect macroeconomic variables while the latter affect MP decisions, and propagation of MP surprises in the financial in only one direction, from the short-term to the long-term rate. Such a restriction, however, may be distorting because within a given period policy shifts not only influence financial variables but may also be responding to them. Even if the central bank does not directly respond to financial indicators, it may respond to underlying correlated variables left out of the VAR.[12] Furthermore, there is a growing body of literature, including Carlstrom et al. (2009), in which findings indicate that MP can influence economic variables simultaneously and that Cholesky identification can distort the results, producing price puzzles or muted responses of inflation and output.[13]

In order to avoid possible identification problems, an identification strategy should avoid direct assumptions regarding elements of the impact matrix while it produces robust exogenous MP shocks regardless of structural identifying assumptions. In this respect, the identification method proposed by Stock and Watson (2012) and Mertens and Ravn (2013) offers attractive features for measuring the effects of structural shocks because it utilizes an information set pertaining to exogenous shocks that are identified outside the VAR and it does

[12]For instance, the results derived from our model with Cholesky identification show that residual series of most financial variables from the proposed VAR model interact simultaneously. Cross-correlations between short- and long-term rates are very high, as high as 0.4-0.9.

[13]Since the 1990s, the Federal Reserve and central banks in other developed countries have increasingly relied on communication to influence market beliefs about the expected paths of policy rates and economic conditions, and in this way MP may have immediate effects on macroeconomic variables. If central banks have more information on the future economic situation, e.g., on aggregate demand and inflation, than the public, an announcement by central banks may change agents' expectations and thereby economic activity. A statement that causes economic agents to expect accommodative future aggregate demand may, for example, lead to a spontaneous increase in current consumption and output.

not assume direct restrictions on relationships between variables. Gertler and Karadi (2015), who adopt this approach, show that it can be extended to monetary VAR analyses by exploiting information about external MP shocks from the HFI to test whether MP and other macroeconomic and financial variables have simultaneous relationships.

1.3.3 External instrument identification scheme

We recover structural parameters related to domestic and foreign MP shocks by using external instrument identification. The main idea behind this identification scheme is to complement the required restrictions for recovering structural parameters from reduced-form VAR residual covariance and the moment conditions that external instruments can be considered orthogonal to other structural shocks but correlated with MP shocks. This scheme enables us to exploit information contained in external instruments and to avoid arbitrary assumptions about structural parameters. The procedures are summarized as follows.

The relationship between residuals of reduced-form VAR (e_t) and structural shocks (ϵ_t) in equation (1.6) can be rearranged as (1.10):

$$\begin{bmatrix} e_t^p \\ e_t^q \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_t^p \\ \varepsilon_t^q \end{bmatrix} = \begin{bmatrix} s_{11}\varepsilon_t^p + s_{12}\varepsilon_t^q \\ s_{21}\varepsilon_t^p + s_{22}\varepsilon_t^q \end{bmatrix} \tag{1.10}$$

where s_{11} represents the response of the residuals of the MP instrument to its own shock and s_{21} represents the responses of residual series of the other variables to the structural MP shock. Since we are interested in understanding how variables respond to MP shocks, s_{11} and s_{21} are the only two parts of the impact matrix (S) to be identified. Next, VAR residuals e_t^p and e_t^qcan be expressed by the other reduced-form residuals and structural shocks ε_t^p or ε_t^q because those are composites of structural shocks:

$$e_t^p = \eta e_t^q + C_1 \varepsilon_t^p \tag{1.11}$$

$$e_t^q = \theta e_t^p + C_2 \varepsilon_t^q \tag{1.12}$$

where $\eta = s_{12} s_{22}^{-1}$, $\theta = s_{21} s_{11}^{-1}$, $C_1 = s_{11} - s_{12} s_{22}^{-1} s_{21}$, and $C_2 = s_{22} - s_{21} s_{11}^{-1} s_{12}$. In particular, the 2×2 matrix C_1 represents variance-covariance between two structural MP shocks, and it has the following relationship with s_{11} and s_{21}:[14]

$$\begin{bmatrix} s_{11} \\ s_{21} \end{bmatrix} = \begin{bmatrix} \left(I - s_{12} s_{22}^{-1} s_{21} s_{11}^{-1}\right)^{-1} \\ s_{21} s_{11}^{-1} \left(I - s_{12} s_{22}^{-1} s_{21} s_{11}^{-1}\right)^{-1} \end{bmatrix} C_1 \tag{1.13}$$

$$C_1 C_1' = \left(I - s_{12} s_{22}^{-1} s_{21} s_{11}^{-1}\right) s_{11} s_{11}' \left(I - s_{12} s_{22}^{-1} s_{21} s_{11}^{-1}\right)' \tag{1.14}$$

Thus, obtaining s_{11} and s_{21} requires identification of two parts: One is $s_{21} s_{11}^{-1} (= \theta)$, which can be estimated by two-stage least squares (2SLS) estimation, and the others are $s_{11} s_{11}'$ and $s_{12} s_{22}^{-1}$, which can be calculated by restrictions from the covariance matrix.

[14] C_1 can be rearranged as $C_1 = s_{11} - s_{12} s_{22}^{-1} s_{21} = \left(I - s_{12} s_{22}^{-1} s_{21} s_{11}^{-1}\right) s_{11}$ and thus $s_{11} C_1^{-1} = \left(I - s_{12} s_{22}^{-1} s_{21} s_{11}^{-1}\right)^{-1}$. Similarly, C_2 can be expressed in terms of partitions of the S matrix as the following form: $s_{21} C_1^{-1} = s_{21} s_{11}^{-1} s_{11} C_1^{-1} = s_{21} s_{11}^{-1} \left(I - s_{12} s_{22}^{-1} s_{21} s_{11}^{-1}\right)^{-1}$.

(Restriction from 2SLS estimation: $s_{21}s_{11}^{-1}(=\theta)$.)

Consider first the regression of equation (1.12). Since the reduced-form residual for MP instrument ($e_t^p(=s_{11}\varepsilon_t^p+s_{12}\varepsilon_t^q)$) is correlated with $C_2\varepsilon_t^q$, denoting it as u_t hereafter, we can obtain consistent estimates of θ of regression e^q on e^p from 2SLS, employing appropriate IVs that satisfy the following moment conditions:

$$[Z_t u_t] = 0 \quad \text{or} \quad [Z_t \varepsilon_t^q] = 0 \tag{1.15}$$

$$[Z_t e_t^p] = \pi(\pi \neq 0) \quad \text{or} \quad [Z_t \varepsilon_t^p] = \phi(\phi \neq 0) \tag{1.16}$$

(Restriction from covariance matrix: $s_{11}s_{11}^{'}$ and $s_{12}s_{22}^{-1}$.)

In addition to the restrictions derived from IV estimation, identification of s_{11} and s_{21} requires the additional restrictions from the covariance matrix. Consider the following reduced form variance-covariance and its partitioning:

$$\Sigma = E[SS'] \quad \Rightarrow \quad \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix} = \begin{bmatrix} s_{11}s_{11}^{'} + s_{12}s_{12}^{'} & s_{11}s_{21}^{'} + s_{12}s_{22}^{'} \\ s_{21}s_{11}^{'} + s_{22}s_{12}^{'} & s_{21}s_{21}^{'} + s_{22}s_{22}^{'} \end{bmatrix} \tag{1.17}$$

Then, $s_{11}s_{11}^{'}$, $s_{12}s_{22}^{-1}$ is obtained by the following closed-form solution:

$$s_{11}s_{11}^{'} = \Sigma_{11} - s_{12}s_{12}^{'} \tag{1.18}$$

$$s_{12}s_{22}^{-1} = \left(s_{12}s_{12}^{'}\theta' + (\Sigma_{21} - \theta\Sigma_{11})'\right)\left(s_{22}s_{22}^{'}\right)^{-1} \tag{1.19}$$

where $s_{12}s_{12}^{'} = (\Sigma_{21} - \theta\Sigma_{11})'\, Q^{-1}\, (\Sigma_{21} - \theta\Sigma_{11})$, $s_{22}s_{22}^{'} = \Sigma_{22} + s_{21}s_{11}^{-1}\left(s_{12}s_{12}^{'} - \Sigma_{11}\right)\left(s_{21}s_{11}^{-1}\right)^{'}$ and $Q = \Sigma_{22} - (\Sigma_{21}\theta' + \theta\Sigma_{21}) + \theta\Sigma_{11}\theta'$.[15]

These restrictions from 2SLS and VAR residual covariance allow for the identification of $C_1C_1^{'}$ and the covariance of $C_1\varepsilon_t^p$. If structural shocks to domestic MP are uncorrelated with foreign MP shocks and vice versa, C_1 is a diagonal and can be directly identified up to a sign convention from equation 1.18.[16] However, if we cannot impose zero cross-correlations between structural shocks, we must make an arbitrary assumption regarding how domestic MP shocks respond contemporaneously to unanticipated movements in foreign MP instruments, and vice versa, in order to disentangle the causal effects of shocks on both MP shocks. To the extent that the model considers two countries, the U.S. and an SOE, Cholesky decomposition of $C_1C_1^{'}$, supposing that the foreign MP shock is ordered before the domestic MP shock, permits economically meaningful results in this analysis. Finally, by plugging the identified C_1 back into equation 1.13, s_{11} and s_{21} are uniquely pinned down.

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[15]Consider first the fact that $\Sigma_{21} - \theta\Sigma_{11} = C_2s_{12}^{'}$ because $\Sigma_{21} - \theta\Sigma_{11} = s_{21}s_{11}^{'} + s_{22}s_{12}^{'} - s_{21}s_{11}^{-1}(s_{11}s_{11}^{'} + s_{12}s_{12}^{'}) = s_{22}s_{12}^{'} - s_{21}s_{11}^{-1}s_{12}s_{12}^{'} = \left(s_{22} - s_{21}s_{11}^{-1}s_{12}\right)s_{12}^{'}$.
The derivation of $s_{12}s_{22}^{-1}$ is straightforward, noticing that $s_{12}s_{22}^{'} = s_{12}s_{12}^{'}\theta' + (\Sigma_{21} - \theta\Sigma_{11})'$.
$Q = Q'$ because Q is symmetric, and it is the same as $u_tu_t^{'}$ or $C_2C_2^{'}$. Using this fact, $s_{12}s_{12}^{'}$ can be obtained by the following form: $s_{12}s_{12}^{'} = s_{12}C_2^{'}C_2^{'-1}C_2^{-1}C_2s_{12}^{'} = s_{12}C_2^{'}Q^{-1}C_2s_{12}^{'} = (\Sigma_{21} - \theta\Sigma_{11})'\, Q^{-1}\, (\Sigma_{21} - \theta\Sigma_{11})$
And from the covariance matrix, $s_{22}s_{22}^{'} = \Sigma_{22} - s_{21}s_{21}^{'}$, and it can be expressed as the above because $s_{21}s_{21}^{'} = s_{21}\left(s_{11}^{-1}s_{11}s_{11}^{'}s_{11}^{-1'}\right)s_{21}^{'} = \left(s_{21}s_{11}^{-1}\right)\left(\Sigma_{11} - s_{12}s_{12}^{'}\right)\left(s_{11}^{-1'}s_{21}^{'}\right)$.

[16]If so, a simpler identification approach, such as the one Gertler and Karadi (2015) employ, can be directly applied to identify s_{11} and s_{21}.

Data

We choose nine monthly (except for Australia, for which it is quarterly)[17] macroeconomic and financial variables in the VAR, reflecting the theoretical set-up described in Section 1.2. In particular, the VAR model comprises logs of the domestic consumer price index (P, 'price' hereafter), logs of seasonally adjusted industrial production (Y, 'output' hereafter), domestic and foreign policy interest rates (MP and MP^*), three-month, three-year, and ten-year government bond yields ($R3m$, $R3y$, and $R10y$), bank lending rates ($Lend$), and logs of the foreign exchange rate against one unit of the U.S. dollar (FX).[18] In addition, following procedures employed in prior literature, four external variables are included to isolate exogenous latent factors that may influence endogenous variables in the VAR system simultaneously: the international commodity price index, a crisis dummy, the CBOE volatility index, and the dollar index (e.g., Kim 2001 and Bjørnland 2009, among many others).

The four focal open countries represent open economies that depend heavily on foreign economies, especially the U.S., from both real economic and financial market perspectives. These countries have employed inflation targeting as an MP regime and used short-term interest rates as an MP operating instrument. Moreover, they are also commonly equipped with well-developed financial markets with sufficient trading volume to validate our use of financial asset prices to identify IVs. And, for the purpose of comparing the empirical results, we also estimate a SVAR model with U.S. data as well as a benchmark. Table 1.1 summarizes the detailed description of the data.

[17]Since Australia reports macroeconomic variables (output, price, etc.) only in the quarterly base, we employ quarterly averages of its financial data.

[18]The variables are specified in levels to implicitly determine any potential co-integrating relationship between them; see Hamilton (1994).

Instrumental variables (IVs)

Prior studies on U.S. MP use mostly high-frequency movements of Federal Fund futures rates around FOMC meetings as ideal instruments for identifying MP shocks. Other economies, however, are not yet equipped with derivative markets for MP instruments. Given this limitation, we propose various sets of alternative IVs for external instrument identification based on prior theoretical and empirical findings, including short-term spot rates, futures rates under financial instruments, and surprise in overnight rates estimated by statistical method and Taylor rule assumption. See the details in Appendix A.

IVs tested for focal SOEs and the U.S. are summarized in Table 1.2. For the U.S., we use IV data proposed by Gertler and Karadi (2015) and Gürkaynak et al (2005), and FFFR changes within a narrow (thirty-minute) window around FOMC meetings. In addition, we test some daily movements of financial instruments for comparison.

1.4 Empirical analysis results

1.4.1 IV selection

To apply external instrument identification, we first turn to the issue of instrument choice in our VAR models. we select suitable instruments in our analysis based on the following conditions:

$$rank(E[Z_t \varepsilon_t^{p\prime}]) = L \ (relevancy)$$

$$E[Z_t \varepsilon_t^q] = 0 \ (orthogonality)$$

where L is the number of endogenous variables. In particular, we use the F-statistic of the first-stage regression residual of a particular policy indicator regressed on various instrument sets to test the relevance of IVs.[19] Moreover, considering that we choose a combination of multiple IVs, we test the over-identification restriction for selected IVs with each first-stage residual series using Hausman-Sargan (hereafter, 'Sargan')[20] statistics.[21]

In estimating open-economy SVAR models for the selected SOEs, following the test results as well as those of prior studies, including Gertler and Karadi (2015), we use intraday movements of Federal fund futures rates and Eurodollar futures rates for some maturities (IV5a, IV5b, IV5d, IV5e, and IV5f) as IVs for U.S. MP shocks. In addition, as for IVs of SOEs' local MP shocks, we use movements of overnight rates (IV1), overnight-rate surprises estimated by statistical method (IV10), and Taylor rule assumption (IV11), which are found to be most suitable, in terms of relevancy and exogeneity. Those instruments are comparable to the traditional IVs (high frequency FFFR movements) for the US. IV test results for the U.S. and the focal SOEs are summarized in Appendix A.

[19]Staiger and Stock (1997) suggest that the F-statistics of the IVs should be greater than 10 to ensure that the maximum bias in the IV estimators is less than 10%. If we are willing to accept maximum bias in IV estimators of less than 20%, the threshold for the F-statistics would be 5. If the IV number is one, the F-statistics should be replaced by t-statistics.

[20]We can test for endogeneity of the IVs using Sargan statistics only if we have more IVs than potentially endogenous explanatory variables (over-identification).

[21]If the Sargan statistic, which follows the chi-squared, is significantly different from zero, then at least some of the instruments are not exogenous.

1.4.2 Results from SVAR: Impulse response functions (IRFs)

To show how the MP transmission mechanism works in the focal SOEs, we first present the IRFs of interest rates at various maturities for domestic MP innovation. Contrary to conventional theory, the increase in long-term interest rates following monetary tightening proved to be much smaller and more short-lived than those of short-term rates. We then show how the interest rates responded to U.S. MP shocks to address the other central question of this chapter: namely, how foreign MP shocks influence domestic interest rates, directly or indirectly. In response to surprise foreign MP tightening moves, interest rates at all maturities exhibit significant and persistent increases of several basis points. We also find that nominal exchange rates respond to monetary policy shocks in line with the overshooting hypothesis in this process, contrary to findings in the existing literature, which report the exchange rate puzzle or delayed overshooting (e.g., Cushman and Zha [1997]).

Effects of MP shocks on the interest rates

When a domestic MP shock occurs, market interest rate responses weaken with longer maturity, contrary to what the conventional New Keynesian framework predicts. The first column in Figure 1.1 displays the effect of a contractionary MP shock on short-term interest rates, with the shock normalized to an initial one-percentage-point increase, while the second and third columns show the corresponding effects on medium- and long-term bond yields, respectively. Clearly, short-term rates respond spontaneously to the shock, increasing one to two percentage points at a maximum. However, medium- and long-term bond yields respond much more weakly and these responses are shorter-lived than those of short-term rates. Especially in Canada, market rates do not seem to react significantly to an MP-tightening shock, even showing negative movement in the early stages of such shocks.

The above-reported empirical results indicate that domestic MP does not propagate sufficiently and quickly enough from short-term rates to medium- or long-term rates or, finally, to real sectors. To shed light on this aspect of MP, Figure 1.2 displays the responses of interest rate spreads to a contractionary MP shock of (1%). Compared with the benchmark (U.S.) case, the responses of spreads between medium- or long-term rates and short-term rates in the focal SOEs are distinctively shorter. Considering the characteristics of SOEs, the above disturbance in the MP transmission mechanism may more or less result from the influence of international monetary and financial spillovers, such as the flow of global liquidity or movements of the exchange rate caused by changes in domestic or foreign MP stances.

To infer further details of the transmission mechanism for MP shocks, We examine the effects of U.S. MP shocks on market interest rates in each focal country. In Figure 1.3, market rates show positive and persistent responses to a contractionary U.S. MP shock. Overall, two results stand out concerning our hypotheses that test international monetary transmissions. First, overnight and short-term interest rates in the focal SOEs show significantly positive responses of up to 1% to the shock in most non-U.S. countries. One possible interpretation of this result is that contractionary U.S. MP shocks lead to international synchronization of MP, or of the corresponding market expectations, which helps absorb the impact of a dramatic change in the exchange rate that applies to direct cross-border monetary transmission. This synchronization of monetary policies may be explained by the monetary coordination between the U.S. and other SOEs. As a monetary transmission from the U.S. takes place, the shock comes to reflect the policy stance of the country through which it passes.[22]

Second, we also investigate the reactions of longer-term yields to examine the indirect channel of foreign MP transmission. Medium- and long-term rates react to foreign MP shocks similarly to short-term rates; in the UK and Canada the shock has negative effects at first but the confidence intervals suggest that these initial reactions are not significantly different from zero. Combining our findings of the linkage between U.S. MP shocks and U.S. market rates and prior results in the literature, which have documented significant comovements among long-term bond yields in multiple countries (e.g., Ehrmann et al. 2011), this result may indicate that U.S. MP shocks also transmit indirectly to domestic long-term bond markets through the linkage between the U.S. and the focal SOE long-term bond markets (indirect cross-border monetary transmission).

To illustrate the characteristics of the IRFs of each MP shock, Figure 1.4 compares the influence of domestic and foreign MP shocks on market interest rates in each country. This confirms our conclusion that foreign MP shocks seem to have weaker but much more persistent effects on the focal SOEs' market interest rates.

The above-reported results contradict the findings of previous studies such as Kim (2001), who suggests that non-U.S. G-6 countries do not react strongly to U.S. MP by documenting that negative U.S. FFR innovations do not lead to a significant and substantial decrease in non-U.S. short-term interest rates. How-

[22]Many studies have discussed the potential benefits between large economies and SOEs, both theoretically and empirically. See, for instance, Frankel and Roubini (2001) or Taylor (2013).

ever, those past studies may be limited significantly in their ability to isolate exogenous U.S. MP shocks. In particular, their identified MP structural shocks depend largely on the questionable assumption of a simultaneous relationship between the variables. After identifying the shocks based on external information outside the VAR framework, we conclude that the endogenous reaction of focal SOE MP and interest rates to U.S. MP surprises is substantial and lasts longer than domestic shocks, consistently with what Faust et al. (2003), who study the U.K. and Germany cases, find.

Effects of MP shocks on the nominal foreign exchange rates

Turning now to consider the effect of MP shocks on the exchange rate, there is no evidence of a puzzle, which is consistent with the overshooting hypothesis of Dornbusch (1976). This is surprising insofar as most empirical VAR studies that have found that, following a contractionary MP shock, the exchange rate either depreciates (this is the exchange rate puzzle; see Grilli and Roubini 1995; Sims 1992), or, if it appreciates, it does so for a prolonged period of up to three years, thereby exhibiting hump-shaped behavior that violates the UIP condition (delayed overshooting; see Eichenbaum and Evans [1995] and Cushman and Zha [1997]).

In particular, as shown in the first columns of Figure 1.5, the initial appreciation of the focal SOE currencies following a contractionary monetary shock is not followed by long and persistent appreciation, as found in previous studies. Except for Australia, which shows a puzzling response (a drop) after the initial appreciation,[23] the exchange rates start to depreciate (rise) gradually after a few

[23]One possible explanation of this is that, as compared with the other focal countries, the

quarters. Note that, while the exchange rates do not depreciate immediately following the impact appreciation, the confidence intervals also suggest that there is no clear, persistent appreciation. Meanwhile, in response to U.S. MP tightening, the currencies of the focal SOEs appreciate gradually, thus depreciating the US dollar, followed by initial depreciation in line with the overshooting hypothesis (except in Korea, whose currency appreciates without initial depreciation). Such a response is quite consistent with previous IRF results regarding domestic MP shocks. In line with several studies (e.g., Bjørnland [2009], Kim and Roubini [2000], Cushman and Zha [1997]), this result suggests that the inappropriate identification of MP shocks may account for the puzzles observed in the prior literature.[24]

Effects of MP shocks on the macroeconomic variables

Finally, it is also important to verify whether output and prices react to MP shocks as expected given available theories, because we cannot say that my identified structural shocks are valid if any puzzles in their responses persist. In all countries, output and the price levels decline smoothly over a given horizon following monetary contraction, consistently with conventional theory. The output of the focal SOEs decreases by one to two percent maximum after 1-2 years, and the effect on prices is also negative and reaches a minimum after 1-1.5 years.

Australian economy as a major commodity-exporting country has become less dependent on the US while the impact of the export activity of other trading partners, such as China and the EU, has strengthened more over the period.

[24]For comparison purpose, we compare IRFs from Cholesky restrictions with ordering as [$MP*$, Y, P, FX, MP, $R3m$, $R3y$, $R10y$, $Lend$] in Figure 1.5. Contrary to the results drawn from the external instrument identification scheme, the responses of exchange rate produce puzzles under the Cholesky scheme as do previous studies.

Another notable finding is that the macroeconomic variables show a positive simultaneous response to the shock, although the response is in some cases not statistically significant. This is quite at odds with the conventional belief that MP transmission is a long and complicated mechanism and thereby has uncertain time lags for feasible effects on macroeconomic variables to manifest. We can explain this by noting that MP decisions can significantly influence market expectations regarding future economic situations. Central banks have been influencing market expectations by forward guidance since the 1990s, and in this channel MP may have an immediate effect on macroeconomic variables under the belief that central banks have better information regarding future economic situations through earlier access to data or superior economic analysis, and thus statements by central banks somehow reveal private information pertaining to future paths of economic activities and inflation. The direction that responses of macroeconomic variables to news of expectation shocks takes may be depend on which news regarding future economic situations is disseminated.[25]

The responses of focal SOE outputs to U.S. MP shocks are mixed. Korea shows a significant negative impact of contractionary shocks, while the other focal SOEs respond positively but less significantly. Meanwhile, the responses of prices to U.S. MP shocks are persistently negative with a time lag, except in Australia. This result may be explained by an import price decrease due to appreciation of the domestic exchange rate relative to the U.S. dollar and a decrease in domestic aggregate demand.

[25] If economic agents believe, for example, that an MP decision to tighten a central bank's supply of money is based on future accommodative economic activities, outputs will respond positively impact to the shock.

1.4.3 Forecast error variance decomposition (FEVD) results

How much do foreign MP shocks affect the overall variability in the process of domestic MP transmission? To shed some light on this issue, as shown in Table 1.3, we quantify the contributions of each MP shock to the variance in market interest rates on the impact for the first four years.[26]

On a short-run forecast horizon, domestic MP shocks seem to have greater influence on market interest rates than foreign MP shocks, but this relationship reverses on the longer-run horizon; the effect of domestic shocks fade quickly while that of foreign shocks decreases (or even increases in some cases) gradually. In particular, domestic MP shocks explain from 10% to 30% of the variation in focal SOE market interest rates (based on a long-run forecast horizon). Domestic shocks have greater explanatory power for short-term and bank lending rates than for medium- or long-term rates. The effect of foreign (U.S.) MP also explains a substantial portion of market interest rate movements. In particular, the contribution of foreign MP shocks to the variation in medium- and long-term rates is greater than that of domestic MP.

Of the four focal open countries, Australia displays a relatively greater share of domestic MP effects on medium- and long-term rates compared with those of foreign MP shocks. But foreign MP shocks also play a non-negligible role in explaining variations in market rates. In Canada and the U.K., the variation in short- and medium-term rates is affected mainly by foreign MP.[27] For long-term rates, foreign MP shocks are still important for explaining the variation in rates

[26]Note that only the columns related to MP shocks, i.e., the first and fourth columns of the S matrix, are identified, so we can quantify the contribution of only domestic and foreign MP shocks.

[27]These results are overall consistent with Cushman and Zha (1997), who found a weak role of domestic MP shocks and strong impacts of foreign factors.

in the U.K., but not in Canada. In Korea, U.S. MP shocks play a slightly stronger role in explaining market rates than domestic MP.

These results emphasize that the short-term rates respond systematically to domestic monetary surprises, but on the long-run horizon they react more strongly to foreign MP shocks. However, domestic monetary shocks do not play an important role in explaining the variation in longer-term bond yields in the focal SOEs, while the other factors, including U.S. MP shocks, do.

Table 1.4 exhibits FEVD results for macroeconomic variables (output, prices, and exchange rates). Consistently with the FEVD results for market interest rates, U.S. MP shocks show substantial influence on movements of the focal SOE macroeconomic variables as well. The two MP shocks, in sum, account for 5% to 20% of the forecast error regarding the output and price variables of the focal SOEs, among which the U.K. shows the greatest impact of U.S. MP shocks. Around 20% to 30% of the movement in the exchange rates of the focal SOEs is explained by the domestic and foreign MP shocks in all the countries.

1.5 Conclusion

This chapter revisits the conventional topic of MP transmission in SOEs, but focuses on how easily MP shocks propagate through financial markets and on whether such transmission is hampered by international monetary spillover. To that end, the SVAR model in this chapter explicitly tests the impact of domestic and foreign MP shocks, as proxied by U.S. MP shocks, on multiple financial variables including market interest rates at a variety of maturities, which other studies implicitly assume to be ideally strong. Furthermore, this chapter tests

MP transmission in national currency markets in light of the findings in the literature that foreign monetary shocks and exchange rates play an important role in MP transmission in open countries.

The study's empirical findings are threefold. First, responses to MP shocks of medium- and long-term interest rates in the focal SOEs are weak and sluggish, discernibly more so than estimates for the U.S., while foreign MP shocks have statistically significant and persistent impacts on domestic financial and macroeconomic variables. Second, foreign exchange rates are seen to respond significantly to MP shocks, consistently with Dornbusch's (1976) prediction. Finally, a group of external instrument variables for the identification are tested and selected, among which IVs, movements of overnight spot rates on MP decision dates, turn out to be the most suitable instrument for identification.

The empirical results indicate that market interest rates do not always react in the way that central banks intend. Other structural shocks, most likely external shocks, may lead them to diverge from domestic MP and thereby attenuate the effects of domestic MP. In our analysis, movements of domestic variables are indeed substantially influenced by foreign MP shocks. VD results, which show a non-negligible contribution of foreign MP shocks to the variation in medium- and long-term rates, also support this idea. Recalling the conundrum that occurred in the U.S. during the 1990s and 2000s, and the vulnerability of the focal SOEs' financial markets to external factors, the empirical results in this chapter may serve to warn central banks that MP implementations in the focal SOEs may be hampered by external influences.

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Tables and Figures

Table 1.1: List of variables in SVAR system

Variable	Category	U.S.	Australia	Canada	Korea	U.K.
MP^*	U.S. MP	-	Effective FFR			
Y	Output	Industrial production (Seasonally Adjusted)				
P	Price	Consumer Price Index				
MP	Overnight rate	Effective FFR	Cash rate	MMF rate	Call rate	Bank rate
$R3m$	Short-term rate	TB (3-month) rate (Korea: CD 91-days rate)				
$R3y$	Medium-term rate	TB (3-year) rate				
$R10y$	Long-term rate	TB (10-year) rate (Korea: TB 5-year rate)				
$Lend$	Lending	Overall lending rate including loan rates to households and firms				
FX	FX rate	-	FX rates per US dollar			
Control Variables		Commodity price index, Dummy variable for the period between 2008.8 ~ 2009.6, CBOE volatility index, U.S. dollar index				

Note: Sample periods are U.S. (1980~2008), Korea (1999~2013), Canada (1996~2013) Australia (1990~2013), U.K. (1997~2013).

Source: Bloomberg, IFS, CEIC database

Table 1.2: Instrumental variables

*Panel A: Short-term spot rates

Category	IV	Country	Instruments
Short-term spot rates	IV1 (overnight rates)	AU	Overnight cash rates
		CA	Overnight MMF rates
		KO	Overnight call rates
		UK	Average 4 UK bank's rates
		U.S.	Effective FFR rates
	IV2 (1-month spot rates)	AU	Bank bills rates (1-month)
		CA	Bank deposit rates (1-month)
		KO	-
		UK	TB (1-month) rates
		U.S.	Euro-dollar deposit (1-month) rates
	IV3 (3-month spot rates)	AU	Bank bills rates (3-month)
		CA	Bank deposit rates (3-month)
		KO	CD rates (3-month)
		UK	Deposit rates (3-month)
		U.S.	U.S. TB (3-month) yield
	IV4 (FX rates)	SOEs	FX rates per U.S. dollar

Notes: 1. '-' indicates that the IV is not available for a given country

2. AU: Australia; CA: Canada; KO: Korea; SOEs: the selected four small open economies

*Panel B: Futures rates and others

Category	IV	Country	Instruments
Futures rates under financial instruments	IV5 (short-term futures)	AU	Futures under 3-month rates
		CA	-
		KO	CD rates (3-month) futures
		UK	Futures under 3-month rates
		U.S.	FFFRs with maturity 1 month, and 3 months, Eurodollar futures rates with 3 months, 6 months, 9 months, 12 months
	IV6 (medium-term futures)	SOEs	Futures under 3-year TB
	IV7 (long-term futures)	SOEs	Futures under 10-year TB
	IV8 (currency futures)	SOEs	Futures under FX rates per USD
	IV9 (stock price futures)	SOEs	Futures under national stock price index
BN	IV10 (BN)	SOEs	BN-decomposed overnight rates
TR	IV11 (Taylor rule)	SOEs	Estimated Taylor-rule residual

Notes: 1. '-' indicates that the IV is not available for a given country

2. AU: Australia; CA: Canada; KO: Korea; SOEs: the selected four small open economies

Table 1.3: Contribution of domestic and U.S. MP shocks to market rate variation

(%)

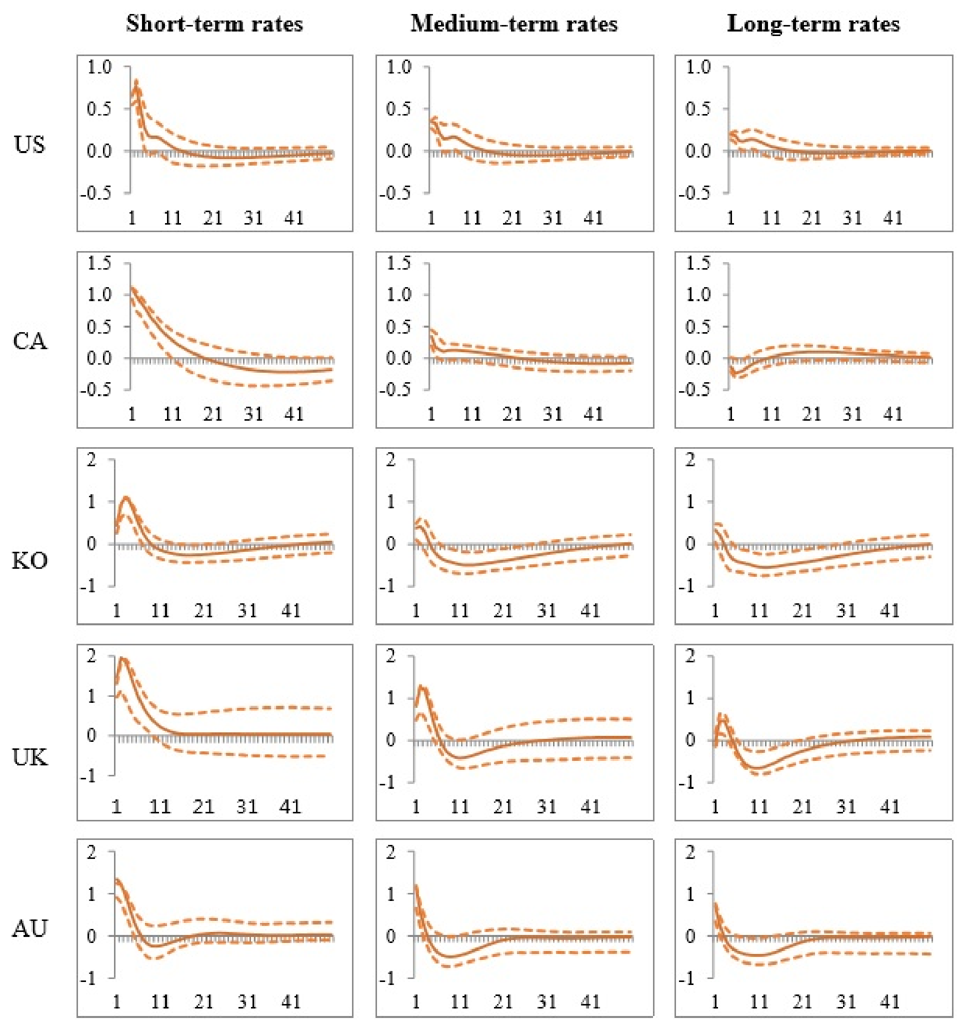
Forecast horizon	Canada		Korea		UK		Australia	
(month)	MP*	MP	MP*	MP	MP*	MP	MP*	MP
(Short-term interest rates)								
1	0.7	39.0	17.5	6.9	6.6	63.2	5.1	68.5
12	5.6	16.0	15.7	13.8	7.5	25.6	7.0	33.2
24	6.9	10.2	14.4	11.7	18.3	14.4	7.9	32.3
48	10.2	10.1	13.2	9.7	24.8	8.9	7.8	32.0
(Medium-term interest rates)								
1	0.3	2.5	14.5	1.6	0.6	10.0	2.6	29.9
12	2.6	1.6	5.5	3.0	6.8	8.8	9.9	18.0
24	3.9	1.3	7.2	5.9	19.9	6.3	11.1	18.7
48	7.0	1.9	8.3	6.0	27.0	4.4	11.1	18.7
(Long-term interest rates)								
1	1.1	0.5	11.7	1.0	4.7	0.0	0.0	19.8
12	0.6	1.1	3.7	3.5	6.7	7.8	6.2	12.0
24	0.8	1.4	5.9	6.8	13.4	9.6	7.4	13.9
48	1.0	1.6	7.3	6.9	21.6	8.0	7.4	14.0
(Bank lending rates)								
1	1.4	59.7	6.7	2.0	0.5	20.9	5.8	62.4
12	5.3	20.6	12.0	14.7	5.0	25.3	8.1	34.3
24	6.7	12.3	13.5	12.7	20.2	19.3	9.0	33.1
48	10.2	11.8	13.0	9.8	27.8	14.7	9.0	32.7

Table 1.4: Contribution of domestic and U.S. MP shocks to macroeconomic variables

(%)

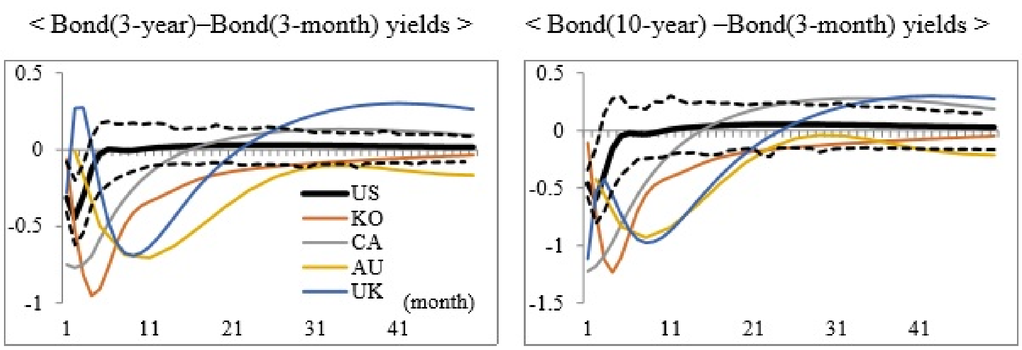
Forecast horizon	Canada		Korea		UK		Australia	
(month)	MP*	MP	MP*	MP	MP*	MP	MP*	MP
(Industrial Production)								
1	1.5	0.0	6.7	2.6	0.1	4.2	10.9	13.0
12	4.8	2.0	5.6	2.8	2.1	4.8	7.2	13.1
24	3.2	3.5	4.3	4.6	7.0	7.8	6.3	10.8
48	2.4	4.5	3.3	5.9	12.3	7.0	6.6	9.5
(Consumer price index)								
1	4.8	0.4	0.1	0.4	1.8	1.2	0.1	2.3
12	12.9	3.8	1.6	0.4	0.6	4.7	3.3	3.0
24	7.5	4.5	3.5	0.4	6.3	3.7	5.9	6.0
48	5.1	2.8	3.5	1.1	20.8	1.9	6.8	6.6
(Foreign exchange rates)								
1	7.1	1.1	2.3	1.6	10.5	14.1	0.2	4.1
12	15.3	8.0	6.5	9.6	10.5	9.2	17.6	11.9
24	16.3	12.3	7.1	11.1	9.2	9.4	17.6	12.0
48	15.4	12.7	6.4	10.4	9.5	9.3	17.6	12.0

Figure 1.1: Response of interest rates to a 1% domestic MP shock



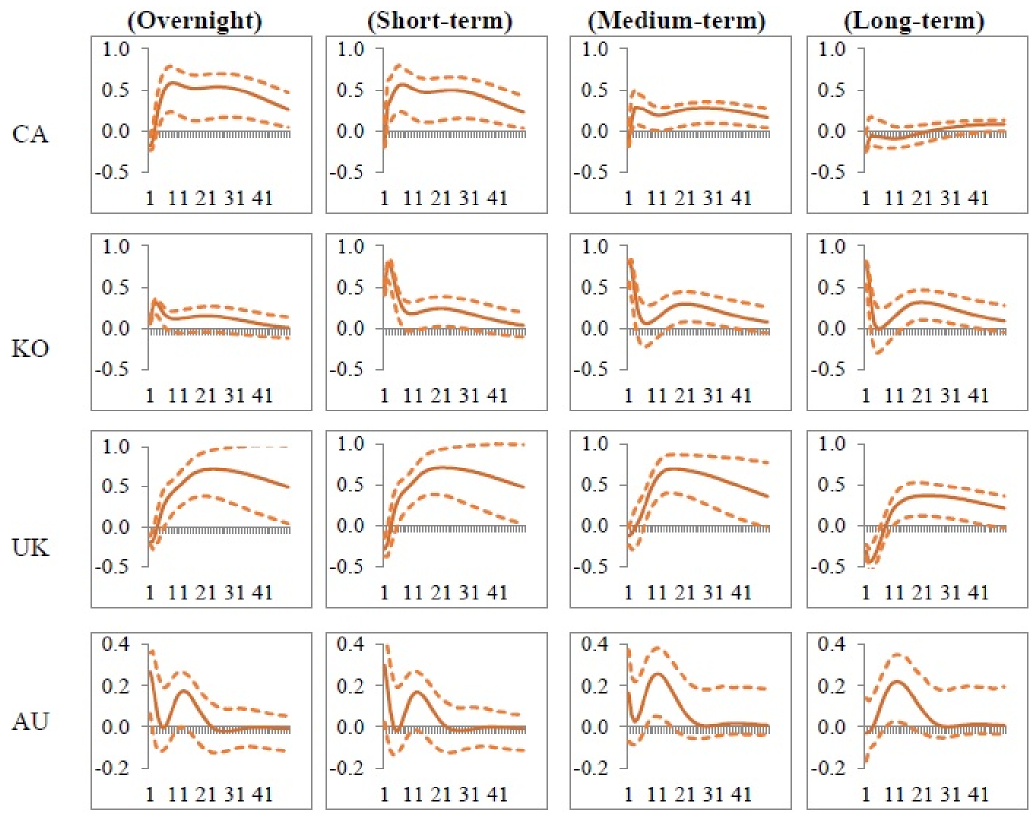
Notes:
1. The Y axis indicates %.
2. The X axis indicates month(s) for the U.S., Canada (CA), Korea (KO), and the U.K. and quarter(s) for Australia (AU).
3. Broken lines are the 16th and 84th quantiles of the empirical distribution of IRFs based on 5,000 draws.

Figure 1.2: Response of interest rates spreads to a 1% domestic MP shock



Note: Black broken lines are the 16th and 84th quantiles of the empirical distribution based on 5,000 draws for the U.S.

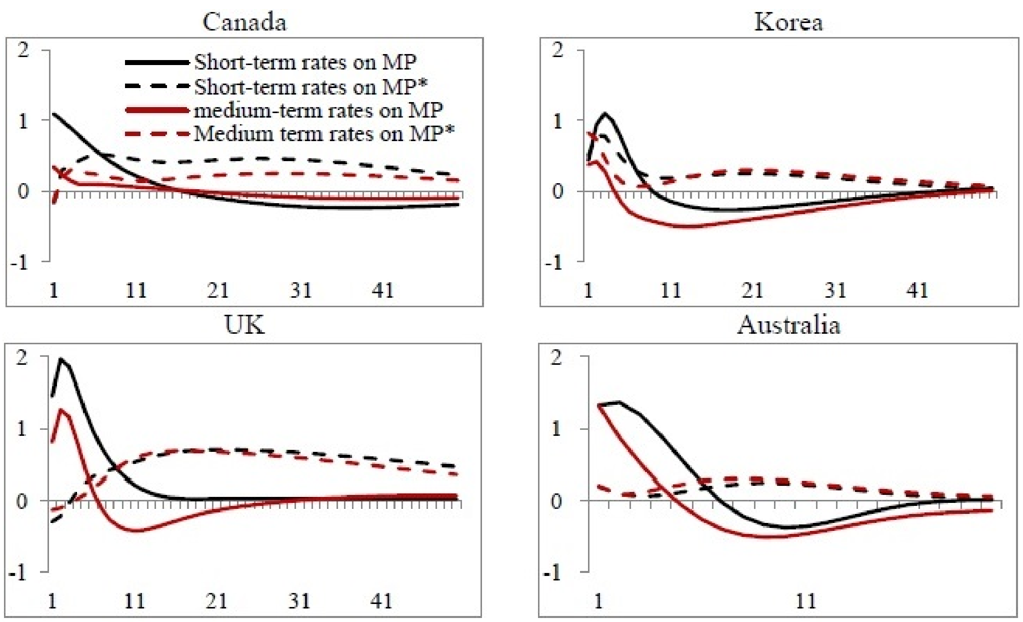
Figure 1.3: Response of SOE interest rates to a 1% U.S. MP shock



Notes:

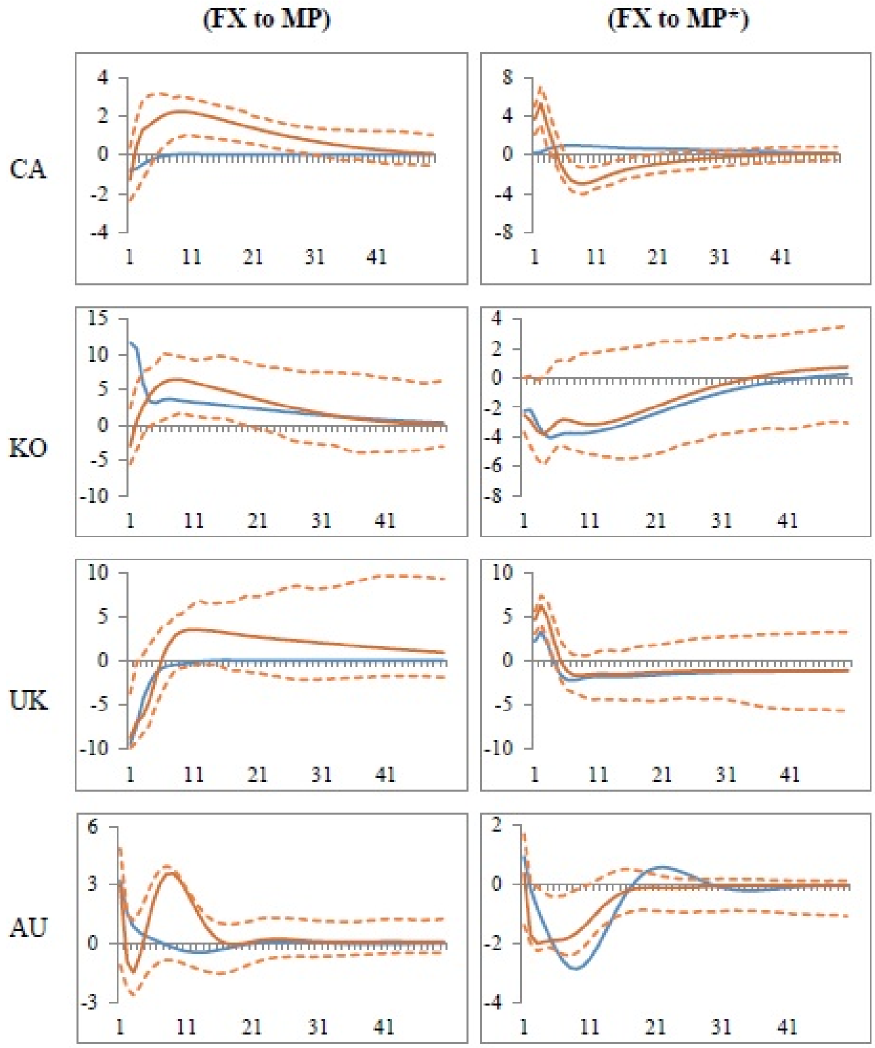
1. The Y axis indicates %.
2. The X axis indicates month(s) for the U.S., Canada (CA), Korea (KO), and the U.K. and quarter(s) for Australia (AU).
3. Broken lines are the 16th and 84th quantiles of the empirical distribution of IRFs based on 5,000 draws.

Figure 1.4: Response of domestic interest rates to 1% domestic and U.S MP shocks



Note: Y axis indicates % and X axis is month(s) for Canada, Korea, and the U.K., and quarter(s) for Australia.

Figure 1.5: Response of FX rates to a 1% domestic and U.S. MP shock



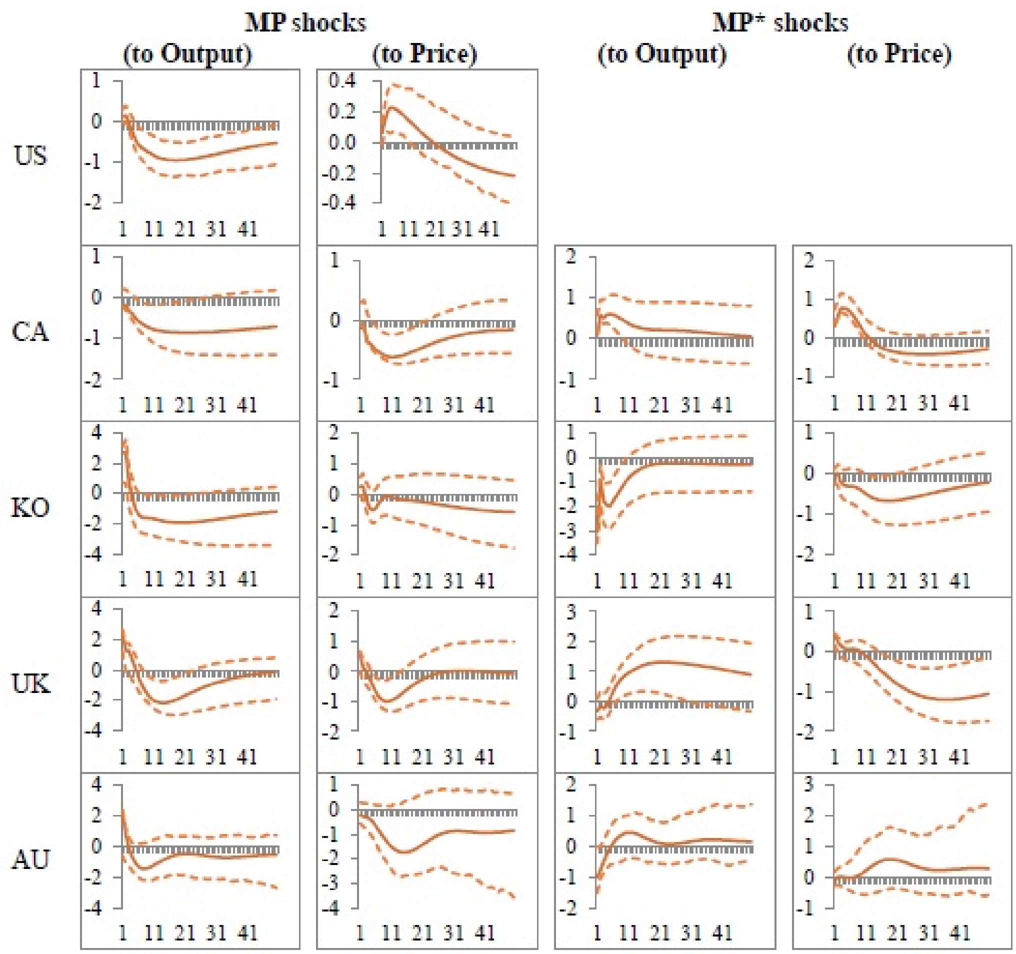
Notes: 1. The Y axis indicates %.

2. The X axis indicates month(s) for Canada (CA), Korea (KO), and the U.K. and quarter(s) for Australia (AU).

3. Broken lines are the 16th and 84th quantiles of the empirical distribution of IRFs based on 5,000 draws.

4. Orange lines indicate estimated IRFs with new identification and blue lines indicate the results with Cholesky identification.

Figure 1.6: Response of macroeconomic variables to a 1% domestic and U.S. MP Shock



Notes:

1. The Y axis indicates %.
2. The X axis indicates month(s) for the U.S., Canada (CA), Korea (KO), and the U.K. and quarter(s) for Australia (AU).
3. Broken lines are the 16th and 84th quantiles of the empirical distribution of IRFs based on 5,000 draws.

CHAPTER 2

INTERNATIONAL TRANSMISSION OF U.S. MONETARY POLICY SHOCKS IN OPEN FINANCIAL MARKETS

2.1 Introduction

Does a flexible foreign exchange rate system insulate domestic financial markets from external monetary shocks? To shed light on this issue, I investigate the international propagation of U.S. monetary policy (hereafter 'MP') shocks into financial markets in other open economies. Financial globalization has strengthened international transmission of monetary shocks in recent decades—particularly from the U.S., a primary hub of the world financial system—and this has attracted significant attention in the literature as well as in policy discussions.[1] While it is still unclear whether financial integration offers gains through growth effects or better risk sharing, the cost of integration, in particular because of monetary spillovers, appears to have grown in recent decades (Kose et al. [2009], Obstfeld [2015]). A growing concern is that external monetary shocks propagate across borders via open financial markets and inevitably complicate the transmission of domestic monetary policies in those economies.

Given these concerns, I test the economic and statistical significance of the international transmission of U.S. MP shocks, with particular focus on the following aspects:

- Through which financial asset markets does such transmission mainly op-

[1] This type of study is based on numerous studies on the international propagation of macroeconomic shocks. See, for instance, Karolyi and Stulz (2003) or Anderson et al. (2007). The latter shows evidence of the strong co-movements of international asset prices when U.S. macroeconomic news is announced.

erate?

- Are dynamic movements in asset prices consistent with classical economic theories?
- Do foreign (U.S.) or domestic MP shocks matter more in open financial markets?
- Does the international propagation of monetary shocks exhibit non-linearity?

I employ a new empirical framework and seek to contribute to the literature in the following ways. First, to fully exploit the strengths of two most commonly used empirical frameworks—the event study and the SVAR framework—I estimate open-economy SVAR models with the *external identification scheme* proposed by Mertens and Ravn (2013) and Stock and Watson (2012), instead of imposing direct arbitrary assumptions on contemporaneous interaction between variables. To clearly show the benefit of the new identification framework, I compare the impulse response results across two identification schemes: external and conventional Cholesky identification schemes. Second, I identify domestic and foreign MP shocks separately within the SVAR system, which is distinct from other earlier studies that identify either domestic or foreign shocks exclusively. I do this by exploiting high-frequency financial data sets from the U.S. and other open economies and then evaluate the influences of the two structural shocks in domestic financial markets in terms of significance, magnitude, and persistence. Third, benchmarking Anderson et al. (2007) and others, I study a broad set of open economies and multiple asset classes rather than focusing on a single asset class or a single country case. In so doing, I test their joint responses based on economic theories. Finally, I explore non-linear features of the international spillovers, by exploiting the local projection method of Jordà (2005). As in Rudebusch (1998) and others, there can be structural changes in the economic situation that require the estimation of non-linear types of impulse response functions (IRFs). Despite plentiful evidence of time-varying MP effects in U.S. financial markets, to date no study has tested this feature in an international context. To the extent that U.S. financial and credit conditions play a leading role in international financial markets, I cast doubt on the validity of the linearity assumption in estimating the structural parameters of interest.

Although the *monetary policy trilemma* predicts that external monetary shocks in flexible foreign exchange (FX) regimes are mostly absorbed by fluctuations in currency values,[2] this prediction has been debated extensively. Even when FX rates respond flexibly to foreign MP shocks in open economies, there exist other theoretical channels through which foreign shocks propagate into other types of financial markets. For example, the manipulation of U.S. policy rates may induce policy interventions in other economies. In order to avoid dramatic movements in FX rates and in macroeconomic variables, central banks are likely to enhance the correlation between domestic and foreign policy rates. U.S. MP shocks can also affect the prices of securities, e.g., sovereign bonds or equities, in open economies since subsequent capital flows following U.S. monetary announcements can lead to adjustments of risk premiums. A tighter U.S. MP, for example, may raise perceived risk, which in turn will depress capital inflows and boost risk premiums in open economies (Bruno and Shin [2015], Turner [2014]).

Empirical studies do not provide clear answers to theoretical debates on the international transmission channels of MPs. On the one hand, many earlier

[2]See, for instance, Obstfeld et al. (2005), for the trilemma.

studies have pointed out that conditional movements of FX rates exhibit puzzling deviations from theoretical predictions. With a positive domestic monetary shock, for instance, the currency either depreciates, exhibiting the so-called *foreign exchange rate puzzle* or, if it appreciates, it does so only gradually for prolonged periods of up to a few years, demonstrating *delayed overshooting*. The evidence further appears to contradict the uncovered interest parity condition, suggesting sizeable and persistent arbitrage opportunities, or the *forward premium puzzle*.[3] On the other hand, few studies explicitly examine how strongly and persistently bond yields or equity prices in open economies respond to foreign monetary shocks. Responses to the shocks, whether in policy rate changes or short-term interest rates, are critically important to the dynamic movements of domestic asset prices, yet they have received little attention in the literature.

Such limitations in the empirical literature may be closely related to the lack of a convincing identification scheme. Let us focus on the estimation of a SVAR model. Identification of monetary shocks in the SVAR system can be problematic, especially in a model with multiple financial variables because of simultaneity issues. Numerous studies using an open-economy framework have imposed arbitrary relationships on endogenous variables (e.g., Cholesky restriction). These relationships specify that some structural shocks have no spontaneous effect on one or more financial variables, and as a result the studies face difficulty in sorting out contemporaneous interactions between the endogenous variables. In addition, monetary shocks identified in such models can be quite different from each other depending on assumptions regarding the identification of such shocks. This may work as a critical limitation when we interpret em-

[3]These studies include Clarida and Gali (1994), Eichenbaum and Evans (1995), Scholl and Uhlig (2008) and many others. In contrast to these studies, more recent studies by Kim and Roubini (2000) and Bjørnland (2009) build from new identifying assumptions to overcome the empirical puzzles.

pirical results pertaining to the dynamic relationship between structural shocks and endogenous variables, e.g., impulse response functions and decomposition of forecast error variances (Rudebusch [1998], Gertler and Karadi [2015]).

Recent methodological innovations in high-frequency identification (HFI) of U.S. monetary shocks seem to have substantially resolved the empirical difficulties. Applying the event study framework, as previously implemented by Kuttner (2001) and Gürkaynak et al. (2005), new research has examined the international propagation of U.S. MP shocks. Hausman and Wongswan (2011), for instance, analyze the impact of U.S. monetary shocks on global equity markets. Ehrmann and Fratzscher (2009) and Gilchrist et al. (2014) similarly investigate their transmission into currency and sovereign bond markets, respectively, in open economies. Although these studies overcome the simultaneity issues and provide significant results pertaining to international spillovers, the results focus only on a very short-term horizon, i.e., within a day, and thus offer no insight into the dynamic movements of the variables. For this reason, more recent studies have started to combine the HFI and SVAR framework. Rogers et al. (2015) estimate a structural VAR in the U.S. and foreign interest rates and exchange rates to assess the effects of monetary policy shocks at the zero lower bound. Passary and Rey (2015) similarly analyze the effect of U.S. monetary shocks on the global financial cycle, the U.S. external finance premium, and the FX rates in the U.K. through the external instrument identification scheme.[4]

Empirical results obtained through the new identification framework pro-

[4]Although these recent studies employ empirical strategies that are similar to the strategy used in with this paper, the latter is differentiated in several respects. This chapter employs alternative external instruments in identifying U.S. MP shocks, namely the target and path factors. Refer to Section 2.4 for details on the instrument variables. Furthermore, the author exploits his own financial data set in open economies to identify MP shocks in those economies. Finally, this chapter strengthens the empirical framework by employing other methodologies, including local projection regression and even study analysis.

vide a number of meaningful insights. First, U.S. MP shocks are strongly transmitted to all types of open financial markets, and the impacts endure on both short- and medium-term horizons. Most notably, conditional movements of FX rates are consistent with predictions of the overshooting theory by Dornbusch (1976) without the puzzles found in earlier studies, e.g., the foreign exchange and delayed overshooting puzzles. These novel results are made possible because of the new identification scheme, as is evidenced by the fact that the conventional recursive scheme fails to lead us to such convincing empirical results.

Second, I find that responses of asset prices to domestic monetary shocks are significant as well, but when I compare the overall influence of the two monetary shocks, U.S. shocks clearly have stronger and more persistent impacts. Interestingly, even short-term interest rates in open economies exhibit significant responses following U.S. MP shocks with certain time lags. These results indicate that an independent monetary policy is feasible for open economies, but there are limits to what it can achieve. On the other hand, the results may also indicate that, to avoid possible monetary spillovers, central banks in open economies may sometimes enhance the correlation of policy actions, e.g., policy coordination, with advanced economies.

Finally, the results support stylized evidence pertaining to the nature of cyclical dependence or asymmetry in spillovers. The propagation of the shocks into bond markets is stronger during economic expansions with contractionary shocks than during recessions with expansionary shocks, whereas the opposite directional feature applies to stock markets. Interestingly, these observations are consistent with the responses of U.S. security prices to U.S. MP shocks. We may interpret these results as implying that credit conditions in the U.S. play a crucial role in global credit markets and thus security prices in open economies exhibit strong co-movement with U.S. asset prices when U.S. monetary announcements occur.

This chapter is organized as follows. After discussing the theoretical background to international monetary spillovers in Section 2.2, I begin my empirical analyses in Section 2.3 with the event study of the movements of international asset prices that occur following U.S. monetary policy announcements. In Section 2.4, I estimate open-economy SVAR models and observe impulse responses of the endogenous variables to U.S. and domestic monetary shocks. In Section 2.5, I test the non-linear impulse response functions through the local projection. Section 2.6 concludes.

2.2 Theoretical motivation

Under financial integration, asset prices in open economies are internationally determined. Thus, international parity conditions naturally apply to asset pricing in open financial markets and thereby suggest a variety of channels through which U.S. monetary shocks influence those asset prices. I first investigate the impact of U.S. monetary shocks on open bond markets under the framework of the uncovered interest rate parity (hereafter 'UIP') condition and then I discuss the impact on international stock markets under the uncovered equity return parity ('UEP') condition.

2.2.1 Transmission of U.S. monetary shocks under the UIP condition

Given the expectation hypothesis of the term structure, monetary policies of central banks influence domestic market interest rates by changing current and expected paths of domestic short-term interest rates, as shown by equation (2.1):

$$R_t^m = m^{-1} E_t \left[\sum_{i=0}^{m-1} R_{t+i} \right] + \xi_t^m \tag{2.1}$$

where R_t^m is an m-period zero-coupon government bond yield at time t, R_t is a short-term interest rate (e.g., a central bank policy rate), and ξ_t^m is an m-period term premium.

In integrated bond markets, however, the extent of a central bank's control over domestic market interest rates is controversial since monetary shocks from foreign countries simultaneously impact domestic bond markets. A country's manipulation of short-term rates (R_t^*), especially if it is a large open economy such as the U.S., inevitably has impacts on interest rates in other open countries following the UIP relationship shown in (2.2):

$$R_t = R_t^* + E_t \Delta (e_t) + \rho_t \tag{2.2}$$

where e_t is a nominal FX rate vis-á-vis the U.S. dollar and ρ_t is a currency risk premium in open economies at time t.

Although changes in the interest-rate differences between two countries are expected to be absorbed mainly by adjustments in FX rates,[5] market interest

[5]The overshooting theory by Dornbusch (1975), for instance, predicts that an increase in

rates in open economies may be directly influenced by U.S. MP shocks as well, depending upon the behavior of FX rates and risk premiums. First, adjustments to U.S. policy rates can induce movements in both policy and short-term rates in open economies. In order to avoid sharp exchange rate movements, their central banks are likely to enhance the correlation between domestic policy rates and the Federal Funds rates (FFR). Second, U.S. MP shocks may operate term premiums in other open economies, through the combination of domestic MP transmission and international spillovers. Equations (2.1) and (2.2) can be combined to show a linkage between international long-term rates of the form (2.3):

$$R_t^m = R_t^{*m} + m^{-1} E_t \left[\sum_{i=0}^{m-1} \left(\Delta e_{t+j} + \rho_{t+j} \right) \right] + \xi_t^m - \xi_t^{*m} \tag{2.3}$$

where R_t^{*m} and ξ_t^{*m} are an m-period zero-coupon bond yield and an m-period term premium in the U.S. at time t, respectively. The other notations are the same as those used in equation (2.1).

The equation implies that U.S. MP surprises first adjust U.S. market interest rates with a variety of maturities and then lead to the correlated movement of market rates in open economies. This holds as long as the changes in expected FX rates are slow over time and term premiums are internationally correlated. Even without monetary interventions, consequential capital flows may occur and this will affect term premiums in open bond markets. A tighter U.S. MP implementation, for example, may raise perceived risk and uncertainty, compressing capital inflows and boosting risk premiums (Turner [2014], Bruno and Shin [2015]).

domestic interest rates should cause the nominal exchange rate to appreciate sharply, and then depreciate in line with the UIP condition.

2.2.2 Transmission of U.S. monetary shocks under the UEP condition

In economies where capital flows are explained mainly by investments in equities rather than in bond or debt instruments, we may need to apply the UEP condition to the relationship between equity returns and FX rates. Following Hau and Rey (2006) and Fratzscher et al. (2009), the UEP condition can be formulated as in equation (2.4):

$$E_t(R_{t+1}) = E_t(R^*_{t+1}) + E_t\Delta(e_{t+1}) + \varepsilon_{t+1} \tag{2.4}$$

where $E_t(R_{t+1})$ and $E_t(R^*_{t+1})$ are the expected rates of return in equity indexes of an open economy and the U.S. at time $t+1$. $E_t\Delta(e_{t+1})$ denotes the expected change in a nominal FX rate vis--vis the U.S. dollar at $t+1$. ε_{t+1} is an error term that includes a variety of market risk premiums.[6]

If the UEP condition holds, any differences in expected returns from two equity markets should be compensated for by future FX rates adjustments. If a contractionary U.S. MP shock lowers equity returns in the U.S. relative to those in open economies, for instance, the lowered U.S. returns are offset by unanticipated appreciation of the U.S. dollar.[7]

[6] Although there is no precise solution that determines which variables contribute to risk premiums, earlier studies agree that short-term interest rates, inflation differentials, and country risk are among the most influential.

[7] The conditional movements of the asset returns under the UEP condition are explained as follows. If we assume that the UEP condition holds (Z=0), then changes in expected FX rates should be equivalent to expected equity return differentials at each time horizon:

$Z \equiv \Delta e - (R - R^*) = 0$

$E_t(\frac{dZ}{dMP^*}) = E_t[\frac{d\Delta e}{dMP^*} - (\frac{dR}{dMP^*} - \frac{R^*}{dMP^*})]dMP^* = 0$

$E_t(\frac{d\Delta e}{dMP^*}) = E_t(\frac{dR}{dMP^*} - \frac{R^*}{dMP^*}), (MP^* \neq 0)$

As we find when analyzing the international transmission of shocks under the UIP condition in the previous sub-section, even when FX rates are adjusted flexibly following the UEP condition, there can be several channels through which U.S. MP shocks directly influence domestic equity prices in other open economies.[8] A surprise in the FFR, for instance, may change discount rates in the two economies that are applied to the current value of expected future dividend stream. To the extent that fluctuations in the FFR positively affect global interest rates, one can predict that a higher FFR will tend to raise the discount rates in foreign countries and lower foreign equity prices. Moreover, unanticipated movements in the FFR may convey information about future economic activity in the U.S., and this can affect the activities of global firms and finally foreign equity prices. In addition, U.S. MP action may change country risk premiums. International investors always benchmark the U.S. MP stance as an important indicator of market sentiments and thus changes in market risk appetite following U.S. monetary announcements will inevitably adjust country risk premiums from time to time.

2.3 Event study analysis

In this section, I employ the event study framework as implemented by Kuttner (2001) and measure the spontaneous responses of asset prices in open economies to U.S. Federal open market committee (FOMC) announcements. This analysis is a preliminary step toward the SVAR estimation and the local projection analyses presented later in this chapter. But the empirical findings

[8]Here I simply assume, following Gorden (1959) and many others, that equity prices are decided by future dividend and market interest (discount) rates as well as some other idiosyncratic factors.

in this section are quite meaningful as well in two respects. First, to the extent that most financial variables respond almost immediately to monetary news announcements, it is useful to test their spontaneous reactions first before estimating short- and medium-term impulse response functions. Second, since I employ extensive data sets that begin in the 1990s and have multilateral financial asset prices—only a few other studies tackle such extensive data sets—the empirical findings in this section may provide interesting new insights to the existing event-study literature on international monetary transmissions.

2.3.1 Empirical framework

Equation (2.5) measures the overall transmission of U.S. MP shocks (MS_t) to daily asset returns ($R_{i,t}$) in open economies based on the 211 FOMC announcements that occurred between January 1990 and July 2014:

$$R_{i,t} = \alpha_i + \beta_i MS_t + XZ_t + \varepsilon_{i,t} \tag{2.5}$$

where $R_{i,t}$ is asset return i of open economies at time t; i = MP (overnight rates), R(3y) (medium-term bond yields), S (equity returns), or FX (FX rates); MS_t indicates a U.S. MP surprise; and Z_t is the vector of control variables at time t. β_i is the parameter of interest and it measures the strength of the transmission of the shock.

Next, I test, through equation (2.6), whether international transmission exhibits features of non-linearity. This equation is identical with (2.5) except that the coefficient on MP transmission (β_i) is separately estimated from two mutually exclusive sub-samples. That is, the dummy variable (D_t) is constructed to be one if an MP surprise falls into a category of interest, and $D_t = 0$ otherwise. The other notations for (2.6) are the same as those used in (2.5):

$$R_{i,t} = \alpha_i + \beta_i^D MS_t D_t + \beta_i^{ND} MS_t (1 - D_t) + XZ_t + \varepsilon_{i,t} \tag{2.6}$$

Two types of non-linearities are tested: cyclical dependency and asymmetry. Following Jensen et al. (1996), I first test the cyclical dependency of the spillovers by dividing the samples into two parts as determined by the U.S. business cycle, i.e., expansions and recessions.[9] This gives us 193 observations for expansions and 18 for recessions. In this case, $D_t = 1$ if an MP shock occurs during expansions, and 0 otherwise.[10] Next, I test asymmetric U.S. MP spillovers. Similarly, I divide the full sample into two parts depending on the type of shocks that occur. Following a number of earlier studies, I focus here on the direction of a shock, i.e., $D_t = 1$ if an MP shock is contractionary and 0 if it is expansionary. This provides 108 contractionary and 103 expansionary U.S. MP shocks.

2.3.2 Data

I consider four dependent variables with daily frequency in the regression—changes in overnight rates, changes in medium-term (3-year) bond yields, rate

[9]In determining the periods, I refer to NBER business cycle dates. Since January 1990 until July 2014, the expansion periods are as follows: from February 1990 to June 1990, from April 1991 to February 2001, and from December 2001 to December 2007, and from July 2009 to July 2014. The remaining periods are regarded as recessionary.

[10]To enhance the robustness of the results, I also consider international financial market turbulence and the phase of financial asset prices as state variables for cyclical dependency of the monetary transmission, as explained in Appendix B.

of returns on equity price index, and rate of returns on currency—of five focal open economies.[11,12] The focal economies are Canada (CA), Australia (AU), New Zealand (NZ), Korea (KO), and the United Kingdom (UK). U.S. asset returns are tested as well as a benchmark. The focal economies are selected in light of the following aspects. First, these economies have been regarded in the literature as representative open economies that have flexible FX rates and close economic and financial linkages with the U.S. Further, these economies have practiced inflation targeting since the 1990s using short-term rates as an MP operating instrument. This fact allows me to study monetary policy transmission in the stylized framework. Moreover, the focal economies are shared by well-developed financial markets and have sufficient trading volume to validate our use of information on financial asset prices as a method of identifying domestic monetary surprises. Meanwhile, following earlier studies, two external variables are included as dependent variables to isolate exogenous latent factors that may influence endogenous variables: the global financial crisis dummy and the CBOE volatility index (e.g., Bjørnland [2009]). Details on the variables are summarized in Table 2.1.

Next, as a proxy variable for a U.S. MP shock, following G*ü*rkaynak et al. (2005) and Gertler and Karadi (2015), I use thirty-minute-window movements of Eurodollar futures rates with a maturity of 1 year (hereafter denoted by '$ED4$'). Gertler and Karadi (2015) employ surprise components in the FFFRs and the Eurodollar Futures rates with a variety of maturities: in the current month's Federal Funds Futures ($FF1$), in the three-month-ahead monthly Federal Funds Fu-

[11]Regarding the responses of bond instruments, I additionally test the responsiveness of long-term (10-year) bond yields in these economies to strengthen the empirical results and implications.

[12]To simplify the interpretation of the results, I converted all FX rates to the local currency equivalents per one U.S. dollar, so that upward movements in the FX rates indicate the depreciation of the currency in our open economies.

tures ($FF4$), and in six-month, nine-month, and a-year-ahead futures on three-month Eurodollar deposits ($ED2$, $ED3$, $ED4$). Among of those multiple futures rates, I choose the $ED4$ rates because since U.S. economy hit the zero lower bound in 2008, there has been little variability in the movements of futures rates with shorter maturities, e.g., $FF1$ and $FF2$, and forward guidance has instead played a significant role as a monetary policy tool.[13]

2.3.3 Results

Linear spontaneous reactions

Table 2.2 displays estimated regression coefficients of the asset returns on a 1% increase in $ED4$ rates, based on equation (2.5). Broadly consistent with the theoretical predictions, currencies of the focal open economies depreciate by around 2%-5% percent while the U.S. dollar appreciates by 3%, all statistically significant at the 5% level. Equity prices decrease by 4%-10% on impact (benchmark S&P index: -8%), which can possibly be explained by higher discount rates and an adverse impact on future cash flows. Interestingly, while overnight rates do not contemporaneously respond to the shocks in all these open economies, their medium-term bond yields show apparent positive responses. The yields respond by around 0.2%-0.4% except in Korea (significant at the 1% level; U.S. benchmark: 0.5%), and long-term (10-year) yields show a similar but slightly smaller impact of around 0.3% (benchmark: 0.4%). All these estimates for the spontaneous reactions of international asset prices are in line with results re-

[13]In estimating the SVAR models in Section 2.4, however, I follow Gertler and Karadi (2015) and employ the multiple futures rates to fully capture information on market expectations and policy surprises.

ported in a number of earlier studies, especially those that have employed a high-frequency measure of MP shocks.[14]

Non-linear spontaneous reactions

U.S. monetary spillovers seem to depend on the U.S. business cycle, as shown in Table 2.3. More specifically, international transmission into medium-term bond markets in the focal open economies exhibit statistical significance only during economic expansions. This pattern becomes more apparent when we focus on the responses of long-term bond yields. These results may imply that U.S. monetary policy shocks, and in particular the forward guidance component in policy surprises, more effectively adjust the future expected path of market interest rates in the focal economies during economic expansions. On the contrary, equity prices and FX rates appear to be affected much more dramatically during economic downturns, although their impact is significant for both periods. Regression coefficients of those asset prices for recessions are two to four times greater in absolute values than those for expansions.[15]

Next, Table 2.4 displays coefficients on two directional—positive and negative—MP surprises. U.S. bond yields, with both medium- and long-term maturities, are more responsive to contractionary shocks, and yields in the focal open economies show a similar pattern. Equity prices show mixed results: expansionary shocks seem to propagate more apparently for the U.S. index as well as for those of Canada, Korea, and the U.K., while MP tightening has a

[14]See, for example, Gürkaynak et al. (2005) and Rigobon and Sack (2004) for the responses of U.S. asset returns, and Faust et al. (2007), Ehrmann and Fratscher (2009), Berge and Cao (2014), and Gilchrist et al. (2014) for results on asset prices of the focal open economies.

[15]As shown in Appendix B, when conditioning occurs instead on financial market turbulence and the phase of financial markets, the estimation results are similar to the results seen in the business cycle case.

stronger impact on Australian and New Zealand equity prices. The U.S. dollar shows significant results for both directional shocks while expansionary shocks seem to have a clearer influence over currencies of our open economies.

2.4 SVAR analysis

In this section, which provides the main portion of the empirical analyses in this chapter, I estimate open-economy SVAR models for each focal open economy. I specify the SVAR system and explain the new identification framework along with the instrumental variables for U.S. and domestic monetary shocks. I then estimate impulse response functions of endogenous variables on the structural shocks, and finally discuss the empirical results in the context of existing theoretical predictions.

2.4.1 Model specification

I assume open economy asset prices are represented by a structural form of equation (2.7):

$$AX_t = \sum_{i=1}^{p} B_i X_{t-i} + \varepsilon_t \tag{2.7}$$

where X_t is an $n \times 1$ vector of financial variables, A and $B_i(\forall i \geq 1)$ are non-singular coefficient matrices, and ε_t is an $n \times 1$ structural disturbances vector. ε_t is serially uncorrelated and $E(\varepsilon_t \varepsilon_t^{'}) = I$, identity matrix. For notational brevity, the specification in (2.7) omits deterministic terms and exogenous regressors.

By pre-multiplying the inverse of the A matrix on both sides of the equation, the reduced-form representation is obtained as (2.8):

$$X_t = \sum_{i=1}^{p} \alpha_i X_{t-i} + e_t \tag{2.8}$$

where $\alpha_i = A^{-1}B_i$, and e_t are the reduced-form residuals. The residuals are related to structural shocks, as seen in (2.9):

$$e_t = \begin{bmatrix} e_t^p \\ e_t^q \end{bmatrix} = S\varepsilon_t = [s^p \;\; s^q] \begin{bmatrix} \varepsilon_t^p \\ \varepsilon_t^q \end{bmatrix} \tag{2.9}$$

where S = A^{-1}. e_t^p denotes a vector for the residuals of domestic and foreign MP instruments (i.e., $e_t^p = \left[e_t^{MP*} \, e_t^{MP}\right]'$), e_t^q is a vector for the residuals of the other variables, and the analogous definition applies to structural shocks ε_t^p and ε_t^q. s^p and s^q denote the columns in matrix S that correspond to the impact structural policy shocks ε_t^p and ε_t^q on each element of the vector of reduced-form residuals e_t. The variance-covariance matrix of the reduced-form VAR is $\Sigma = E[e_t e_t'] = E[SS']$.

Next, the Wold representation as a function of the structural shocks is given as (2.10):

$$X_t = \sum_{j=0}^{\infty} C_j S \varepsilon_{t-j} = \sum_{j=0}^{\infty} C_j s^p \varepsilon_{t-j}^p + \sum_{j=0}^{\infty} C_j s^q \varepsilon_{t-j}^q \tag{2.10}$$

where C_j denotes the coefficients of the structural moving average (MA) form. Accordingly, if the financial variables respond to MP innovations, the impulse response functions (IRFs) of the k-th element of vector X (X_k) to a unit shock of ε_t^p at time $t + j$ is obtained by (2.11):

$$IRF_{k,j} = \frac{\partial X_{k,t+j}}{\partial \varepsilon_{k,t}^p} = C_{k,j} s^p \tag{2.11}$$

where $C_{k,j}$ is the k-th row of C_j.

Forecast error variance decomposition (FEVD) at time $t + j$ can also be calculated from the structural MA representation by (2.12):

$$FEVD_{k,j} = \frac{\operatorname{var}\left(\sum_{l=0}^{j} C_{k,l} s^p \varepsilon_{t-l}^p\right)}{\operatorname{var}\left(\sum_{l=0}^{j} C_{k,l} e_{t-l}\right)} \tag{2.12}$$

2.4.2 External instrument identification scheme

Although we can easily identify components in the B_i matrix though the OLS estimates of the reduced-form VAR system in equation (2.8), we need to apply certain identifying restrictions to disentangle components in matrix S. If the identification restrictions are assumed without correctly modeling the relationships between variables, the model may generate biased results. For the purposes of ease and convenience, short-run zero restrictions on the impact matrix are conventionally assumed, and these orthogonalize reduced-form disturbances by Cholesky decomposition. This restriction has been widely used in the monetary SVAR literature under the assumption that MP transmission is occasionally unidirectional. That is, it is assumed that MP shocks do not affect macroeconomic variables while the latter affect MP decisions for a given period, and the propagation of MP surprises into financial markets flows only in one direction, for instance from short-term to long-term bond yields. Such restrictions, however, cannot be applied in this study in which the SVAR system consists of multiple financial variables of multiple asset classes. Asset prices mutually and simultaneously interact, and even the policy shifts that influence financial variables but may also respond to them. Even if the central bank does not directly respond to financial indicators, it may respond to underlying correlated variables omitted in the SVAR system. In order to overcome these identification issues, we need to avoid imposing direct assumptions regarding the elements of the impact matrix while still successfully producing robust exogenous MP shocks.

Given these circumstances, I employ the *external instrument identification method* proposed by Mertens and Ravn (2013) and Stock and Watson (2012). The identification scheme offers attractive features for measuring the effects of structural shocks because it utilizes an information set pertaining to exogenous shocks that are identified outside the VAR system and thus it does not assume direct restrictions on relationships between variables. Gertler and Karadi (2015), who adopt this approach, show that the identification method can be extended to monetary VAR analyses by exploiting information about external MP shocks from the high-frequency identification to test whether monetary policy instruments and other macroeconomic and financial variables have simultaneous relationships. The procedures related to and details on the identification scheme are explained in Chapter 1.

2.4.3 Instrumental variables and data

Instrumental variables (IVs)

To apply the external instrument identification, I first select suitable instruments for our analysis based on the following conditions. That is, the instrumental variables should be closely related to structural monetary policy shocks while being orthogonal to other structural shocks.

$$rank(E[Z_t \varepsilon_t^p]) = L \ (relevancy)$$
$$E[Z_t \varepsilon_t^q] = 0 \ (orthogonality)$$

where L is the number of endogenous variables.

To obtain reliable instrumental variables for U.S. MP shocks, I extend and exploit the target and path factors of Gürkaynak et al. (2005). As already explained in Section 2.3, related studies employ surprises in the FFFRs and the Euro-dollar Futures rates with a variety of maturities, e.g., $FF1$, $FF4$, $ED2$, $ED3$, and $ED4$. Although I follow them and employ those instrumental variables together, to enrich the economic implications of the analysis, I further extract two principal components from movements of the multiple financial instruments and use the two factors for my instrumental variables.[16,17] Since I employ two instrumental variables for one structural shock, this is an over-identifying restriction.

[16] Regarding the estimation and economic interpretation of the two factors, refer to Gürkaynak et al. (2005).

[17] These economic factors are actively exploited even during the periods of zero lower bound. Swanson (2016), for instance, adapt the methods of Gürkaynak et al. (2005) to estimate two dimensions of monetary policy during the 2009-2015 in the U.S. The author shows that the two dimensions can be interpreted as 'forward guidance' and 'large-scale asset purchases' (LSAPs) and that those estimates correspond closely to identiable features of major FOMC announcements over that period.

To confirm the relevancy of the over-identifying instrumental variables, following Gertler and Karadi (2015), I observe the F-statistics of the two instrumental variables on the first stage residuals of the U.S. overnight rates, i.e., the FFR. The F-statistics from SVAR models for each focal economy are similarly distributed in the 7 to 9 range, supporting the validity of employing the variables in the analysis.[18]

Meanwhile, unlike the U.S., the focal open economies are not yet equipped with futures markets on MP instruments at a sufficient trading volume. I thus cannot apply the same methodology of G*ü*rkaynak et al. (2005) to the identification of domestic monetary shocks in these open economies. Given this limitation, I benchmark the empirical results of studies such as Cochrane and Piazessi (2002), Gilchrist et al. (2014), and Ha and So (2015); I exploit daily movements in short-term spot or futures rates in the economies as alternative instrumental variables.[19] That is, I define a domestic MP surprise as the daily change in the prices of financial instruments around monetary policy decision announcements of the focal open economies. As Cochrane and Piazessi (2002) explain very efficiently, if financial market participants anticipate MP decisions before the actual policy announcements are made, then the short-term rates may have already been adjusted. If on the contrary the MP announcement is a total surprise, market rates will adjust only after the announcements.

[18]Staiger and Stock (1997), for instance, suggest that the F-statistics of the instrumental variables should be greater than 10 to ensure that the maximum bias in the IV estimators is less than 10 percent. If we are willing to accept a maximum bias of less than 20 percent in the IV estimators, the threshold for the F-statistics would be 5.

[19]In identifying monetary shocks in the U.S., Cochrane and Piazessi (2002) and Gilchrist et al. (2014) suggest the use of daily movements to spot short-term interest rates in spot overnight interest rates or short-term bond yields on FOMC days. Benchmarking against them, Ha and So (2015) propose and test a variety of financial asset prices in four advanced open economies—Canada, Australia, South Korea, and the U.K.—as instrumental variables from domestic MP shocks in those economies. The test results from the latter chapter are summarized in Appendix B.

More specifically, I test and employ the following three short-term financial instrumental variables: overnight rates (IV1), Treasury bill rates with maturity of 3 months (IV2), and futures prices under short-term interest rate instruments (IV3). Relevancy test results on these proposed instrumental variables are summarized in Table 2.5. The instruments show statistical significance for the first-stage residuals. Based on these results, I choose the movements in overnight rates on the MP decision dates as the baseline instrumental variable for the domestic monetary surprise; however, in cases where the movements in overnight rates do not show a noticeable difference from changes in the target policy rates, I instead exploit the movements in short-term spot rates variable.[20] For Canada, Australia, and Korea, I employ domestic MP shocks identified from overnight rate movements (IV1), and for New Zealand and the U.K., I exploit the information obtained from short-term spot rates (IV2).[21]

Endogenous variables in the SVAR system

As dependent variables in the two-country SVAR system, I choose eight—four domestic and four foreign (U.S.)—asset prices. Considering the time differences in the focal open economies and the U.S., I follow Ehrmann et al. (2011) and others and employ two-business-day frequency data. In particular, the endogenous variables consist of policy interest rates (MP, MP*), medium-term bond yields ($R(3y)$, $R(3y)$*), and logs of composite equity index (S, S^*) of two pair economies—the U.S. and each open economy—and logs of the dollar index

[20]In the case of New Zealand and the U.K., the overnight rate movements do not usually deviate from target changes, which indicates that the series does not reflect a surprise in market expectations regarding the MP decision.

[21]As a robustness check, I also employ an alternative instrumental variable, e.g., IV3, or multiple instrumental variables, e.g., the combination of IV1 and IV2, for each economy and check the sensitivities of the results.

(DXY) and nominal FX rates vis--vis U.S. dollar (FX). In so doing, I seek to construct a structural model that embeds the theoretical background cited in Section 2.2 as well as model specifications on asset pricing from earlier studies, in which significant cross- and within-border financial market interactions are reflected. In other words, I assume in this SVAR system that asset prices in the focal open economies are explained by current and historical movements in other asset prices in domestic and U.S. financial markets as well as their own lag variables. The lag length in the SVAR system is two, following the Akaike information criterion and Schwarz information criteria. In addition, following the same reasoning as was used in the event study, two external variables are included to isolate exogenous latent factors that may influence the endogenous variables: the global financial crisis dummy and the CBOE volatility index.[22] Sources of data used for each variable are the same as those used in the event study, as shown in Table 2.1.

2.4.4 Impulse response functions (IRFs)

IRFs on U.S. monetary policy shocks

Figure 2.1 displays IRFs of open economy asset prices on a positive 1% U.S. MP shock. Let us first focus on the movements of the FX rates as a primary channel of international monetary spillovers. On impact, domestic currencies of the open economies depreciate immediately and then slowly appreciate for a few months; this observation is consistent with the prediction of the over-

[22]I here employ levels of interest rate variables and logged levels of equity price indexes and FX rates in the focal economies, to implicitly determine any potential co-integrating relationship between them, referring to Hamilton (1994).

shooting theory. No currencies show evidence of delayed overshooting or the foreign exchange rate puzzle raised by many preceding studies.[23] This finding supports recent studies that argue that these earlier empirical puzzles may be the result of making implausible identifying assumptions. Cushman and Zha (1997) and Kim and Roubini (2000), for instance, consider short-run identification schemes that differ from the Cholesky decomposition and find empirical results that overcome the puzzles. Bjørnland (2009) employs a different type of identifying restriction such that a monetary policy shock cannot have long-run effects on the level of FX rates and provide similar results.

In spite of the flexible reactions observed in FX rates, the results indicate that security prices in the open economies simultaneously and persistently respond to U.S. MP shocks as well. Equity prices spontaneously decrease around 5%-10% on the shock, and the impact lasts a few weeks. Although few earlier studies have examined the medium-term response of equity prices to MP shocks, this result is in line with recent studies such as Patelis (1997) and Gal and Gambetti (2015).[24] On the other hand, medium-term bond yields display rather heterogeneous reactions across these economies. In the case of Canada and the U.K. as well as the U.S., their Treasury bond (3-year) yields respond spontaneously to the shock and the impact gradually shrinks, while Australian yields exhibit peak impact roughly one quarter after the shock. The bond yields in New Zealand and Korea show a positive response over time as well, but with lower statistical significance. Finally, overnight rates in the focal open

[23] A number of earlier studies, including Clarida and Gali (1994), Eichenbaum and Evans (1995), and Scholl and Uhlig (2008), have documented that in response to an MP contraction, the peak appreciation of the nominal and real exchange rates occurs with sizeable lag only: that is, the IRF exhibits a hump-shape pattern, the so-called delayed exchange rate overshooting puzzle.

[24] Patelis (1997), for instance, finds that increases in the FFR have a significant negative impact on predicted U.S. stock prices in the short run, but a positive one at longer horizons.

economies gradually show a positive impact, although the contemporaneous impact is almost zero or even negative. The peak of the impulse response functions appears around three to six months after the shock with a magnitude of around 0.3%-0.6%. These estimates are comparable to findings of Bluedorn and Bowdler (2011). Their study employs U.S. MP shocks taken from Romer and Romer (2003) and shows that short-term interest rates in Canada and the U.K. respond by up to 0.5%-1% in response to a 1% increase in the FFR.

Figure 2.2 summarizes the point estimates of the IRFs in Figure 2.1, classifying them by asset classes. The figure indicates that the multilateral asset prices are quite consistent in responding to the U.S. monetary shocks in terms of magnitude and persistence. FX rates of the focal open economies in particular exhibit stylized responses. This indicates that international currencies react quite sensitively to changes in U.S. monetary conditions and to subsequent fluctuations in the value of the U.S. dollar. Equity prices in these economies also show similar reactions to each other, reflecting integrated global stock markets and strong co-movements among equity price indexes. Bond yields of the economies react rather heterogeneously to the shock, as may be explained by variations in the depth and openness of bond markets in these economies. We still find, however, that U.S. MP shocks propagate into bond markets with economic and statistical significance.

More interesting is the response of overnight rates, variables that serve as MP operating instruments in inflation-targeting open economies. Consistently with the findings in Chapter 1, even when the SVAR system explicitly separately controls the impact of local monetary policy shocks, the overnight rates in the open economies show significance response following a contractionary U.S. MP shock. A plausible interpretation of this result may be that central banks in the open economies enhance correlation of their policy actions with U.S. monetary actions, which will help absorb the impact of a dramatic change in the exchange rate or in other financial asset prices that apply to cross-border monetary transmission. One extreme view of this synchronization of policy actions may be explained by the monetary coordination between the U.S. and other open economies. As the monetary transmission from the U.S. takes place, the shock comes to reflect the policy stance of the country through which it passes.[25]

Comparing country-specific results, I find that Canada shows the most significant and strongest transmission of U.S. MP shocks into all types of financial markets. Considering Canada's close economic and financial relationship with the U.S., this result is quite natural. The responses of asset prices in the U.K. and Australia are economically and statistically significant for all types of asset classes as well, reflecting the size and depth of the financial markets in these economies. In the case of Korea, equity prices are quite responsive to U.S. monetary announcements, whereas bond yields provide less clear evidence of a significant propagation of the shocks. This result may be explained by the fact that Korea de facto opened its government bond markets only after the mid-2000s. Interestingly, New Zealand shows the most flexible reactions in FX rates while security prices in the country show a relatively weak impact in response to U.S. monetary shocks. Classical trilema theory predicts this behavior that foreign monetary shocks are substantially absorbed by fluctuations in FX rates, and as a result other domestic asset prices would show little volatility in their movements.[26]

[25]As mentioned in Chapter 1, many studies, including McKibbin and Sachs (1991) and Taylor (2013) have discussed benefits of monetary policy coordination between advanced economies.

[26]This result seems to be supported by the empirical results presented in the next sub-section. Among our open economies, domestic monetary policy shocks have a comparatively stronger

Next, for the sake of comparison, I additionally estimate the SVAR models with the same endogenous variables, but identify U.S. MP shocks using the zero short-term (Cholesky) restriction instead.[27] Figure 2.3 displays impulse responses of the asset prices to a positive 1% U.S. MP shock under the Cholesky identification. I find that the responses of overnight rates and sovereign bond yields show patterns similar to those obtained under the baseline external identification scheme, although the magnitude of responses of bond yields is much weaker in the case of the Cholesky identification. Equity prices in the U.S. and other open economies show quite puzzling results, exhibiting persistent positive reactions to contractionary U.S. monetary shocks. The most interesting result is the response of FX rates. As shown in the last column of the figure, the DXY index shows persistent appreciation with delayed overshooting on a positive U.S. MP shock; other currencies also exhibit puzzling responses that deviate from theoretical predictions. These observations clearly imply that the SVAR estimation results are quite sensitive to identification schemes. Perhaps more importantly, employing the external identification method allows us to overcome identification difficulties and enables us to resolve empirical puzzles found in earlier studies. As explained by Gertler and Karadi (2015), in the case where we have multiple financial variables as endogenous variables in the SVAR system, arbitrary assumptions regarding the interactions among endogenous variables can severely distort the empirical results.

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impact on domestic financial asset prices in New Zealand.

[27]Because the order of variables is important in the Choesky identification scheme, I test two orderings of the endogenous variables; (1) $[MP^{*}, DXY, FX, R^{*}, S^{*}, MP, R, S]$ and (2) $[MP^{*}, R^{*}, S^{*}, DXY, MP, R, S, FX]$. The first ordering assumes that the currency values of each economy respond by first following MP shocks and then security prices follow in response. The second ordering assumes that security prices fluctuate first following MP shocks and currency values respond to the changes. I find that the results across two types of orderings of the variable show results similar to each other, revealing puzzling movements of financial variables in these economies. Due to space limitations, I report IRF results only from the first case.

IRFs on domestic monetary shocks

The IRFs of the financial variables on a positive 1% domestic MP shock are displayed in Figure 2.4. On impact, both overnight rates and medium-term bond yields respond significantly in all our open economies. These results are not surprising, as they are typical results for these open economies, as described in the monetary transmission literature. Unlike responses observed after U.S. MP shocks, market interest rates show stylized positive responses of around 0.5%, and this impact continues for three to six months. Equity prices in these economies decrease 1%-4%, with the exception of the U.K. Finally, the currencies of these open economies appreciate on impact and then depreciate over a few months. We therefore do not find any evidence for either the exchange rate puzzle or for delayed overshooting for domestic MP shocks.[28]

Figure 2.5 then compares impulse response functions from two types of MP shocks—domestic and the U.S. As we have seen in country-specific results described earlier, U.S. MP shocks show a stronger and more persistent influence on each asset class in the focal economies. In the case of equity prices and FX rates, the influence of U.S. shocks seems to be quite dominant, displaying impacts two to three times greater than that of domestic monetary shocks. On medium-term bond yields, U.S. monetary shocks exhibit much stronger and more persistent impact as well in Canada, Australia, and the U.K. Even overnight rates or short-term interest rates, which are used as policy instruments in inflation-targeting countries, respond significantly to U.S. MP shocks, although their responses are

[28] Korea is an exception, showing a puzzling response, depreciating on contractionary domestic MP shocks. It is not straightforward to explain this puzzling response in the framework of this chapter. However, in open economies, especially those with high external economic dependency such as Korea, foreign exchange intervention may explain some part of the odd movements following domestic MP shocks.

rather slow over time. This result indicates that as financial and economic dependencies between the U.S. and other open economies become stronger, central banks in the open economies have stronger incentives to enhance the correlation between their target rates and the FFR in order to stabilize their economic systems.

2.4.5 Forecast error variance decomposition (FEVD) results

To what extent do domestic and U.S. MP shocks affect the overall variability in domestic asset pricing? To shed more light on this issue, I quantify the contributions of each MP shock to forecast error variances in asset prices in our open economies.[29] I divide the results based on three forecast horizons: contemporaneous, 1-year, and 3-year horizons. The results for each forecasting horizon are displayed in Table 2.6.

On impact, domestic MP shocks seem to have greater influence on domestic overnight and medium-term interest rates than U.S. shocks. On equity prices and FX rates, however, U.S. MP shocks have much greater impact. Looking at country-specific results, among the five focal open economies, Canada displays a relatively greater FEVD portion for U.S. MP shocks for all types of asset prices. Consistently with the previous IRF results, New Zealand exhibits quite a high (44%) portion of U.S. MP shocks for FX rates, but not for other asset prices. Next, short- and medium-term FEVD results are measured based on one- and three-year forecast horizons. For overnight rates and sovereign bond yields of these economies, U.S. MP shocks have significant explanatory power, account-

[29]Note that only columns of the S matrix that are related to the two structural shocks—domestic and U.S. MP shocks—are identified, so we can quantify the contribution of only the two monetary shocks.

ing for roughly 10%-15% of the total variation observed in these variables in Canada, Australia, and the U.K. This result is consistent with our previous observations based on IRFs, which indicate that sovereign bond yields of those three economies show quite a significant response to U.S. monetary shocks. For equity prices in these economies, the explanatory power of the two MP shocks is still weak in general; however, U.S. MP shocks are responsible for a greater portion than domestic shocks. For FX rates, the overall share of the two MP shocks gradually shrink, but again the U.S. MP shocks exhibit a much higher and dominant share of the variables' variability.

2.4.6 Joint dynamic movements of asset prices and international parity conditions

Given that conditional movements of FX rates following U.S. monetary policy shocks are consistent with theoretical predictions, we can further generally test the international parity conditions—the UIP and the UEP—contingent on hypothetical U.S. monetary shocks.

I start by testing the deviations from the UIP condition, or specifically the forward premium puzzle. Following Faust et al. (2003) and many others, deviations from the UIP conditional on U.S. MP shocks are measured using the information represented in the estimated IRFs of interest rates and the FX rates of a pair countries.[30] The UIP deviations for each open economy are plotted in

[30]More specifically, it takes the form: UIP deviation = IRF(R^*, h) − IRF(R, h) − [IRF(FX, h+maturity) − IRF(FX, h)], where the first argument of each IRF (R^* , R, or FX) denotes the relevant endogenous variable and the second argument (h or h+maturity) denotes the relevant IRF horizon. R and R^* indicate domestic and U.S. bond yields, respectively, and FX indicates FX rates between the two economies. *maturity* and h indicate maturity of the bonds and forecasting

Panel A of Figure 2.6. Although a sizable excess return on U.S. bonds arises following an exogenous U.S. monetary contraction, the arbitrage opportunity does not last more than one or two quarter(s). This stylized result across countries differs from those of earlier studies in terms of the persistence of the UIP deviation; Eichenbaum and Evans (1995) and Cushman and Zha (1997), for instance, show that the puzzle endures for at least a few years. During the first few months the interest rate differential between the U.S. and each focal economy shown in Panel B is positive for all cases and this differential partially explains the UIP deviations. The differentials, however, account for only 3%-6% of total UIP deviations, and generally disappear within six months. This may imply that the UIP deviations or forward premium puzzles are explained mostly by fluctuations in FX rates following monetary announcements.

Next, I test the UEP condition conditional on a positive 1% U.S. MP shock. As shown in Panel C of Figure 2.6, equity prices of the U.S. and the focal open economies simultaneously decrease but the magnitude of the negative impacts on open economies are clearly less than that on the S&P index, and thus the expected relative rates of return on equity indexes increase in these open economies. Meanwhile, as shown in Panel D of the figure, the currencies of the focal economies depreciate over time. These results are consistent with the prediction of the UEP condition, showing a negative correlation between expected equity return diffentials and expected changes in FX rates conditional on the MP shocks, as discussed in Section 2.2.

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horizon, respectively. In measuring the UIP deviation, I here employ the IRF results for 3-year bond yields. However, considering that the UIP condition is applied mainly to the relationship between short-term interest rates in multiple economies I alternatively measure the UIP deviation instead by employing 3-month yields for the open economies and the U.S. The results exhibit similar UIP deviation in terms of the pattern and persistence, although the magnitude of the deviation differs across the two bond instruments.

The results on the two types of international parity conditions presented above indicate that the puzzling response of forward premiums, which appears to be explained mostly by large fluctuations in currency values, may be closely related to the dynamic relationship between equity prices and FX rates following a common U.S. MP shock. In an effort to explain why the UIP condition has been empirically documented in the literature to fail, a recent strand of research has highlighted the importance of a recent increase in capital flows across stock markets and its impact on FX rate fluctuations, based on the concept of the UEP condition. Hau and Rey (2006), for instance, test and support the prediction of the UEP condition by estimating the correlation of daily return differentials and changes in the the FX rates for 17 OECD countries. Cappiello and De Santis (2005) similarly support the validity of the UEP assumption by providing empirical results indicating that stock return differentials are good predictors of the sign of the expected foreign exchange rates.

2.5 Local projection estimation

In this section, I estimate non-linear impulse response functions of open economy asset prices using the local projection method. As illustrated by Ramey and Zubairy (2014), the local projection method offers a simple solution to some issues that arise in computing the functions in regime-switching models. The method has other advantages as well in that it does not constrain the shape of the functions, so it is less sensitive to misspecification of SVAR models; further, it does not require that all variables be used in all equations, so one can use a comparatively parsimonious specification.[31] After briefly discussing earlier studies that have examined non-linear monetary transmission into U.S. financial markets, I specify empirical models for open economies and summarize the results. Since this study is motivated by recent empirical findings on significant non-linear monetary transmission into bond and stock markets in the U.S., I concentrate similarly here on these two security markets in the focal open economies to explore the non-linear propagation of U.S. monetary shocks.

2.5.1 Sources of non-linear monetary spillovers

A number of studies in the related literature investigate the non-linear transmission of monetary policy shocks into U.S. financial markets, and more interestingly, the studies often report that heterogeneous kinds of non-linearities are applied to distinct types of financial markets. Such a discussion originates in such seminal papers as Jensen et al. (1997), who find that reactions of stock prices to monetary shocks are significant only during expansionary policy periods, while responses of bond yields or term spreads are significant only during periods of contractionary policies. Other recent studies, e.g., Angrist et al. (2013) and Hanson and Stein (2015), provide similar evidence regarding the response of bond yields. These studies explain that the asymmetric response of bond yields is mainly the result of time-varying movements in term premiums depending on the state of the economy at the time of the shock. Regarding equity prices, recent studies (among them Boyd et al. [2005], Chen [2007] and Jansen and Tsai

[31] On the other hand, however, the method does not uniformly dominate the standard SVAR method for calculating impulse responses. Because it imposes no restrictions that link the impulse responses at h and $h+1$, the estimates are often erratic because of the loss of efficiency. Also, as the horizon increases one loses observations from the end of the sample and, at longer horizons, the impulse responses sometimes display oscillations.

[2010]) show that equity price responses to monetary shocks are much larger and more sensitive during recessions or when tight credit conditions exist, or in bear stock markets rather than in good economic times or bull markets. In the remainder of this sub-section, I discuss how theoretical studies explain the empirical findings of non-linear monetary transmission into financial markets.

As indicated by the phrase 'pushing on a string,'[32] transmission of MP shocks are known to be state-dependent, that is, generally stronger during economic expansions than during recessions. Existing studies provide evidence that the traditional interest rate channel of MP transmission is more effective during times of economic expansion. In an era of increased transparency and improved communication in policy making, in which policy stances have become more predictable to market participants, longer-term bond yields may be quite sensitive to revisions of policy paths. In this sense, as explained by Van nieuwerburgh and Veldkamp (2006), uncertainty about future policy stances as well as economic situations may play a critical role in the response of market bond yields to macroeconomic shocks. During booms, we observe more economic activity and information is provided more readily, and thus agents respond more sensitively to any shock. In contrast, with less information from lower levels of activity during recessions, economic agents may be more careful and respond more slowly to shocks.

Other studies explain that MP transmissions can instead become stronger during recessions, especially when we consider the reactions of stock markets. They focus on the credit channel of monetary transmission proposed by Bernanke and Gertler (1995). The credit channel predicts that firms should re-

[32]This is a conventional metaphor for the effect of monetary policy. It means that while a central bank can certainly slow down an economy, the bank may not be able to boost an economy during a recession.

act more dramatically to macroeconomic shocks in bad economic times than in good times. This is because of a general reduction in the availability of credit and a further adverse effect on the balance sheets of the financially constrained firms. Furthermore, an extra loan premium can be charged to compensate for the lower probability of a successful project. In this context, monetary shocks during recessions are believed to play an additional role in stabilizing financial markets and the macroeconomic situation by relaxing credit conditions or by lowering risk premiums.

Meanwhile, the literature suggests a theoretical explanation of the asymmetric MP effects, conditional on the direction of shocks. If we assume that the risk premium is a convex function of borrowers' net worth, following Bernanke and Gertler (1995) and others, we conjecture that tighter policies are generally expected to be more effective than expansionary ones. Another possible explanation for the asymmetry is associated with the markets' perception of the Fed's news announcements. Reactions of financial asset prices to policy announcements can reveal important messages on the markets' understanding of the Fed decision. A rate hike, for instance, can be viewed as increasing the likelihood of a favorable future economic situation and such actions may serve to increase asset prices; a similar scenario, however, may not occur following expansionary MP actions if market participants do not take similar views of the actions.

2.5.2 Model specification and data

The linear IRFs can be specified under the framework of the local projection method, as in equation (2.13):

$$x_{t+h} = \alpha^h + \Psi^h(L)y_{t-1} + \beta^h MP_t + \varepsilon_{t+h}, h = 0, 1, 2, ... \quad (2.13)$$

where x_t is a dependent variable and y_t is a vector of explanatory variables that include lags of endogenous variables in the SVAR estimation as well as the external control variables at time t. $\Psi^h(L)$ is a polynomial in the lag operator, and MP_t is the identified monetary policy shock at time t. The coefficient β^h gives the response of x at time $t+h$ to the shock at time t. Thus, we construct the IRFs as a sequence of the β^hs estimated in a series of single regressions for each horizon.

Then, local projection is adopted to estimate a non-linear—state-dependent or asymmetric—model. I estimate a set of regressions for each horizon h as (2.14):

$$x_{t+h} = \alpha^h + \Psi^h(L)y_{t-1} + D_t[\beta^{A,h} MP_t] + (1 - D_t)[\beta^{B,h} shock_t] + \varepsilon_{t+h}, h = 0, 1, 2, ... \quad (2.14)$$

where D_t is a dummy variable that indicates the state of the economy or the type of involved shock.

Here I allow the coefficient on MP shocks (β^h) to vary over time, by allowing the forecast of x_{t+h} to differ according to the state variables when shocks occur or the shocks' characteristics. Following Ramey and Zubairy (2014), I use the Newey-West correction for standard errors (Newey and West [1987]) to account for possible serial correlations in error terms. I test the same type of state-dependency or the asymmetry of the monetary spillovers against those used for the event study in Section 2.3.[33] That is, for the test of state-dependency

[33] Please refer to Section 2.3.1 in pp. 57 for the definitions.

in the propagation, I divide the sample into two periods depending on the U.S. business cycle, but to strengthen the empirical results I also report here the results when I use financial market turbulence as the state variable. To test the asymmetry, I divide the MP shocks into positive (contractionary) and negative (expansionary) shocks.

Finally, the data sets for each financial variable in this analysis are the same as those used for the SVAR estimation in the previous section. As proxy variables for U.S. MP shocks, I employ the $ED4$ movements as a benchmark and use the target and path factors to check the sensitivities of the results.

2.5.3 Estimation results

Figure 2.7 displays the impulse response functions of bond yields and equity prices of our open economies conditional on two phases of the U.S. business cycle. Both of two security prices provide evidence of the cyclical dependence of the spillovers, but they exhibit patterns of cyclical dependency that are diametrically opposed to one another. More specifically, sovereign bond yields in the second columns show statistically significant results only during expansionary periods. Meanwhile, equity prices in the last column show mixed results: the U.S., Canada, and Korea show greater sensitivity and persistence during economic downturns, while the prices of the other economies reveal no critical differences. These results should, however, be interpreted with caution given that the sample period covers only a small number of observations of recessionary periods.[34] Figure 2.8 describes the impulse response functions based on financial turbulence as an alternative state variable in the test of cyclical-

[34]The number of observations for the U.S. MP announcements during recessions is 18.

dependency of the spillovers. Medium-term bond yields in the U.S., Canada, and the U.K. are quite responsive during normal times, but not during turbulent periods. Other economies do not show significant results with either sample. On the other hand, equity prices in the economies show faster responses, having greater magnitude during turbulent periods while responding more persistently during normal periods.

Next, Figure 2.9 displays asymmetric IRFs on two directional—positive and negative—MP shocks. Sovereign bond yields of the focal economies show significantly persistent results only with contractionary shocks. The peak of the response functions occurs around six months to a year after the shock with a magnitude of around 3%-4%. Equity prices also show asymmetric responses, but again in a direction opposed to the direction of bond yields. The response of the S&P 500 index is stronger and more persistent with negative shocks; the focal open economies' equity prices also show a similar boost following expansionary shocks.

Because the business cycle is an important factor that can explain the nonlinear transmission of the shocks, I further control for the business cycle and test for any difference in effectiveness between the two directional MP shocks. Separate results for each pace of the business cycle are displayed in Figure 2.10. As shown in the second and third columns of the figure, expansionary shocks do not seem to propagate into our open economy bond markets; in fact, only contractionary shocks have a significant impact during expansions. On equity prices, as shown in the last two columns in the figure, expansionary shocks appear to propagate more clearly. Expansionary shocks have greater impact on the variables not only during expansions but also during recessions, although the persistence of the response functions is weaker during recessions.

In sum, empirical results reported above confirm the state-dependent and asymmetric features of international monetary spillovers. Moreover, non-linearity is heterogeneous across two classes of securities.

Considering the theoretical background of the non-linear monetary spillovers described in Section 2.5.1, my empirical results not only strengthen the earlier findings on the U.S. financial markets, but also provide new evidence on the characteristics of international monetary spillovers. The international transmission of U.S. monetary shocks seems to share features with domestic transmissions seen in U.S. financial markets. Fed announcements seem to generate common changes in risk premiums in international financial markets. This channel of international risk-premium transmission may operate through common patterns in capital flows following news announced to the closely linked international financial markets, or sometimes even without fundamental linkages through the irrational herding behaviors of international investors. We may conjecture that, when U.S. monetary stances are announced, the traditional interest rate channel of MP transmission may work in the integrated bond markets of other open economies, with the impacts being clearer and stronger during economic expansions or on contractionary MP shocks. Similarly, given similar credit conditions across global economies, we may expect that U.S. MP announcements will change the risk appetite in worldwide credit markets, and do so more effectively during recessions. This will in turn relax the risk-avoiding behaviors and thereby increase the willingness to invest in risky assets during recessions.

2.6 Conclusion

Financial globalization complicates the implementation of monetary policies in open economies. Even for countries with flexible foreign exchange regimes, foreign monetary shocks are propagated through a variety of domestic financial markets. Thus, without a thorough understanding of the nature of monetary spillovers, open economies cannot successfully achieve macroeconomic and financial stability. This motivates my paper: I estimate open-economy SVAR models for focal open economies and observe impulse responses of multiple financial asset prices in the focal economies, following U.S. and domestic monetary shocks. To avoid simultaneity issues, the structural monetary shocks are identified with external instruments of high-frequency data sets for each economy.

The empirical results of this chapter can be summarized as follows. First, U.S. MP shocks are simultaneously transmitted into the focal financial markets and the impacts persist over short- and medium-term horizons. While FX rates of the focal economies respond flexibly to monetary shocks, as predicted by classical overshooting theory, other types of asset prices apparently respond to the shocks as well, to a statistically significant level. Meanwhile, this chapter also confirms significant transmission of domestic monetary policy shocks, but U.S. MP shocks have much stronger and more persistent influences over domestic financial markets. Finally, the empirical results provide stylized evidence of the non-linear features of the spillovers. As is consistent with the U.S. benchmark case, sovereign bond yields and equity prices in our open economies show distinct pattern of state-dependency or asymmetry in the spillovers. Returning to the question of the monetary autonomy of open economies, this study shows that independent monetary policy is feasible for financially open economies, but is highly limited in what it can achieve. When a domestic monetary policy stance deviates from that of the U.S., the results imply that domestic policy effects can be distorted substantially. This requires more careful policy decisions as well as new stabilizing policy tools from monetary authorities in open economies.

This chapter has taken several important steps to explore the linear and non-linear features of international spillovers. In a follow-up study, I plan to investigate these further in the following ways. First, I will examine whether other types of U.S. monetary announcements, e.g., target changes or forward guidance, have different consequences in open financial markets. Furthermore, decomposing domestic monetary shocks in open economies into similar types of news shocks, I also plan to test whether forward guidance prevails in monetary policy shocks in open economies. Second, I plan to enhance the robustness of my results on non-linear transmission by employing other recent methodologies such as Radial basis function analysis. Although the local projection methods provide a variety of meaningful insights, by employing the new method as a supplement to the current framework, I expect to obtain more consistent results across linear and non-linear model specifications.

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Tables and Figures

Table 2.1: List of variables

Denotation	Category	Data
MP^*	U.S. MP instrument	Effective FFR
MP	open economy MP instrument	Overnight rates
$R(3y)^*$ or $R(10y)^*$	U.S. bond yields	3-year (10-year) Treasury Bond yields
$R(3y)$ or $R(10y)^*$	open economy bond yields	3-year (10-year) Government Bond yields
S^*	U.S. equity price	S&P 500 index
S	open economy equity price	National stock price index
DXY	U.S. Dollar	Dollar (DXY) index
FX	open economy FX rates	Nominal FX rates vis-á-vis U.S. dollar
Z	control variables	Dummy variable for the period from September 2008-June 2009, CBOE volatility index

Note: Sample periods are U.S., Canada, and Australia (Feb. 1991 - June 2014), Korea (Jan. 1999 - June 2014), New Zealand (Mar. 1999 - June 2014), U.K. (Feb. 1992 - June 2014).

Source: Bloomberg, IFS, CEIC database

Table 2.2: Linear regression coefficients of asset returns on U.S. MP shocks

MP	R(3y)	R(10y)	S	FX	MP	R(3y)	R(10y)	S	FX
		[US]					[CA]		
0.73***	0.47***	0.38***	-8.14***	3.29***	-0.03	0.43***	0.26***	-6.14***	2.90***
(0.26)	(0.08)	(0.08)	(1.41)	(0.72)	(0.12)	(0.08)	(0.06)	(1.31)	(0.70)
		[AU]					[NZ]		
-0.07	0.30***	0.23***	-5.27***	5.38***	0.28	0.22***	0.11***	-4.23***	5.26***
(0.09)	(0.09)	(0.09)	(1.51)	(1.08)	(0.19)	(0.07)	(0.07)	(1.17)	(1.07)
		[KO]					[UK]		
-0.14	0.20	0.15	-9.98***	4.60***	0.15	0.36***	0.29***	-5.15***	2.08***
(0.10)	(0.11)	(0.11)	(2.70)	(1.28)	(0.16)	(0.08)	(0.08)	(1.34)	(0.79)

Notes: 1. Regression coefficients (β_i) of the OLS: $R_{i,t} = \alpha_i + \beta_i MS_t + XZ_t + \varepsilon_{i,t}$.
2. In the U.S. case, the notations are instead MP*, R(3y)*, R(10y)*, S*, DXY.
3. Numbers in parentheses are standard errors. *** and ** indicate significance at 1% and 5% percent levels, respectively.
4. A positive coefficient for FX rates indicates depreciation of open economy currencies.
5. The number of observations for each regression is 211.

Table 2.3: State-dependent coefficients of asset returns on U.S. MP shocks

coefficients	MP	R(3y)	R(10y)	S	FX	MP	R(3y)	R(10y)	S	FX
			[US]					[CA]		
expansion	0.47	0.49***	0.37***	-6.63***	2.27***	-0.04	0.42***	0.27***	-4.13***	1.54***
(β_i^D)	(0.29)	(0.09)	(0.09)	(1.57)	(0.89)	(0.14)	(0.09)	(0.08)	(1.44)	(0.77)
recession	1.68	0.39***	0.43***	-13.5***	6.89***	0.02	0.46***	0.22***	-13.2***	7.70***
(β_i^{ND})	(0.53)	(0.16)	(0.17)	(2.90)	(1.47)	(0.26)	(0.17)	(0.15)	(2.67)	(1.41)
			[AU]					[NZ]		
expansion	-0.06	0.31***	0.22***	-5.38***	3.50***	0.21	0.29***	0.20***	-3.60***	3.12***
(β_i^D)	(0.10)	(0.10)	(0.10)	(1.75)	(1.19)	(0.23)	(0.09)	(0.09)	(1.34)	(1.17)
recession	-0.11	0.24	0.27	-4.96***	11.9***	0.42	-0.01	-0.18	-6.29***	12.8***
(β_i^{ND})	(0.19)	(0.20)	(0.19)	(2.91)	(2.19)	(0.31)	(0.16)	(0.15)	(2.37)	(2.16)
			[KO]					[UK]		
expansion	-0.17	0.29***	0.26***	-7.96***	2.43***	0.11	0.34***	0.28***	-5.10***	1.29
(β_i^D)	(0.12)	(0.13)	(0.13)	(3.22)	(1.50)	(0.06)	(0.09)	(0.09)	(1.51)	(0.88)
recession	-0.09	0.02	-0.01	-14.5***	9.63***	0.27**	0.44**	0.30	-5.31**	4.86***
(β_i^{ND})	(0.18)	(0.18)	(0.17)	(4.86)	(2.26)	(0.13)	(0.16)	(0.17)	(2.78)	(1.63)

Notes: 1. Regression coefficients(β_i^D and β_i^{ND}) of the OLS: $R_{i,t} = \alpha_i + \beta_i^D MS_t D_t + \beta_i^{ND} MS_t(1 - D_t) + XZ_t + \varepsilon_{i,t}$.
2. MS_t indicates shocks measured by movements in $ED4$ rates. D_t indicates dummy variables of interest, i.e., $D_t = 1$ when the U.S. business cycle is expansionary and $D_t = 0$ otherwise.
3. In the U.S. case, the notations are instead MP^*, $R(3y)^*$, $R(10y)^*$, S^*, DXY.
4. Numbers in parentheses are standard errors. *** and ** indicate significance at 1% and 5% levels, respectively.
5. A positive coefficient for FX rates indicates depreciation of open economy currencies.
6. The number of observations for each regression is 211 with 193 observations of expansions and 18 of recessions.

Table 2.4: Asymmetric coefficients of asset returns on U.S. MP shocks

coefficients	MP	R(3y)	R(10y)	S	FX	MP	R(3y)	R(10y)	S	FX
			[US]					[CA]		
contractionary (β_i^D)	-0.03	0.74***	0.55***	-5.72	3.41**	0.07	0.80***	0.56***	-5.55	3.19
	(0.59)	(0.18)	(0.19)	(3.29)	(1.69)	(0.29)	(0.19)	(0.17)	(3.06)	(1.64)
expansionary (β_i^{ND})	1.05***	0.35***	0.32***	-9.17***	3.24***	-0.07	0.27***	0.13	-6.39***	2.79***
	(0.34)	(0.10)	(0.11)	(1.89)	(0.96)	(0.17)	(0.11)	(0.09)	(1.75)	(0.94)
			[AU]					[NZ]		
contractionary (β_i^D)	-0.04	0.57***	0.42**	-8.51***	4.58	0.77	0.50***	0.53***	-7.28***	4.86
	(0.22)	(0.22)	(0.21)	(3.32)	(2.53)	(0.42)	(0.17)	(0.17)	(2.65)	(2.51)
expansionary (β_i^{ND})	-0.09	0.18	0.15	-3.69	5.72***	0.04	0.10	-0.06	-2.85	5.42***
	(0.13)	(0.13)	(0.12)	(2.09)	(1.45)	(0.26)	(0.10)	(0.09)	(1.60)	(1.44)
			[KO]					[UK]		
contractionary (β_i^D)	-0.02	0.25	0.10	-6.75	3.05	0.29**	0.19	0.44**	5.10	3.27
	(0.16)	(0.17)	(0.17)	(4.50)	(2.14)	(0.14)	(0.19)	(0.19)	(3.17)	(1.89)
expansionary (β_i^{ND})	-0.21	0.16	0.19	-11.7***	5.44***	0.09	0.43***	0.20	-4.80**	1.44
	(0.12)	(0.13)	(0.14)	(3.34)	(1.59)	(0.99)	(0.11)	(0.11)	(1.82)	(1.09)

Notes: 1. Regression coefficients of the OLS: $R_{i,t} = \alpha_i + \beta_i^D MS_t D_t + \beta_i^{ND} MS_t(1 - D_t) + XZ_t + \varepsilon_{i,t}$.
2. MS_t indicates the shocks measured by movements in $ED4$ rates. D_t indicates dummy variables of interest, i.e., $D_t = 1$ when the MP shock is positive and 0 otherwise.
3. In the U.S. case, the notations instead are MP^*, $R(3y)^*$, $R(10y)^*$, S^*, DXY.
4. Numbers in parentheses are standard errors. *** and ** indicate significance at 1% and 5% level, respectively.
5. A positive coefficient for FX rates indicates depreciation of open economy currencies.
6. The number of observations for each regression is 211 with 109 observations of contractionary shocks and 102 of expansionary shocks.

Table 2.5: Explanatory power of instrumental variables for domestic MP shocks

Instrumental variables	CA	AU	NZ	KO	UK
IV1	52.6***	54.3***	35.1***	28.2***	19.9***
(Spot overnight rates)	[0.60]	[0.62]	[0.40]	[0.30]	[0.18]
IV2	12.5***	7.86***	5.62***	16.2***	10.9***
(Spot short-term interest rates)	[0.08]	[0.03]	[0.02]	[0.12]	[0.06]
IV3	4.74***	-7.62***	-9.95***	-	-13.1**
(Futures rates on short-term interest rates)	[0.01]	[0.03]	[0.05]		[0.09]

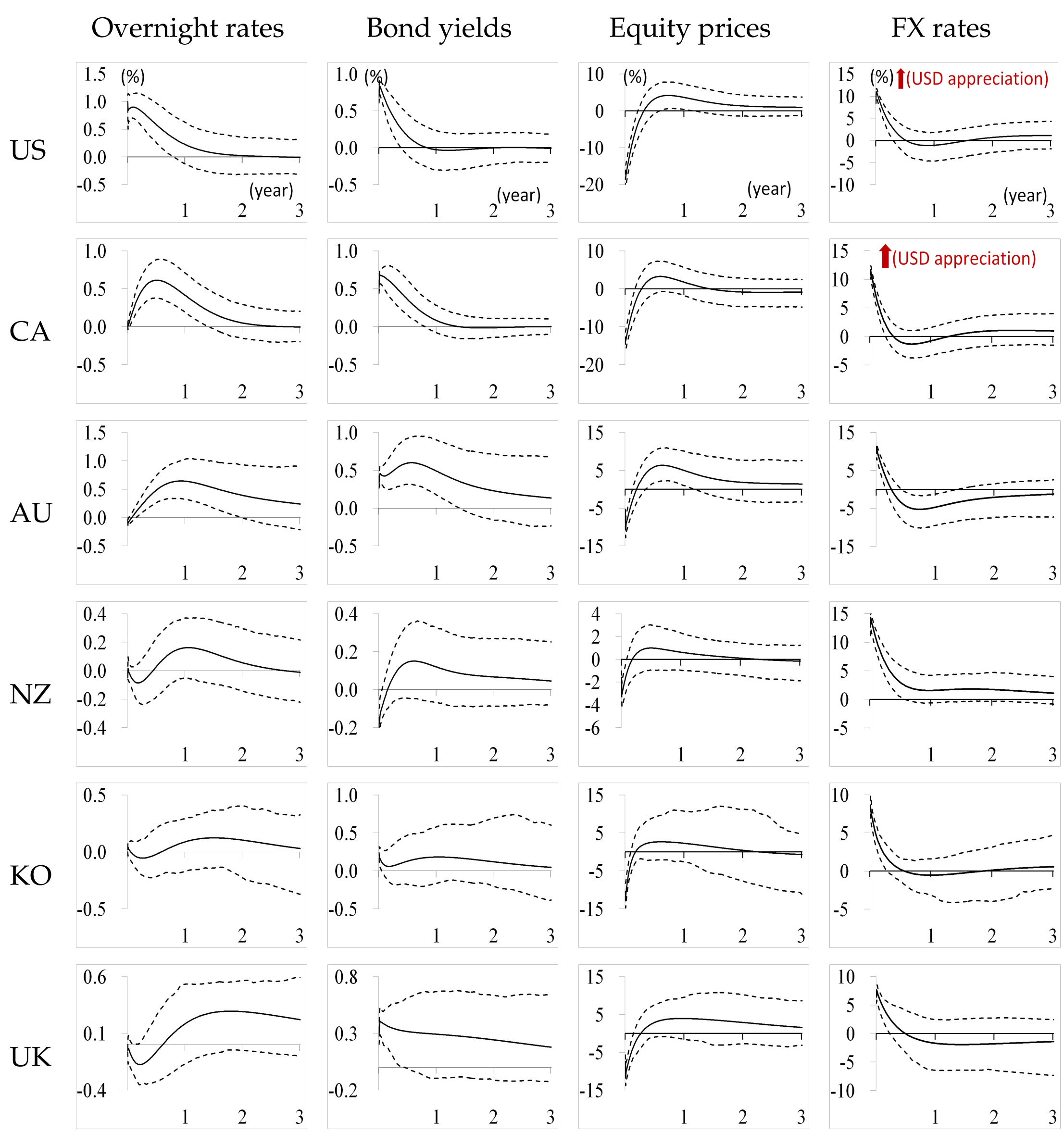
Notes: 1. The table reports t-values and R^2 in the brackets for each IV from the first-stage regression between the residual series of domestic MP instruments and each IV.
2. - indicates that a selected IV is not available for a given country.
3. *** and ** indicate significance at the 1% and 5% levels, respectively.

Table 2.6: Forecast error variance decomposition results

country	CA		AU		NZ		KO		UK	
MP shocks	MP*	MP	MP*	MP	MP*	MP	MP*	MP	MP*	MP
contemporaneous forecast horizon										
MP	0.1	83.7	0.3	87.6	0.1	69.9	0.1	97.9	0.1	79.7
R	11.4	10.2	3.1	6.5	1.9	14.5	0.0	8.7	3.0	16.4
S	14.4	0.1	4.0	0.0	1.1	3.7	3.0	0.0	4.3	2.2
FX	42.3	2.5	15.5	3.3	44.2	2.1	7.6	0.1	12.6	2.9
1-year forecast horizon										
MP	22.8	49.3	12.0	25.7	0.5	63.8	1.7	37.6	5.0	41.2
R	23.0	5.8	15.3	0.6	1.7	3.1	1.4	0.6	10.7	13.9
S	4.5	2.2	7.8	0.5	1.3	3.4	1.2	0.3	3.5	0.8
FX	12.3	1.3	8.9	0.3	26.6	1.1	5.0	2.7	3.8	6.7
3-year forecast horizon										
MP	15.9	24.9	15.9	7.5	1.5	36.1	2.5	28.7	8.8	26.7
R	18.0	5.3	15.1	0.5	2.9	2.7	1.6	0.6	11.5	11.6
S	3.4	1.9	7.9	1.2	1.3	5.8	1.1	0.4	3.3	1.9
FX	5.5	2.2	8.9	0.3	18.5	1.5	3.6	2.7	5.0	7.5

Notes: 1. This table displays FEVD shares of the two monetary policy shocks (MP* and MP) for domestic asset prices on each forecasting horizon.
2. The numbers in the table are percentages.

Figure 2.1: IRFs on a 1% U.S. MP shock: External instrument identification



Note: Broken lines indicate 90% confidence intervals through 5,000 draws from bootstrap samples.

Figure 2.2: Point estimates of IRFs on a positive 1% U.S. MP shock

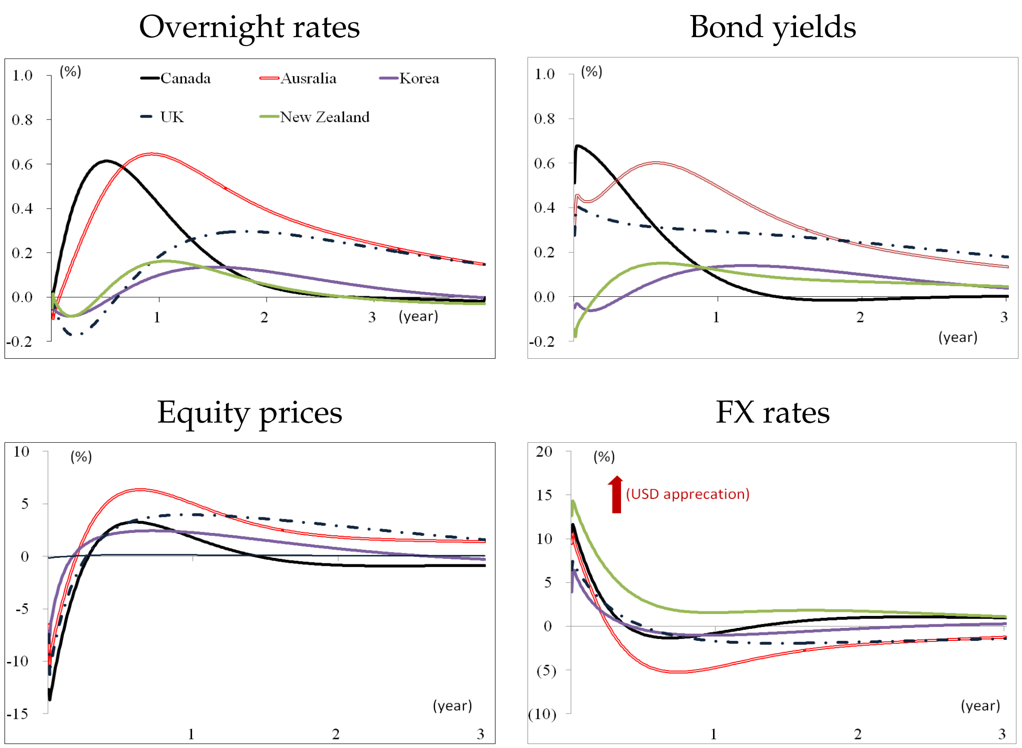
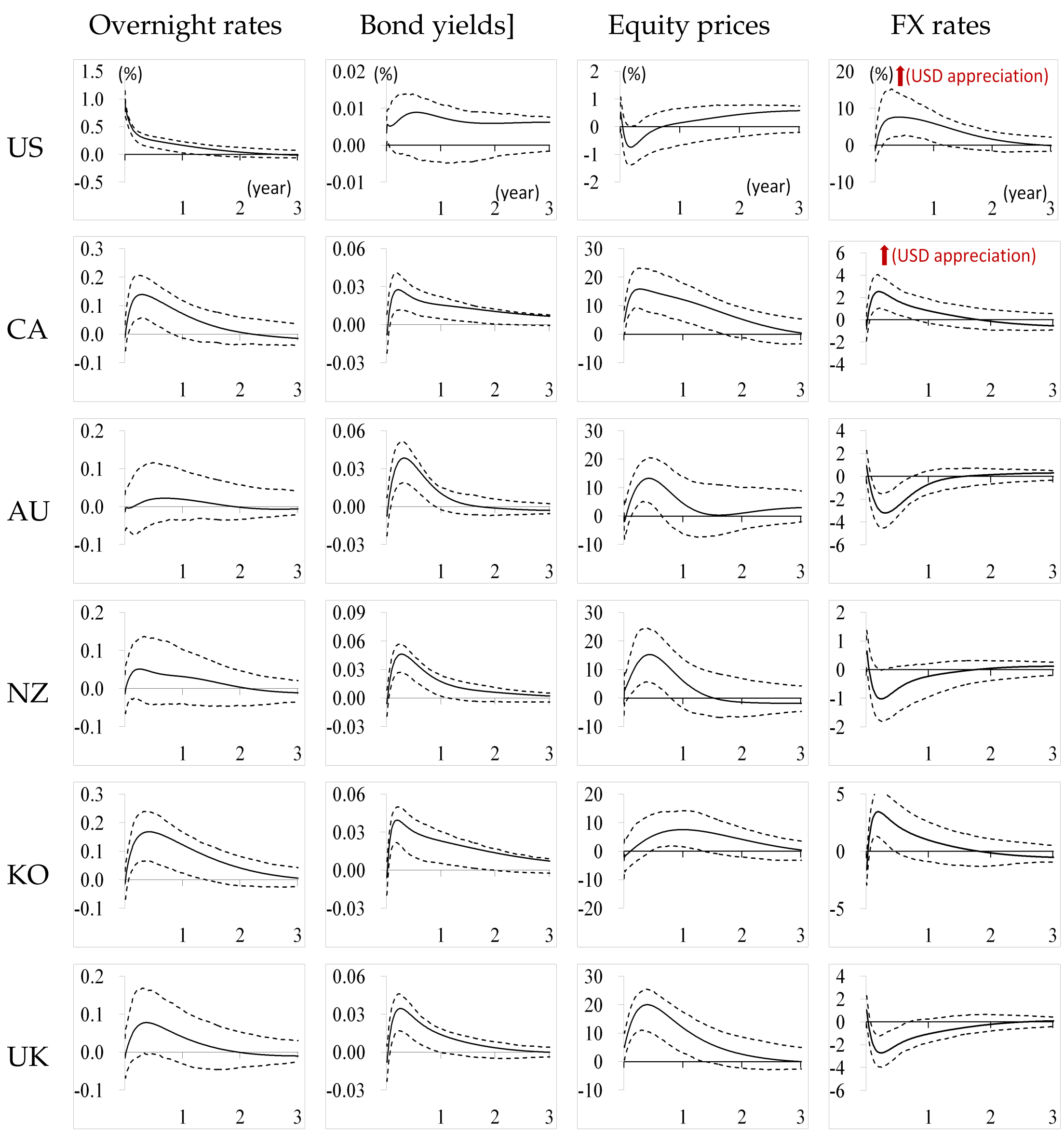
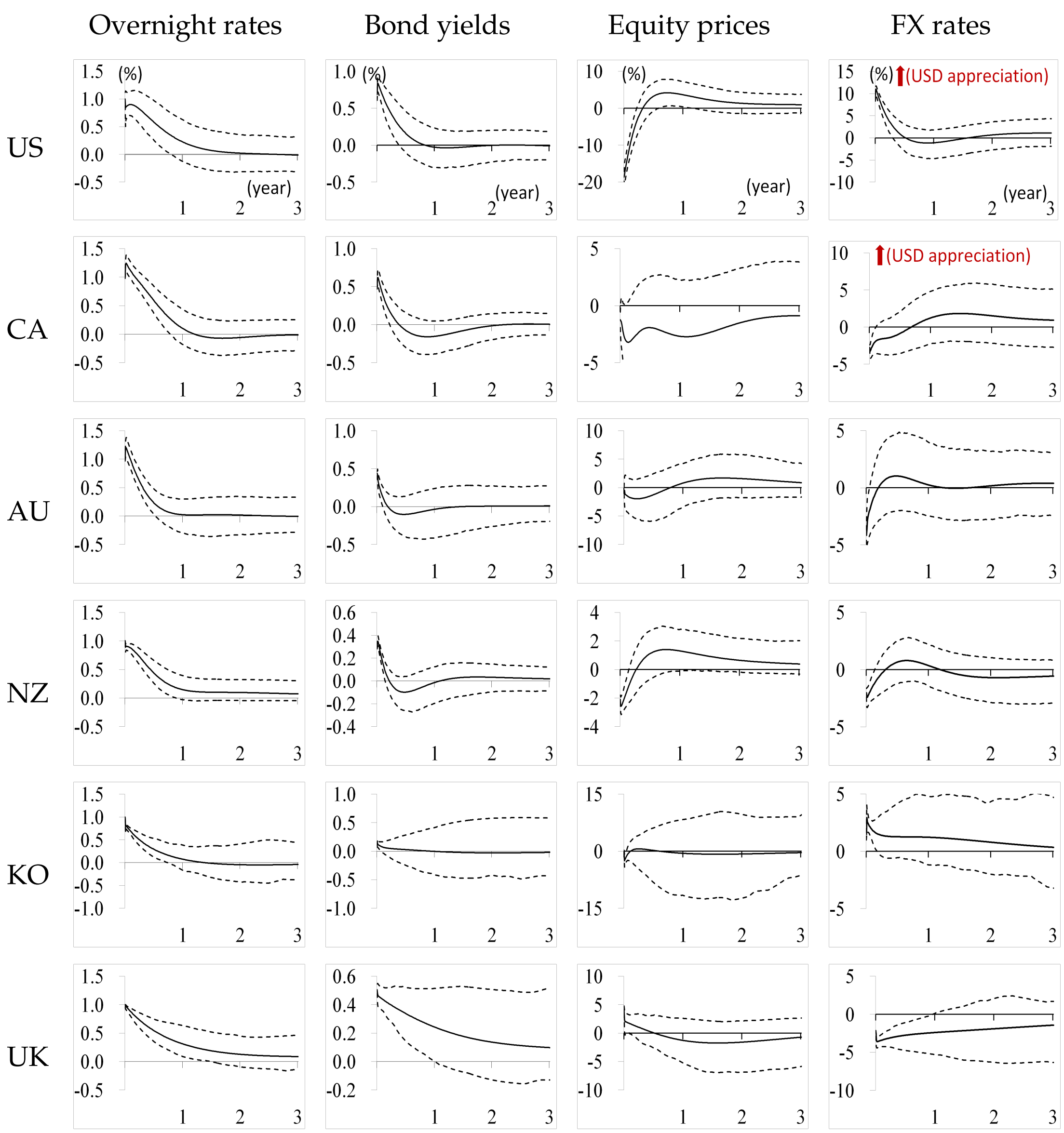


Figure 2.3: IRFs on a positive 1% U.S. MP shock: Choleski identification



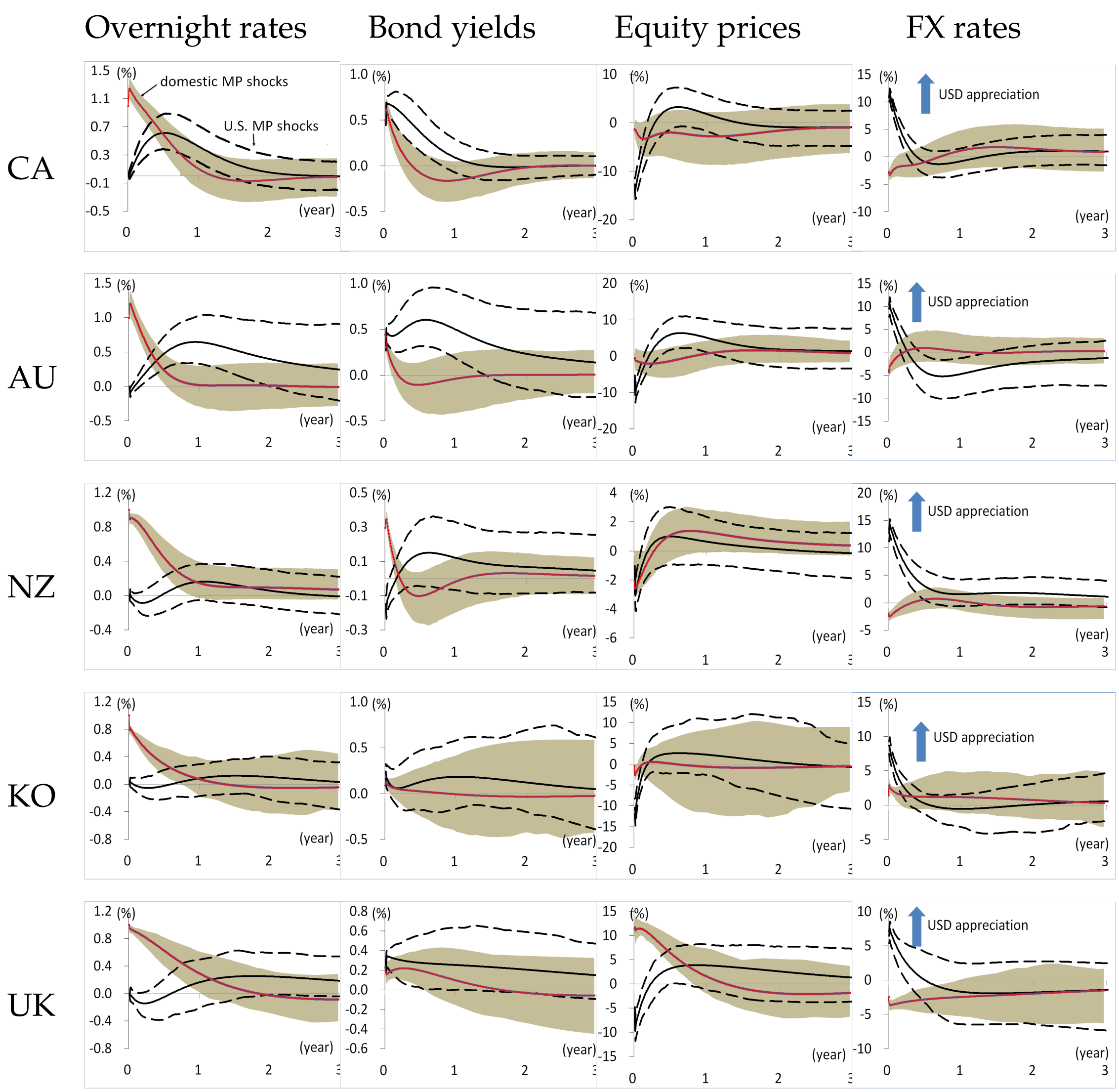
Note: Broken lines indicate 90% confidence intervals through 5,000 draws from bootstrap samples.

Figure 2.4: IRFs on a positive 1% domestic MP shock



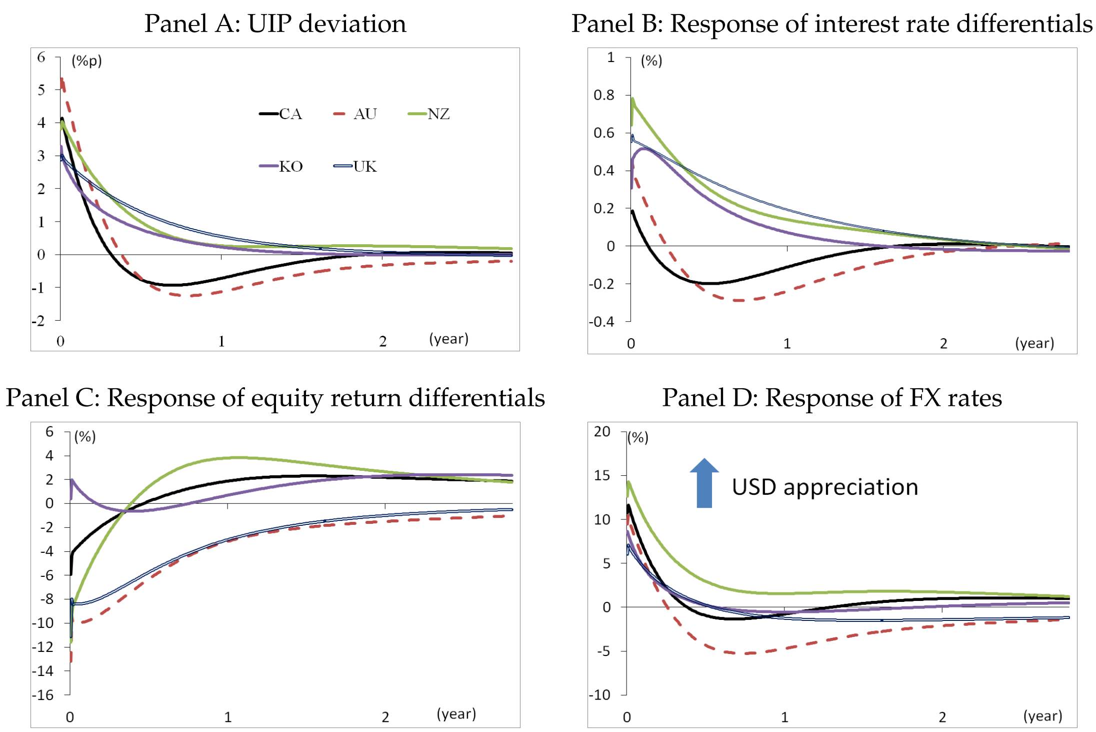
Note: Broken lines indicate 90% confidence intervals through 5,000 draws from bootstrap samples.

Figure 2.5: Comparison of IRFs following positive 1% U.S. and domestic MP shocks



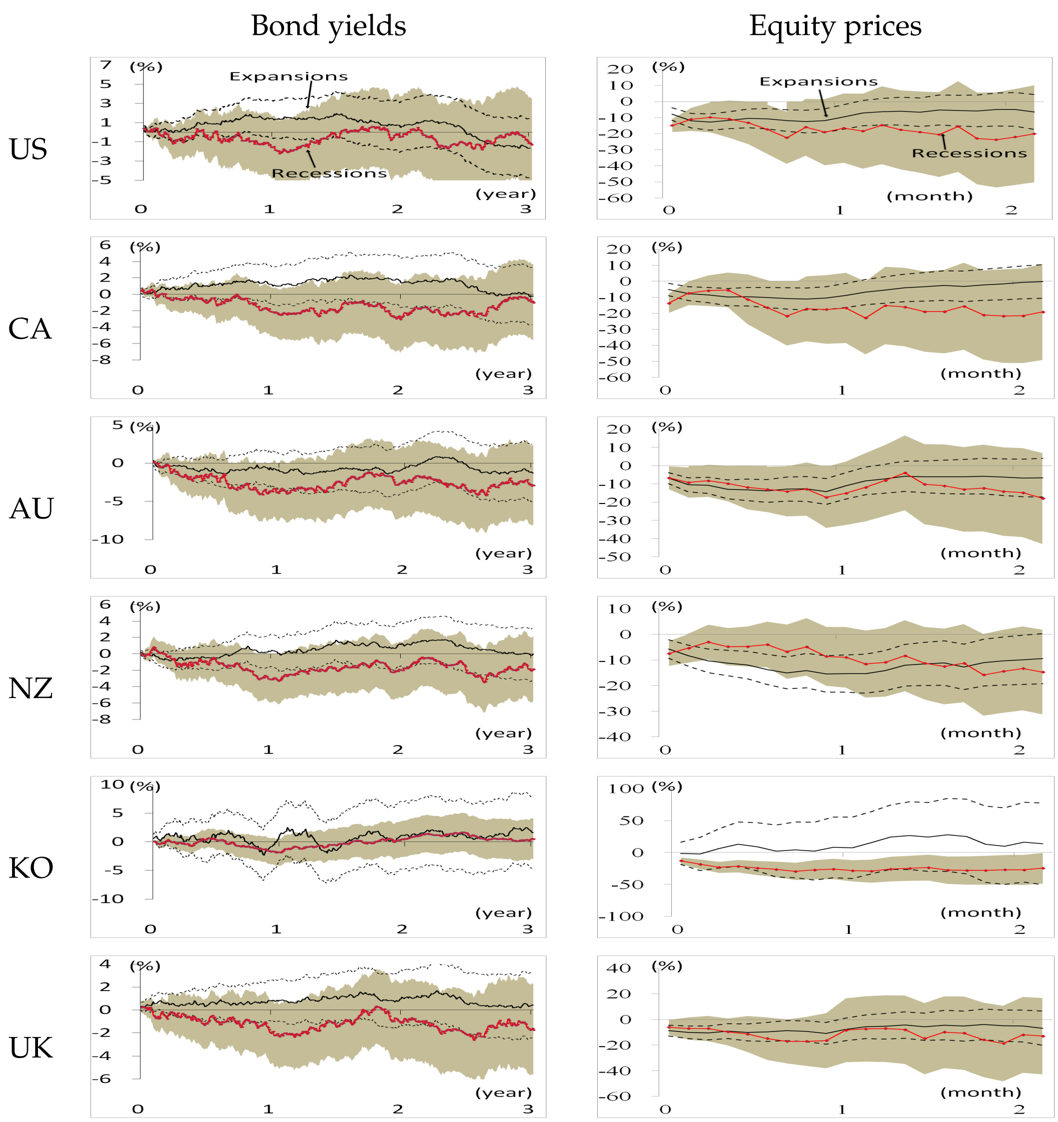
Note: Broken lines and shaded areas indicate 90% confidence interval through 5,000 draws from bootstrap samples for the IRFs from two types of MP shocks.

Figure 2.6: UIP deviations and other measures



Notes: 1. All results are based on the impulse responses of variables to 1% U.S. MP shocks.
2. Interest rate differentials are measured by [IRF(R^*, h) − IRF(R, h)], where R and R^* indicate domestic and foreign bond (3-year) yields, respectively.
3. Equity return differentials are similarly measured by [IRF(S^*, h) − IRF(S, h)], where S and S^* indicate the rates of return on domestic and foreign equity indexes, respectively.

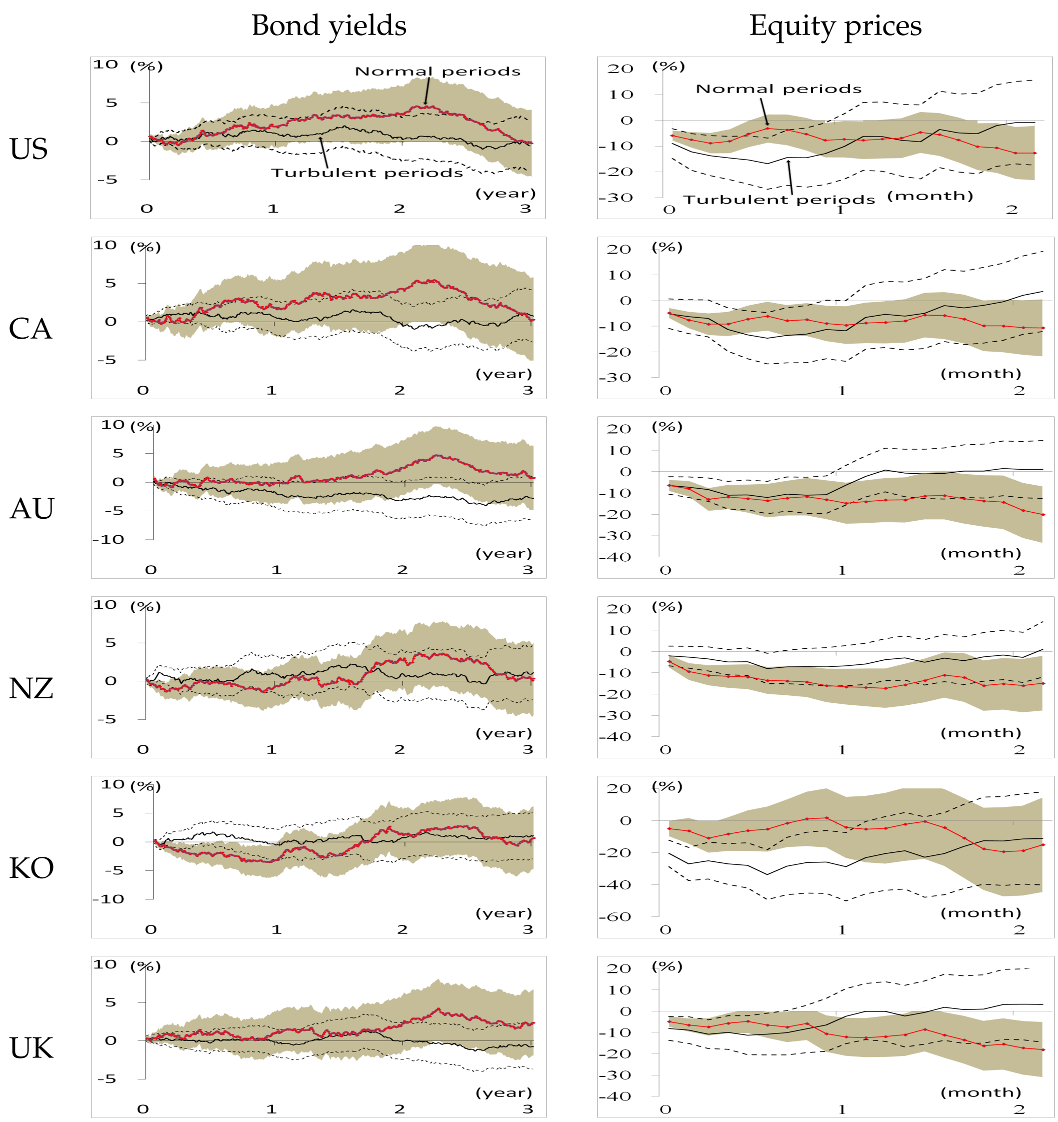
Figure 2.7: State-dependent IRFs: U.S. business cycle



Notes: 1. IRFs on a 1% increase in $ED4$ rates, based on the local projection non-linear model, $x_{t+h} = \alpha^h + \Psi^h(L)y_{t-1} + D_t[\beta^{A,h} shock_t] + (1 - D_t)[\beta^{B,h} MP_t] + \varepsilon_{t+h}$. $D_t = 1$ if the shocks occurred during a U.S. expansion, and $D_t = 0$ otherwise.

2. Broken lines and shaded areas represent 90% level confidence intervals of the two IRFs.

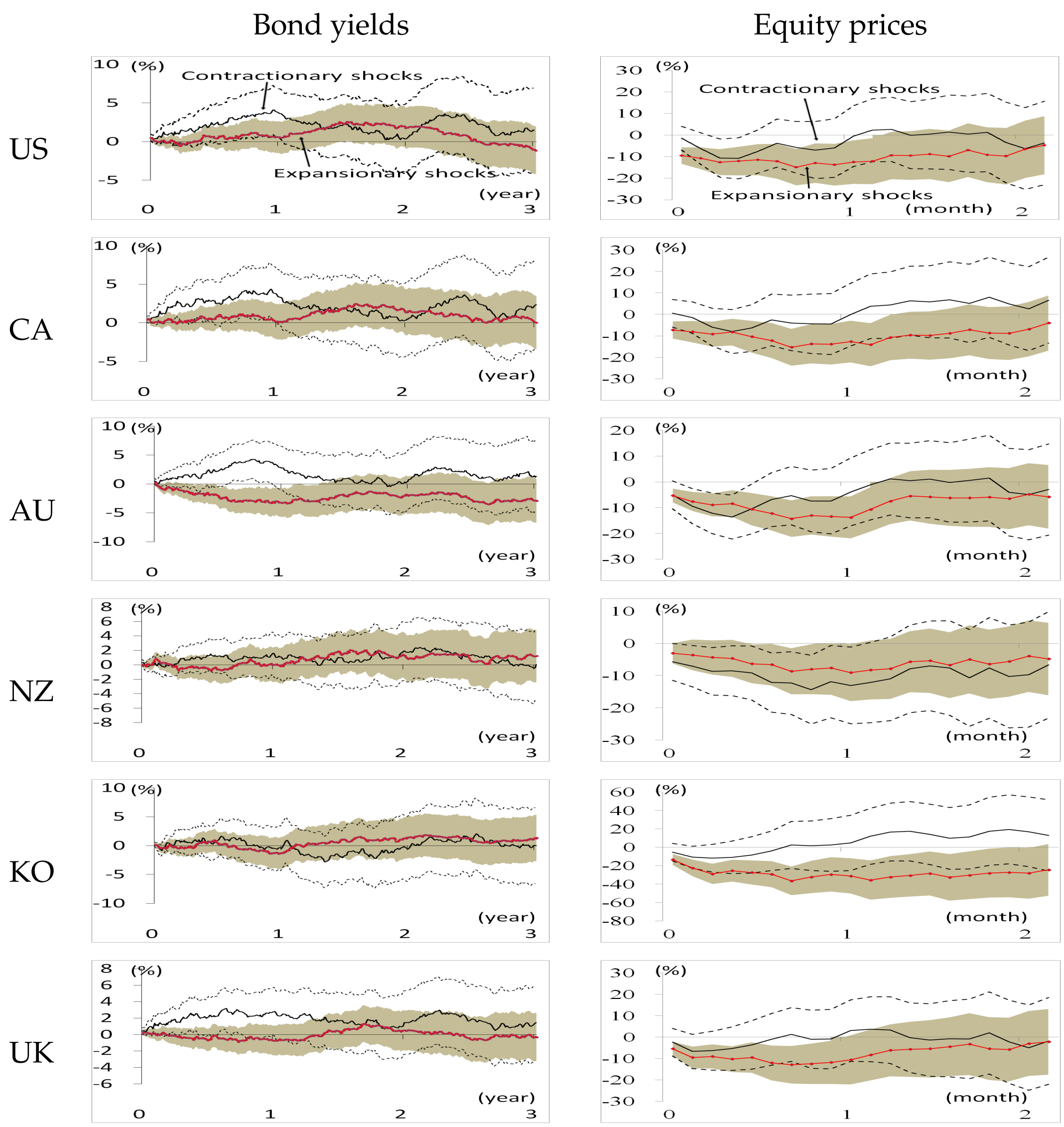
Figure 2.8: State-dependent IRFs: Financial turbulence



Notes: 1. IRFs on a 1% increase in $ED4$ rates, based on the non-linear local projection model, $x_{t+h} = \alpha^h + \Psi^h(L)y_{t-1} + D_t[\beta^{A,h} shock_t] + (1 - D_t)[\beta^{B,h} MP_t] + \varepsilon_{t+h}$. $D_t = 1$ if the shocks occurred during a period of financial turbulence, and D_t =0 otherwise.

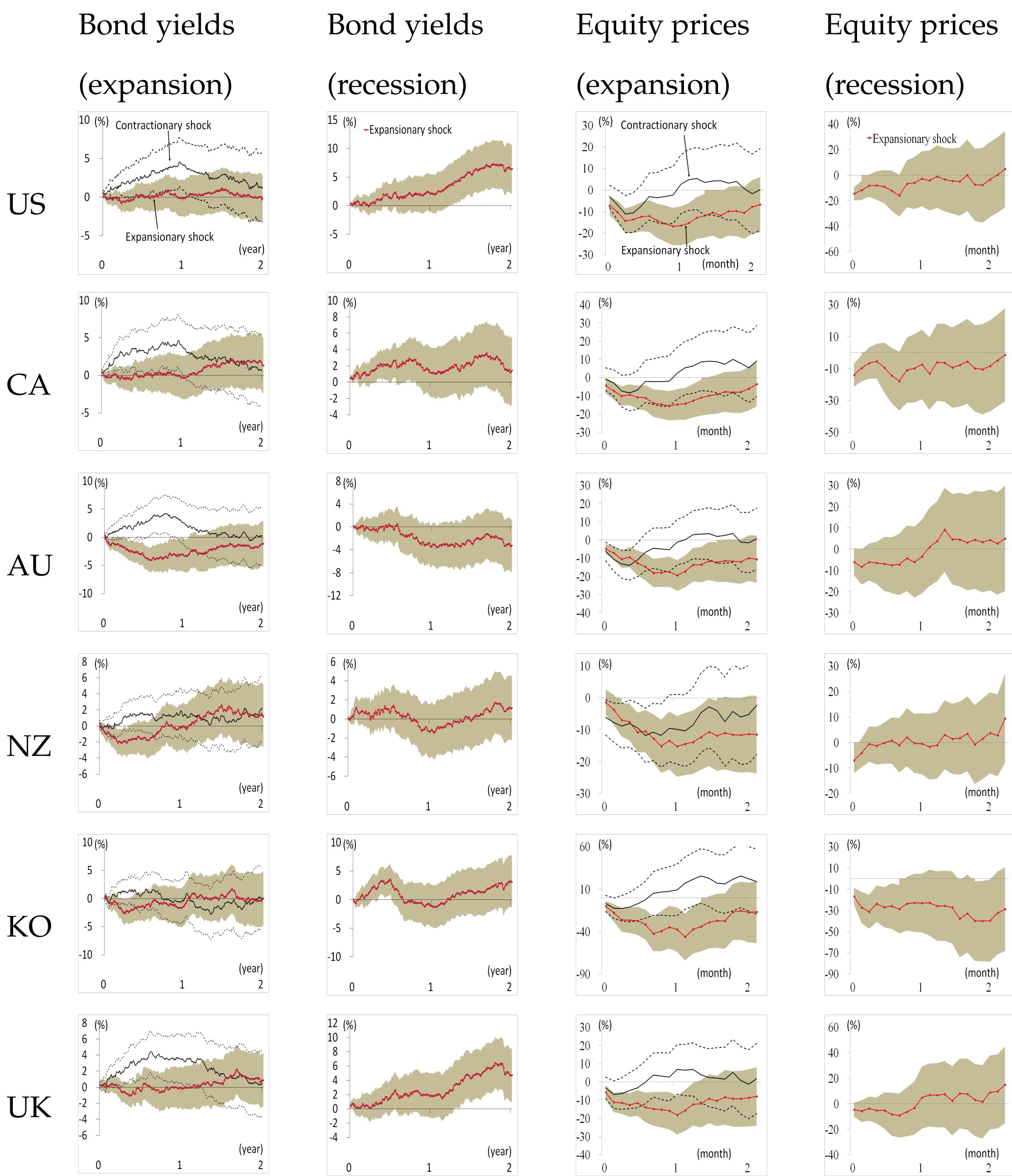
2. Broken lines and shaded areas represent 90% level confidence intervals of the two IRFs.

Figure 2.9: Asymmetric IRFs: Direction of shocks



Notes: 1. IRFs on a 1% increase in *ED*4 rates, based on the non-linear local projection model, $x_{t+h} = \alpha^h + \Psi^h(L)y_{t-1} + D_t[\beta^{A,h} shock_t] + (1 - D_t)[\beta^{B,h} MP_t] + \varepsilon_{t+h}$. $D_t = 1$ if the shocks are positive (contractionary) and $D_t = 0$ otherwise.
2. Broken lines and shaded areas represent 90% level confidence intervals of the two IRFs.

Figure 2.10: Asymmetric IRFs conditional on US business cycles phases



Notes: 1. IRFs on a 1% increase in $ED4$ rates, based on the non-linear local projection model, $x_{t+h} = \alpha^h + \Psi^h(L)y_{t-1} + D_t[\beta^{A,h} shock_t]EX + (1-D_t)[\beta^{B,h} MP_t]EX + \varepsilon_{t+h}$. D_t is 1 if the shocks is contractionary and 0 otherwise. EX_t is 1 if the shocks occurred during expansions and 0 otherwise. 2. Broken lines and shaded areas represent 90% level confidence intervals of the two IRFs.

CHAPTER 3

WHAT EXPLAINS VOLATILITY SPILLOVERS IN THE FINANCIAL SYSTEMS OF EMERGING MARKET COUNTRIES?

3.1 Introduction

Since the liberalization of the capital and foreign exchange (FX) markets in emerging market (EM) countries, dependencies between these markets have intensified considerably.[1] There are several potential explanations for this phenomenon. As financial markets become deeper and wider after liberalization, the markets tend to share more information in common than before. In addition, opening up financial markets can increase their dependencies by introducing foreign investors. Foreign investors, in contrast to domestic agents, are more sensitive to new shocks in both capital and FX markets and move quickly from one market to another, transmitting information across markets. Another potential explanation comes from financial crises and the contagion effect. Since the 1990s, EM financial markets have been hit by a series of crises, including the 1994 Mexican peso collapse, the 1997 East Asian crisis, and the global financial crisis of 2008-9. A striking feature of these crises is that during such periods markets tend to move more closely together than they would during tranquil times. Such excessive high co-movement is referred to in the literature as contagion, and it may partially explain why EM financial markets have become more interdependent in recent years.

There are a variety of ways in which market dependencies can be measured and tested, and indeed the literature includes several approaches. Ear-

[1]Empirical evidence of increasing market dependency is presented in Section 3.2.

lier studies have often focused on linear interactions between asset prices (returns). However, as financial markets and their interdependencies have become more complex in recent decades, it has become particularly important to study higher-moment relationships as well. Most notably, the development of the Autoregressive Conditional Heteroskedasticity (ARCH) model in the 1980s and 1990s brought relationships of the second moments of asset returns considerable attention in the literature. This chapter extends this line of research and investigates volatility spillovers between EM financial markets.[2]

Studying volatility spillovers across domestic asset markets is important from both policy and academic perspectives. Policy-wise, a strong relationship between financial markets increases systemic risk in the financial sector. Unexpected or sudden market turmoil, for example, may propagate instability across the financial system by influencing investment activities in other markets as well. In order to implement policies effectively, policy authorities must understand how any new shock is transmitted through the markets. From an academic standpoint, the existence of volatility spillovers is closely linked with classical finance theories such as market efficiency theory. The latter predicts that spillovers should not occur, as a market shock should be fully and without delay reflected in the asset pricing of another market. In reality, however, ample empirical evidence suggests that financial markets do not instantly incorporate all information into prices, exhibiting apparent return and volatility spillovers (Hamao et al. [1990], Lin and Ito [1994], Savva et al.[2009]). Some studies regard significant spillover as evidence of market failure.

A group of studies has tried to reconcile such disparities between theory and

[2]In the literature, studies on the volatility spillovers are divided into two groups. One group examines cross-border (or inter-country) spillovers and the other examines cross-asset markets (or intra-country) spillovers. This study focuses on the second case.

empirical evidence by investigating the sources of volatility spillovers. They assert that spillover effects should be carefully interpreted regarding which source or channel mainly explains volatility spillovers. One argument, for instance, is that if financial markets share common news, and news about the fundamentals is serially correlated, then the existence of spillovers need not necessarily imply a failure of market efficiency (Ebrahim [2000]). Other studies, including Lin and Ito (1994), assert that such a spillover could also be generated without common fundamentals, suggesting market contagion.

More specifically, studies have postulated several possible channels for volatility spillovers across asset classes. The first channel is common information, which affects a set of financial assets simultaneously. If there are fundamental linkages between markets, a variation in common information is likely to cause volatility spillovers across markets. The second comes from the information transmission caused by cross-market rebalancing or hedging.[3] Such information transmission is a sequential flow of information that alters expectations in one market and impacts trading and volatility in other markets. Finally, contagion due to irrational behaviors such as the bandwagon effect can also explain spillovers. The contagion hypothesis notes that agents who observe a price decline in one market become more risk-averse and reduce their positions in other markets and create apparent spillover effects.

Recently, studies discussing the existence of volatility spillovers involving asset markets of EM countries have begun to emerge. However, no study, to

[3]Rebalancing occurs when new information affecting returns in one market causes an investor to want to change portfolio holdings in that market. Such a change can lead to a change in portfolio holdings in other markets as well, even though no new information about the other markets is available (Kodres and Pritsker [2002]). Fleming et al. (1998) and Underwood (2009) find evidence of cross-market hedging as a channel of transmission. Hedging is undertaken to insure a given position in an asset and involves the purchase or sale of a position in another asset.

the best of my knowledge, has empirically investigated the sources of volatility spillovers for EM financial markets. This study therefore offers new insights and implications by proposing a new method for identifying each proposed source of volatility spillovers. Moreover, few studies have tried to test diverse characteristics of spillovers by employing long time series that include pre-liberalization periods of financial markets and a number of financial crises. This is particularly important in studying the sources of volatility spillovers because, for example, agents may exhibit fundamentally different behaviors during financial crises that alter market dependencies, and by utilizing long time series we can control for and test these anomalous effects. Finally, no study has considered multiple EM countries together to discern stylized patterns of spillover dynamics.[4] This study, following Kanas (2000) and others, employs and analyzes extensive data on 14 major EM countries in a comprehensive manner, instead of focusing on a single country case.[5]

The remainder of the chapter assumes the following structure: Section 3.2 presents the theoretical basis and stylized empirical facts regarding dependencies between the FX and stock markets and introduces the data used in this chapter. Section 3.3 reviews the existing literature on volatility spillovers. Section 3.4 specifies a bi-variate GARCH model as a benchmark, and then introduces several alternative models by importing restrictions on both sides of the GARCH model, i.e., on the mean and variance equations. Section 3.5 reports the empirical results obtained from the benchmark and alternative models. Section 3.6 concludes.

[4]On advanced countries, Kanas (2000) is representative in suggesting stylized results for volatility spillovers of G7 countries.

[5]These open economies have all experienced rapid financial market growth after financial market liberalization and most are adopting the flexible exchange rate regime.

3.2 Dependency in the FX and stock markets

3.2.1 Theoretical relationship

The theoretical relationship between stock markets and FX markets that is found in the literature is summarized in the following two groups of models.

The first approach uses the flow-oriented model of Dornbusch and Fischer (1980). Under this model the behavior of the exchange rate is a major determinant of stock returns. Depreciation of a domestic currency, for example, has a positive effect on the competitiveness of domestic goods versus that of foreign goods and a country's balance of trade. This in turn increases domestic aggregate demand and output. Insofar as stock prices reflect expected future cash flows, which are influenced by future aggregate demand, a rise in the exchange rate may increase stock prices.

An alternative model is the so-called 'stock-oriented model' developed by Branson (1981) and Frankel (1987). On this approach, agents allocate their wealth across alternative assets including domestic currency and domestic and foreign securities. The exchange rate balances the demand for and supply of assets. Any change in the demand for or supply of assets will change the equilibrium exchange rate. An increase in domestic stock prices will, for instance, increase wealth and demand for money, and consequently interest rates will rise. High interest rates in turn will attract foreign capital, resulting in appreciation of the domestic currency. Return spillovers may also result in volatility spillovers.

Which approach has been supported by empirical studies? The answer might be twofold: 'both' and 'neither' depending on the country and sample period considered. A group of studies including Kanas (2000) and Tai (2007) supports spillovers from stocks to currency return fluctuations. Another group including Apergis and Rezitis (2001) supports spillovers from exchange rates to stock returns.[6] Other studies find bi-directional spillovers.[7]

3.2.2 Stylized facts on asset return volatilities and their dependency

The second moments of the asset returns of EM countries exhibit the following patterns. First, their synchronization seems to have increased substantially since financial market liberalization. As shown in Table 3.1, cross-correlations between daily currency and stock returns have significantly increased since the 1990s. In more recent data following the global financial crisis of 2008-9, all countries except China exhibit very high correlations.

Second, the volatility of asset returns shows an asymmetric distribution. While the first moments exhibit similar standard deviations across upturn and downturn periods, the second moments show substantially different levels, as shown in Table 3.2, and are more volatile during downturn (or depreciation) periods.

[6]Using New York and London FX and stock market data, Apergis and Rezitis (2001) find a volatility spillover from the FX market to the stock market, but not in the reverse direction. Yang and Chang (2008) conclude from an analysis of data on five countries (Taiwan, Singapore, South Korea, Japan, and the US) that FX markets play an important role in explaining domestic stock returns.

[7]For example, Wu (2005) reports a bi-directional relationship between the volatility of stock prices and exchange rate changes in Asian countries during the recovery following the Asian crisis of 1997. Zhao (2010) finds bi-directional volatility spillover between the Renminbi and the Shanghai stock market index.

Third, the volatility of asset returns, especially that of currency returns, substantially expands during times marked by turbulence. As reported in Table 3.3, EM currency return volatilities nearly triple on average during the crisis compared with pre-crisis levels, which is a more dramatic increase than what is observed in advanced countries. Before the global financial crisis (the so-called period of 'great moderation'), EM currencies enjoy low volatilities, but following the crisis they suffer soaring volatilities. The increasing rate of currency return volatilities rises to six times the normal levels, presumably depending on such factors as the FX market regime and foreign investor participation in each country.

Finally, dramatic increases in currency return volatilities during crises seem to be attributed primarily to the influence of capital markets. As seen in Figures 3.1 and 3.2, currency return volatilities seem to depend on how closely related the FX and stock markets are, rather than on capital market volatility itself.

3.2.3 Data

This study employs daily asset returns of 14 EM countries: Brazil (BRA), China (CHN), Hong Kong (HKG), Indonesia (IDN), India (IND), Korea (KOR), Mexico (MEX), Malaysia (MYS), the Philippines (PHL), Russia (RUS), Singapore (SGP), Thailand (THA), Taiwan (TWN), and Turkey (TUR), considering such factors as financial market developments and foreign investors' participation. Table 3.4 and Figure 3.3 show indicators of financial market developments. The sample dates from January 1980 through November 2012, although data availability issues resulted in smaller samples for some countries.

To obtain stock and currency return figures, the prices of the national composite stock index (based on local currencies) and the inverse of the exchange rate per US dollar of each EM country are used. Asset prices (P_t) are converted to rates of return (R_t) by taking first differences of log levels, i.e., $R_t = 100*[ln(P_t)\text{-}ln(P_{t-1})]$. Details on the data used in this study are listed in Table 3.5.

Table 3.6 and 3.7 present summary statistics of daily asset returns, the mean values of which are slightly positive in most cases. The kurtosis coefficient, a measure of the thickness of the tail of the distribution, is quite high. The Jarque-Bera normality test yields very high values, rejecting the null hypothesis of normality at the 5% significance level.[8]

3.3 Literature on volatility spillovers

There is a voluminous body of literature on volatility spillovers across distinct asset markets. In the current trend towards financial market globalization, studies have concentrated on the existence and dynamics of volatility spillovers between cross-border markets. Karolyi (1995), for example, examines the dynamics of returns and volatilities of stocks traded on the New York and Toronto stock exchanges. While most studies are confined to discussing developed markets, the literature began focusing on EM markets after their financial markets liberalized. Engle et al. (2008) analyze spillovers in East Asian financial markets and Beirne et al. (2009) report evidence of spillovers from developed to EM markets.

[8] Although not included in the thesis, the author executed an ARCH effect test for the original returns and it shows that all asset returns reject the null hypothesis and that there is no volatility clustering in the time series at the 1% significance level, which favors employing an ARCH (GARCH) model

Turning from cross-border analyses, another group of studies focuses on volatility spillovers across intra-country (domestic) markets. Kanas (2000) investigates dependency between stock returns and currency returns in six developed countries by estimating a bi-variate EGARCH model. Spillovers from stock to FX markets are found for all countries except Germany, while no evidence is found of spillovers in the opposite direction. Yang and Doong (2004) similarly confirm spillovers between FX markets and stock markets in G7 countries with only a uni-directional (stock-to-FX markets) relationship.

Studies on EM countries have also drawn attention in recent years. Based on empirical results obtained using a GARCH (1,1) model, Mishra et al. (2007) conclude that volatility spillovers between the Indian stock and FX markets are significant. Belloti and Williams (2010) estimate conditional prices and volatility transmission across FX, domestic,and international stock markets in the BRIC countries (Brazil, Russia, India, and China).

Another group of studies focuses on sources of significant spillovers. Fleming et al. (1998) investigate the nature of volatility linkages in the US stock, bond, and money markets. They develop a simple speculative trading model using Generalized Method of Moment techniques that predict volatility linkages between the markets. The study suggests two kinds of channels for volatility spillovers: common information and information transmission caused by cross-market hedging. Their results suggest that volatility linkages between the three markets are strong and that the linkages have become stronger since the 1987 stock market crash. Ebrahim (2000) uses a tri-variate GARCH model to investigate information transmission between FX markets (USD/CAD, USD/DEM, and USD/JPY) and associated Eurocurrency money markets. The study finds strong evidence of price and volatility spillovers, with some found to be asymmetric. Based on the finding that pair-wise contemporaneous correlations between innovations are low, the paper suggests that significant spillovers indicate either that investors in one market are processing information from other markets gradually, or that the spillovers are the result of market contagion effects.

Some papers focus specifically on contagion effect as an important source of volatility spillovers. Beirne et al. (2009) model volatility spillovers from mature to emerging stock markets, and test for changes in the transmission mechanism in the presence of turbulence in mature markets using a tri-variate BEKK GARCH model. They conclude that mature market volatility affects variances in emerging markets and that spillover parameters shift during turbulent episodes.

3.4 Empirical model

3.4.1 Bi-variate BEKK GARCH(1,1) (Benchmark model 1)

It is well known that financial asset return series exhibit volatility clustering.[9] To catch such volatility clustering, the ARCH model used by Engle (1982) and the GARCH model used by Bollerslev (1986) have been developed and used extensively in the literature. This study employs a GARCH(1,1) model following

[9] Although not reported in the thesis, Plots of series indeed show obvious volatility clustering.

Hansen and Lunde (2005) and others.[10]

To analyze spillovers between multiple asset returns, we need to make an assumption regarding the covariance matrix of the series. Spearheaded by the VECH model of Bollerslev et al. (1988), a variety of GARCH models have been developed.[11] Among them, this study employs the BEKK GARCH framework of Baba, Engle, Kraft, and Kroner (1991). The model has been widely used in the study of volatility spillovers since it enables us to estimate the coefficients in a way that reflects the extent of cross-market spillovers. The model also has the advantage that it permits time-varying correlation between innovations and guarantees positive definiteness of the variance-covariance matrix.

The framework of the bi-variate BEKK GARCH model (1,1) follows the two-stage estimation method as below. The first stage involves using the least squares method to estimate the parameters of the mean equations; and the sec-

[10]Although ARCH models have been used extensively in these studies, the models have limitations, one of which is the problem of deciding the order (q) of the squared residual in the model. We can decide the q from statistical testing using, for example, Lagrange Multiplier (LM) statistics. In some cases, however, the q might have to be very large to capture all of the dependency in conditional variance. Alternatively, GARCH models offer the benefit of providing a simple framework with richer information. Suppose we have $h_t = \omega + \alpha \mathrm{u}_{t-1}^2 + \beta \mathrm{h}_{t-1}$, where h_t and u_t are the variance and residual term at t, respectively. Then a one-period lag yields, $h_{t-1} = \omega + \alpha \mathrm{u}_{t-2}^2 + h_{t-2}$, and substituting back yields $h_t = \omega + \omega\beta + \alpha \mathrm{u}_{t-1}^2 + \alpha\beta \mathrm{u}_{t-2}^2 + \beta \mathrm{h}_{t-2}$. In this way, the simple GARCH(1,1) model is known to be sufficient for capturing volatility clustering in financial data, indicating that higher-order GARCH models may not be necessary in general. Representatively, Hansen and Lunde (2001) support the view that GARCH(1,1) models provide good in-sample parameter estimates.

[11]One of the first rigorous attempts in this category was the VECH model of Bollerslev et al. (1988). This approach extends the basic model of Engle (1982) and Bollerslev (1986) by using the simultaneous equation form of the original model. The VECH model proves to be a cumbersome approach, as a large number of coefficients have to be estimated, thus utilizing relatively small degrees of freedom in the estimation process. To resolve this estimation problem, Bollerslev (1990) introduces the constant conditional correlation (CCC) model. This model simplifies the estimation of the multivariate GARCH coefficients by imposing restrictions on the variance-covariance matrix derived from the system of simultaneous equations. Although the CCC model is a useful improvement over the VECH, there are apparent drawbacks. First, the major assumption of constant correlations between the variables in the system of equations is thought to be unrealistic. Furthermore, the model does not ensure that the estimated variance-covariance matrix is positive. This condition is necessary to ensure the existence of a solution to the system of equations. (Hurditt [2004])

ond stage involves applying a bivariate BEKK GARCH. First, the mean equation is given by equation (3.1). The latter is structured as a Vector Autoregressive (VAR) model with lag 2.[12] The vector $R_{i,t}$ represents the currency and stock returns, respectively, of country i, at time t. The vector $\alpha_{i,t}$ and vector $\epsilon_{i,t}$ are the intercept and error terms, respectively. $\beta_{i,q}$ is the coefficient matrix for autoregressive variables.

$$R_{i,t} = \alpha_i + \sigma^2_{q=1}\beta_{i,q}R_{i,t-q} + \epsilon_{i,t} \tag{3.1}$$

where $R_{i,t} = [R_{1,i,t}R_{2,i,t}]'$, $\alpha_{i,t} = [\alpha_{1,i}\alpha_{2,i}]'$, $\epsilon_{i,t} = [\epsilon_{1,i,t}\epsilon_{2,i,t}]'$,

$$\beta_{i,q} = \begin{bmatrix} \beta_{11,i,q} & \beta_{12,i,q} \\ \beta_{21,i,q} & \beta_{22,i,q} \end{bmatrix}$$

Second, the associated variance-covariance matrix of the error term ($E(\epsilon_{i,t}\epsilon'_{i,t}) = H_{i,t}$) is then represented by equation (3.2). The variance-covariance equation represents the BEKK formulation of the bi-variate GARCH procedure assuming a quadratic form of the multivariate GARCH. The intercept matrix is decomposed into CC where C is constructed as a lower triangular matrix. With no further assumption, CC is positive and semi-definite. Matrices A and B represent an ARCH and GARCH coefficient, respectively. Accordingly, the model represents nearly all positive definite representations.[13]

[12]The lag polynomials can in principle be of different orders. For simplicity, however, this study restricts them to be VAR(2) for the mean equation of each EM country

[13]With some restrictions added, the model could eliminate all other observationally equivalent structures. For example, regarding the term $A\epsilon_{t1}\epsilon_{t1}A$, the only other observationally equivalent structure is obtained by replacing A by A, in which case the restriction of $a_{11}(b_{11})$ being positive is sufficient to eliminate A from the set of admissible structures. Assuming a GARCH(1,1) model, Engle and Koroner (1995) suggest the following proposition: suppose that the diagonal elements in C are restricted to being positive and that a_{11} and b_{11} are also restricted to being positive. Then there exists no other C, A, or B that will yield an equivalent representation.

$$H_{i,t} = C_i'C_i + A_i'\epsilon_{t-1}\epsilon_{t-1}'A_i + B_i'H_{i,t-1}B_i \tag{3.2}$$

where

$$H_{i,t} = \begin{bmatrix} \sigma_{11,i,t} & \sigma_{12,i,t} \\ \sigma_{21,i,t} & \sigma_{22,i,t} \end{bmatrix}, C_i = \begin{bmatrix} c_{11,i} & 0 \\ \sigma_{21,i} & \sigma_{22,i} \end{bmatrix}, A_i = \begin{bmatrix} a_{11,i} & a_{12,i} \\ a_{21,i} & a_{22,i} \end{bmatrix}, B_i = \begin{bmatrix} b_{11,i} & b_{12,i} \\ b_{21,i} & b_{22,i} \end{bmatrix}$$

Elements of the variance-covariance matrix yield, for example, the following equations (3.3) and (3.4). The equations provide a full description of factors that influence asset return volatilities. They show that asset variances depend on the constants, the lags of squared residual terms($\epsilon_{11,t-1}$ or $\epsilon_{22,t-1}$), the products of the lags of the cross-residual terms($\epsilon_{12,t-1}$ or $\epsilon_{21,t-1}$), the lags of the variances($\sigma_{11,t-1}$ or $\sigma_{22,t-1}$), and the lags of the co-variances($\sigma_{12,t-1}$ or $\sigma_{21,t-1}$).

$$\begin{aligned} \sigma_{11,t} = c_{11}^2 + c_{12}^2 + a_{11}(a_{11}\epsilon_{11,t-1} + a_{21}\epsilon_{21,t-1}) + a_{21}(a_{12}\epsilon_{12,t-1} + a_{21}\epsilon_{22,t-1}) + \\ b_{11}(b_{11}\sigma_{11,t-1} + b_{21}\sigma_{21,t-1}) + b_{21}(b_{11}\sigma_{12,t-1} + b_{21}\sigma_{22,t-1}) \end{aligned} \tag{3.3}$$

$$\begin{aligned} \sigma_{22,t} = c_{22}^2 + c_{21}^2 + a_{22}(a_{22}\epsilon_{22,t-1} + a_{12}\epsilon_{12,t-1}) + a_{12}(a_{22}\epsilon_{21,t-1} + a_{12}\epsilon_{11,t-1}) + \\ b_{22}(b_{22}\sigma_{22,t-1} + b_{12}\sigma_{12,t-1}) + b_{12}(b_{22}\sigma_{21,t-1} + b_{12}\sigma_{11,t-1}) \end{aligned} \tag{3.4}$$

where subscript i for each term is omitted for simplicity.

To observe common- and cross-market volatility spillovers, the impact of lagged squared residuals ($\epsilon_{11,t-1}$ and $\epsilon_{22,t-1}$, ARCH terms) or lagged variances ($\sigma_{11,t-1}$ and $\sigma_{22,t-1}$, GARCH terms) on the asset return volatilities could be used. This study considers both ARCH and GARCH terms for the spillover effects. The squares of each diagonal coefficient of matrices A and B are then interpreted to represent the impact of common market shocks on next-day asset returns. For example, a_{11}^2 estimates the magnitude of the influence of an FX market (market 1) shock on next-day currency volatility. Off-diagonal coefficients, on the other hand, describe the spillovers from one market to the other. For instance, a_{12}^2 is the estimated effect of a shock in the FX market on next-day stock return (market 2) volatility, and vice versa for a_{21}^2.

In estimating the conditional covariance matrix in the model, the maximum likelihood method is used. $H_t(\theta)$ is a positive definite 2 by 2 conditional covariance matrix of 2 by 2 residual vector ϵ_t, parameterized by vector θ. If we denote the available information at time t by F_t, we obtain equations (3.5) and (3.6).

$$E_{t-1}[\varepsilon_t | F_{t-1}] = 0 \tag{3.5}$$

$$E_{t-1}[\varepsilon_t \varepsilon_t' | F_{t-1}] = H_t(\theta) \tag{3.6}$$

The maximum likelihood approach estimates parameters (θ) by maximizing the Gaussian log likelihood function (3.7).[14]

$$\log L_T(\theta) = -\frac{NT}{2}\log(2\pi) - \frac{1}{2}\sum_{t=1}^{T} |H_t| - \frac{1}{2}\sum_{t=1}^{T} \varepsilon_t' H_t^{-1} \varepsilon_t \tag{3.7}$$

where N=2 and T indicates the sample period for each EM country.

[14]It is assumed that time-series data on EM countries are stationary and their distribution is pre-defined as a conditional Gaussian distribution.

3.4.2 Extension of Benchmark model 1

This section extends Benchmark model 1 by adding proposed sets of four dummy variables to the variance equation. The motivation for introducing the dummy variables is based on assumptions pertaining to the time shift of volatility spillovers; that is, spillover parameters need not be invariant over time. The parameter could shift depending on the sample period, market conditions, and so forth. If the dummy variables increase the explanatory power of the benchmark model, we sense that spillover effects are shifting over time. Variance equation (3.3) for currency returns can be modified to obtain equation (3.8).[15] Equation (3.4) for stock return volatility can be modified analogously.

$$\begin{aligned}
\sigma_{11,t} = c_{11}^2 + c_{12}^2 + a_{11}(a_{11}\epsilon_{11,t-1} + (a_{21} + Da_{21d})\epsilon_{21,t-1}) \\
+(a_{21} + Da_{21d})(a_{12}\epsilon_{12,t-1} + (a_{21} + Da_{21d})\epsilon_{22,t-1}) \\
+b_{11}(b_{11}\sigma_{11,t-1} + (b_{21} + Db_{21d})\sigma_{21,t-1}) \\
+(b_{21} + Db_{21d})(b_{11}\sigma_{12,t-1} + (b_{21} + Db_{21d})\sigma_{22,t-1})
\end{aligned} \tag{3.8}$$

where D indicates a dummy variable for periods of interest.

The extended BEKK GARCH(1,1) model then estimates 15 parameters. Spillovers between the two markets are reflected in the parameters for the full sample period [a_{12}, a_{21}, b_{12}, and b_{21}] and those for the sub-sample of interest [a_{12d}, a_{21d}, b_{12d}, and b_{21d}]. The second set of parameters is interpreted to capture changes in spillover effects during times of interest. If we assume that parameters a_{12} and a_{12d} are both significant, for instance, the spillover effect from market 1 to market 2 during the full sample period is measured by the square of a_{12}, and

[15]The conditional variance of stock returns ($\sigma_{22,t}$) could be decomposed in the same way.

that during periods of interest by the square of the sum of a_{12} and a_{12d}. The following three sub-sections propose alternative sets of dummy variables to model the parameter shift of volatility spillovers.

Financial liberalization and volatility spillovers

The first candidate for triggering a parameter shift is financial market liberalization. Following liberalization, market dependency in the financial system of EM countries increased rapidly, as discussed in Section 3.2. Previous studies, including Kim and Rogers (1995), also suggest that capital market liberalization promotes market dependency.

I propose three plausible critical breakthrough points for financial liberalization from historical and statistical perspectives: 1990, 1998, and 2008. As seen in Table 3.8, most EM countries opened their stock markets during the late 1980s or early 1990s. As an alternative to the de jure liberalization point, I also propose a de facto critical point that triggered the sudden increase in foreign investments into EM financial markets. As shown in figure 3.4, incoming foreign investments in the financial markets of EM countries have increased steadily since the late 1990s and the speed of the inflows seems to have accelerated around 2008. A statistical breakpoint test (the Quandt-Andrews unknown breakpoint test) supports the observation, as shown in Table 3.9.

Following those arguments, I test the hypothesis that, since the breakthrough points of foreign investments occurred (1990, 1998, or 2008), market dependency has undergone structural change.

Asymmetric volatility spillover

With respect to the second parameter-shift candidate, this study tests asymmetric spillover. As explained by Kroner and Ng (1998), stock and currency return volatilities tend to rise more in response to negative shocks (bad news) than to positive shocks (good news). Such asymmetry is expected to occur if there is an increase in information following an announcement of bad news, which will affect covariance between returns.

Since this study considers pair-wise asset returns, dummy variables for asymmetric spillover in turn need to be constructed in two ways. Dummy variables in the first set represent the days in which the closing value of a domestic currency has depreciated from the previous day. The second set represents periods during which the daily stock price has decreased.

Turbulence and volatility spillover

With respect to the third parameter-shift candidate, following Beirne et al. (2009), I propose examining crisis periods. Applying the concept of contagion shift as described by Forbes and Rigobon (2002) to this analysis, I define volatility contagion as a shift in the transmission of volatility as a result of changes in market conditions and participant sentiment.

I define turbulent periods, using international financial market sentiment, as represented by the VIX (the Chicago Board Options Exchange Market Volatility Index). Figure 3.5 illustrates the movement of the VIX and the EMBIG spread, which have fluctuated depending on world economic conditions and the financial market situation. Turbulent periods are assumed to be those during which the daily VIX remains above the first quartile level (24.1) of long-term time series.

3.4.3 Source of volatility spillovers

Limitation of the VAR-typed mean equation

The mean equation in Benchmark model 1 is, following many other studies, set up as a bi-variate VAR model, such that the dependent variables in the equation are regressed with their lag series using the ordinary least squares method. Residuals in the equation are then taken as shocks in each market, and spillovers between the markets are tested in the variance equation.

The explanatory power of the lag variables measured by the R square (R^2) of the mean equations is, however, very weak for most EM countries, as shown in the first and second columns of Table 3.10. Furthermore, cross correlations between the pair-wise residuals are mostly very high, indicating that they share a substantial amount of common information.[16] Cross-correlations between the two residuals rise to 0.5, as shown in the first column of Table 3.12, and each residual series shows further symptoms of autocorrelation,[17] indicating that news shocks are correlated both serially and across asset markets.

In this case, the results of significant volatility spillovers provide no clue to

[16]Kanas (2000), for instance, considers correlations between the standardized residuals of stock returns and exchange rate change equations. The standardized residuals are interpreted as exchange rates and stock returns from which linear and nonlinear dependencies have been filtered through bi-variate EGARCH modeling. He finds that the correlation coefficients are negative and significant for all countries analyzed, indicating that there are statistically significant contemporaneous relationships between the two markets returns.

[17]Autocorrelations of asset returns are displayed in Table A-1 in the Appendix.

the source of the spillovers. The results, for example, are not sufficient to support the conclusion that information is inefficiently transmitted gradually across markets or that the market efficiency theory is violated. Volatility spillovers could result instead from common information across markets, generating comovements of asset returns or a contagion effect during times of unfavorable market conditions.

An alternative approach

Considering the limitation of the VAR-formed mean equation, how could we distinguish distinct sources of volatility spillovers? To answer this question, this study refers to the intuition that underlies the linear factor model.[18] The idea of the model is to summarize all the relevant economic or financial variables in a set of indicators that are the main explanatory factors.[19,20,21] It is then assumed that such factors are sufficient to characterize the common (or fundamental) component of the securities' returns, and any remaining uncertainty in the security returns can be attributed to market-specific (or idiosyncratic) shocks.

Several methodologies have been suggested to extract the implicit factors.

[18] The linear factor model relates the return on an asset to the values of a limited number of factors, with the relationship described by a linear equation. In its most generic form, such a model can be written as: $r_i = b_{i1} * f_1 + ... + b_{im} * f_m + e_i$, where: r_i is the return on asset i, b_{i1} is the change in the return on asset i per unit of change in factor 1, f_1 = the value of factor 1, f_m = the value of factor m, $b_i m$ = the change in the return on asset i per unit of change in factor m, m is the number of factors, and e_i is residual.

[19] According to the multiple factor model that is widely used in the finance literature, for instance, asset returns in open financial markets are ideally explained by global, regional, or country factors, etc.

[20] Bekaert and Harvey (2003) argue that defining the factor model is equivalent to taking a stand on the global, regional, and country-specific fundamentals as well as the mechanism that transfers fundamentals into correlation.

[21] For the extraction of factors that are latent in macroeconomic variables, Kose et al. (2012) representatively use a dynamic factor model, which decomposes macroeconomic variables into four factors (global, group-specific, country-specific, and idiosyncratic).

A statistical approach involves extracting the factors that explain most of the variation in security returns. Principal Component Analysis is used extensively, which draws common factor(s) from multiple time series. This methodology, however, is not technically applicable to this study insofar as daily asset returns do not share continuous time-series data.[22]

Another approach would be to use economic theory to identify the most relevant factor. This method uses observable asset-specific characteristics such as country or industry classifications to determine the common risk factors. Financial studies, employing mostly high-frequency data, use other asset returns that are assumed to represent the given factors. The multi-factor model, for instance, assumes that asset returns can be decomposed into (common) market returns and (idiosyncratic) country returns combined with such classical asset pricing theories as the world capital asset pricing model (CAPM), the regional CAPM, and so forth.[23] Following that concept, this study assumes that a country's FX and stock returns are explained by two common factors: international and regional financial market factors.[24] Such factors are assumed to influence both stock markets and FX markets in open economies as common shocks to multiple markets.

[22]This technical problem is due to the mismatch of the time series of each EM country. If each of the countries observes its own holidays, for instance, we could not apply principal component analysis due to missing data.

[23]Bekaert and Harvey (2003), for instance, apply a two-factor model to stock markets in three regions: Europe, South-East Asia, and Latin America and check for a contagion effect in asset returns. They used U.S. equity returns and regional equity portfolio returns to control the two common factors.

[24]A country factor might also be required to represent a common factor. I include lag variables of stock and FX market returns as explanatory variables, which could be interpreted as proxies for country-level financial factors.

Specification of alternative mean equations

Alternative mean equations with common factors are proposed as (3.9) and (3.10). Vector S_t represents all the information that contains movements of international (S_t^G) and regional (S_t^R) stock and FX markets that are obtainable on day t, represented by sets of variables for the respective markets.

(Alternative mean equation 1: returns are projected by VAR (2) and global variables.)

$$R_{i,t} = \alpha_{i,t} + \sum_{q=1}^{2} \beta_{i,q} R_{i,t-q} + \sum_{m=1}^{M} \gamma_{i,m} S_{m,t}^{G} + \varepsilon_{i,t} \tag{3.9}$$

(Alternative mean equation 2: returns projected by VAR (2), global, and regional variables.)

$$R_{i,t} = \alpha_{i,t} + \sum_{q=1}^{2} \beta_{i,q} R_{i,t-q} + \sum_{m=1}^{M} \gamma_{i,m} S_{m,t}^{G} + \sum_{n=1}^{N} \gamma_{i,n} S_{n,t}^{R} + \varepsilon_{i,t} \tag{3.10}$$

where M and N indicate the number of explanatory variables representing global and regional financial market movements, respectively.

As proxy variables for world market factors, I employ the world stock price Index ($MXWO$), the G7 stock price Index ($MXGX$), the dollar index (DXY), and yen-dollar exchange rates (USD/JPY). For the regional market factor, I use the EM stock price composite index ($MXEF$), Asian and Latin American stock prices ($MXMS$, $MXLA$), and the EM currency index ($FXMX$). All variables used to control the global and regional factors are summarized in Table 3.11.

Residual series in the alternative mean equations are drawn and used in the variance equation when estimating alternative models. As shown in the third through sixth columns of Table 3.3, the explanatory powers of the global and regional market variables relative to domestic asset returns rise to 80. Correlation coefficients between the two residuals after controlling for global and regional variables, as shown in the second and third columns of Table 3.5, shrink to almost zero or very low levels. These preliminary results support the idea of employing a factor model in the mean equation of the GARCH model.

Scenarios and interpretations

Based on the results obtained with alternative GARCH models as suggested above, when combined with those obtained with Benchmark model, I expect one of the following four scenarios to take place. If the spillovers remain with those residual series in both (normal and crisis) sample periods, which we denote as [Scenario 1], we observe that the spillovers are not entirely a byproduct of a high degree of correlation between the two asset returns from the common fundamentals shock, but also result from other spillover sources, such as sequential information transmission and contagion. If spillovers turn out to be significant only during periods of crisis [Scenario 2], the results would indicate that they are explained mostly by fundamentals shocks in normal periods but, during crises, contagion would also serve as an important source of spillovers. The reverse case, in which spillovers are significant only during normal times [Scenario 3], supports the information transmission hypothesis while rejecting the contagion hypothesis. If the parameters for cross-market spillovers are insignificant at all times [Scenario 4], the results would indicate that the spillovers stem mostly from fundamentals rather than contagion or information transmission. The expected results and possible interpretations of each scenario are summarized in Table 3.6.

3.5 Empirical analysis

3.5.1 Existence of volatility spillovers

Table 3.14 reports eight common- and cross-market spillover parameters estimated with Benchmark model 1. At the 95% confidence level, nine countries (BRA, HKG, IND, KOR, MEX, MYS, RUS, TUR, and TWN) show significant spillovers.[25] Five countries (CHN, IDN, PHL, SGP, and THA) do not exhibit clear evidence of such spillovers.

Volatility spillovers running from the stock market to the FX market are easier to detect. Of the nine countries with significant spillovers, five exhibit spillovers in both directions, while four show evidence of spillover only from the stock market to the FX market. No country shows evidence of spillover only from the FX market to the stock market.[26] These results support the theories of relationships between asset markets discussed in Sub-section 3.2.1, especially the stock-oriented models of Branson (1981) and Frankel (1987).

Comparing the magnitude of the coefficients, we find that common market shocks have greater impact on the FX and stock markets than do spillover in-

[25] At the 90% confidence level, 11 countries show significant volatility spillovers.

[26] One explanation for the lack of spillovers from the FX market to the stock market in the literature is that positive exchange rate volatility effects on stock returns for some firms are offset by negative effects for others (Jorrison, 1990). Another possible explanation is that spillovers are neutralized by the effective use of exchange rate risk hedges, such as forwards, futures, and currency options. The use of financial hedging against exchange risk is widespread among large companies, whose stock prices are the main constituents of national stock market indices (Bodnar and Genry, 1993)

fluences from other markets. The coefficients for cross-market spillovers range from one-tenth to one-half of those for common market spillovers, which is intuitive and generally consistent with findings in the literature.[27]

3.5.2 Parameter shifts of volatility spillovers

Financial liberalization and volatility spillover

Likelihood Ratio (LR) statistics shown in Table 3.15 support the overall validity of introducing the dummy variables. At the 95% confidence level, all countries reject the null hypothesis that the dummy variables are all meaningless. Out of three sets of dummy variables, countries differ as to which set they should take to best fit their data.

Table 3.16 shows the estimated parameters for cross-market spillovers: four for the full sample and four for the others after the 1990s (Alternative model 1-1). Out of five countries that satisfy the data availability condition, data from four countries (IND, KOR, MYS, and TWN) suggest that there is a significant time shift in the parameters, i.e., significant dummy variables. For KOR, however, only the parameters for the dummies are significant, which indicates that spillovers are significant only after the 1990s.

Including the 1998 dummy variables (Alternative model 1-2), we find that the dummy variables in the model specification play a significant role in five out of the 10 countries analyzed, as shown in Table 3.17. In the cases of BRA

[27] Hurditt (2004), for example, finds that the impact of volatility spillovers from other markets in the Jamaican bond market is around one-tenth of the influence of shocks in the bond market itself.

and TUR, however, only the dummy variables are significant, indicating that spillovers are significant only after 1998.

Finally, the model with dummy variables for the post-2008 period (Alternative model 1-3) is estimated. As reported in Table 3.18, the time shift of the spillover parameters is significant for nine countries. In the cases of PHL and SGP, which do not show volatility spillovers with any other models, parameters for the dummy variables turn out to be significant.

The above results indicate two points. First, spillover parameters have shifted depending on the sample period, which can be interpreted as the result of a structural change in market dependency. After de jure or de facto financial market liberalization, the trading behaviors of market participants might have changed substantially. As explained in the introduction, such a time shift in spillover effects could be generated by increased common shocks across markets or by unusual behavior on the part of investors during times of financial market instability. Second, in some countries, only dummy variables turn out to be significant, i.e., volatility spillovers are observed only in the recent sample. In any case, the above results showing a recent increase in market dependency support the occurrence of a positive and significant relationship between financial liberalization and market dependence.

Asymmetric spillover effects

LR test results in Table 3.19 support the significance of the dummy variables for asymmetric spillovers at the 5% significance level. Except for SGP and PHL, none of the countries accepts the null hypothesis of symmetric spillovers. Based on likelihood statistics, the results for five countries are better explained by dummy variables for currency depreciation days (Alternative model 1-4), while the results for the other seven countries are better accommodated by stock return decreasing days (Alternative model 1-5).

The role of the assumption of asymmetric spillovers is interpreted differently across countries, with the results displayed in Table 3.20 and Table 3.21. CHN, HKG, and THA, which do not show significant spillovers with Benchmark model 1, are estimated to have volatility spillovers with the inclusion of those dummy variables. Those countries show volatility spillovers only when asset prices are decreasing. BRA, MEX, TUR and TWN turn out to have significant spillovers with both the benchmark and alternative models, indicating that while spillover effects are significant as a whole they are statistically asymmetric. The results for PHL and SGP do not show a clear relationship between markets in spite of the introduction of asymmetric spillover parameters.

The above results suggest that the assumption of asymmetric spillovers is in most cases helpful in estimating GARCH-based volatility spillover models for EM countries, which is consistent with the results of many previous studies including Kanas (2000). Combined with the stylized asymmetric distribution of the second moments of asset returns observed in Sub-section 3.2.2, the asymmetric spillover effects imply that past negative volatility shocks have more significant and stronger effects than do past positive shocks, which is also known as the 'leverage' effect. The leverage effect occurs when there is an increase in information following an announcement of bad news. In such a case, the results can also be interpreted as evidence for the market contagion hypothesis insofar as market conditions and the sentiments of market participants are influential factors for volatility spillover dynamics.

Turbulence and volatility spillover

LR statistics in the third column in Table 3.19 indicate that dummy variables for turbulent periods (Alternative model 1-6) add explanatory power to Benchmark model 1 at a very high (99%) confidence level. Table 3.22 then reports the estimation results with the four dummy variables. Of the 14 analyzed countries, eight reveal a contagion shift of volatility spillovers during turbulent periods.

Including four dummy variables for turbulence periods, EM countries are divided into four groups based on their empirical results. Six countries (HKG, KOR, MEX, RUS, TUR, and TWN) show spillovers in both normal and turbulent periods. These countries are interpreted to have significant spillovers during normal periods and the parameters are seen to shift during times of crisis. BRA and PHL show significant spillovers only during crisis periods. Some countries (CHN, IDN, and SGP), which do not show volatility spillovers with Benchmark model 1, do not yield any notable results during turbulent periods either.

As shown in Table 3.3, the volatilities of the currency and stock returns of EM countries have increased more dramatically compared with those of advanced countries, and this could be partially explained by the significant shift in contagion parameters. Inasmuch as most EM countries suffered through several financial crises following liberalization, and their financial markets have been severely interrupted during and after such crises, the assumption pertaining to contagion-shift parameters should not be omitted from this analysis. Indeed, based on the maximum likelihood criteria displayed in Tables 3.15 and 3.19, turbulent period dummies turn out to be the most powerful factor in explaining the parameter shifts in volatility spillovers within the BEKK GARCH(1,1) framework.

In accordance with the empirical results obtained with Benchmark model 1, we should acknowledge that the stock market still plays a role as a main spillover exporter during turbulent periods. That is, of eight countries exhibiting contagion-shift volatility, all except TUR run only from the stock market to the FX market. This result could provide a clue to the soaring and persisting volatilities in the currency markets of EM countries during crises. Even a small news shock in capital markets could create instability in currency markets when market sentiment is very sensitive.

3.5.3 Source of volatility spillovers

In this section, volatility spillovers are tested with a BEKK GARCH(1,1) model with restricted mean equations. Considering the previous result that spillovers are significantly influenced by market conditions and thereby exhibit asymmetric or contagion-shift characteristics, I set two additional benchmark models: a BEKK GARCH(1,1) model with crisis dummy variables (Benchmark model 2-1) and one with asymmetric dummy variables (Benchmark model 2-2). In addition, considering that most countries show significant parameter shifts after 2008, the sample period for the estimation of the new benchmark and alternative models in this section is narrowed to recent periods (after 2008).

Empirical results with the contagion-shift model

Table 3.23 shows estimation results of Benchmark model 2-1, which are consistent overall with those obtained with Benchmark model 1. Four countries (KOR, MEX, PHL, and TWN) show significant spillovers in both the full and sub- (crisis) sample. The other five countries (BRA, CHI, IDN, RUS, SGP, and THA) are found to have significant spillovers only during crises. HKG and MYS show no significant evidence of spillovers.

After the asset returns are controlled for with global variables in the mean equation (Alternative model 2-1-1), all countries report very similar results from the perspective of the significance of cross-market spillover parameters. All the parameters turn out to be insignificant in the full sample, whereas the dummy variables for turbulent periods remain significant in all countries, as shown in Table 3.24. For some countries (HKG, MEX, MYS, and TUR), residuals in the mean equation do not even show significant common market spillover parameters (a_{11}, a_{22}, b_{11}, and b_{12}) at the 95% confidence level, rendering them appropriate for analysis with a multivariate BEKK GARCH model. I have therefore excluded them from the analysis.

After introducing regional variables (Alternative model 2-1-2), the results are consistent with the results obtained with Alternative model 2-1-1. As shown in Table 3.25, no country exhibits significant spillover effects. Meanwhile, all countries show significant crisis dummy variables. Again, six countries turn out to be inappropriate for the BEKK GARCH estimation.

The above results support the second of the four scenarios introduced in Sub-section 3.4.3. Spillovers have originated to a significant extent from common information about fundamentals during normal periods, but idiosyncratic market shocks are not found to be transmitted into other markets. During crisis periods, however, even after fundamental factors are extracted, spillovers remain significant, which supports the presence of contagion effects.

Strong co-movements between asset returns, as shown by the cross-correlation coefficients shown in Table 3.12, indicate that common information is being shared to a significant extent across domestic asset markets. The greater the depth and width of the financial markets, and the higher the proportion of foreign investors in the trading volume in those financial markets, the more common news the capital and FX markets will be expected to share. In this sense, financial market liberalization and integration should be an important factor in explaining significant spillovers in EM countries. Meanwhile, during turbulent periods, unfavorable market situations make market sentiment very sensitive and all kinds of news shocks are seen to spill over and influence other markets.

Empirical results with the asymmetric spillover model

With the inclusion of dummy variables for asymmetric spillovers (Benchmark model 2-2), as shown in Table 3.26, 11 countries show significant results, with significant coefficients for the full and sub-samples for seven countries.

Comparing the results obtained with Alternative models 2-2-1 (with global market variables in the mean equation) and 2-2-2 (with global and regional market variables in the mean equation), the effects of controlling for fundamental factors are less obvious. As shown in Table 3.27, some countries, including PHL and RUS, show no spillovers in any case. For other countries, including IND, however, spillovers are significant for both the full sample and the sub-sample. After controlling for regional variables, as shown in Table 3.28, there remain countries that do not reject the null hypothesis of no spillovers between markets. Combined with the results reported in the previous sub-section, the significant spillovers seen for some countries in this case are expected to be explained mostly by market turbulence.

3.6 Conclusion

This chapter takes three empirical steps to shed light on volatility spillovers between stock returns and currency returns in EM countries. First, volatility spillovers are found to be significant in most countries. Such spillovers are observed running mostly from stock markets to FX markets, supporting such classical theories on market relationships as the stock-oriented model. Second, the study modifies the classical BEKK GARCH model by introducing alternative sets of dummy variables for the parameter shift in the variance equation. The results indicate that the pace of volatility spillovers has changed as EM countries have experienced financial liberalization. Such spillovers are also seen to be significantly influenced by market conditions, a finding that is broadly consistent with the results of several previous studies. Most countries show evidence of both asymmetry and contagion shift in spillover parameters.

Finally, this chapter analyzes the sources of volatility spillovers. To this end, variables representing global and regional financial market movements are introduced as additional control variables in the mean equation of the GARCH model, thereby eliminating substantial co-movement between the two types of asset returns. After controlling for common factors, the residual series in the mean equation provides no evidence of volatility spillovers, a result that indicates that spillovers are explained mostly by reference to co-movement of two markets rather than by sequential information transmission between markets. During turbulent periods, however, spillovers through controlled residuals remain significant, which is interpreted to mean that volatilities are transmitted from one market to another with no common fundamentals shock, supporting the contagion hypothesis.

The empirical results drawn above underscore that FX markets and stock markets in EM countries are characterized by quantifiable linkages of their fundamentals. During times of crisis, not only common shocks but also irrational behaviors could propagate spillovers between markets. In these circumstances, financial system participants, including regulators, must consider these intricate market connections, which involve uncertainty spillovers that are relevant to financial system stability and monetary transmission.

The results obtained in this study should be interpreted in light of several limitations. The study does not consider country-specific factors such as financial market development and foreign exchange regimes. The study also fails to describe the dynamics of volatility spillovers in each country. These questions are left for future research.

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Figures and Tables

Table 3.1: Cross-correlations between currency and stock returns of EM countries

(1^{st} moment)	1980 - 1989	1990 - 1999	2000 - 2009	2010 - 2012
BRA	-	0.0048	-0.5307	-0.4957
IND	-0.0127	0.0085	-0.3611	-0.4963
CHN	-	0.0240	-0.0144	-0.1336
KOR	-0.0373	-0.2200	-0.3560	-0.6339
IDN	-	-0.2152	-0.3232	-0.4956
MAL	-0.0217	-0.2950	-0.2486	-0.4589
(2^{nd} moment)	1980 - 1989	1990 - 1999	2000 - 2009	2010 - 2012
BRA	-	0.2512	0.4494	0.3212
IND	0.0217	0.0124	0.4373	0.3517
CHN	-	0.0375	0.0013	-0.2274
KOR	-0.0077	0.2631	0.4324	0.3152
IDN	-	0.3034	0.1795	0.2160
MAL	-0.0070	0.5205	0.1186	0.2342

Notes: 1. Cross-correlations between first differences of log levels
2. ′-′ indicates that data are not available.

Table 3.2: Volatility of currency and stock Returns of EM countries

(unit: %)	currency				stock			
moment	1^{st}		2^{nd}		1^{st}		2^{nd}	
daily price change	up	down	up	down	up	down	up	down
BRA	0.79	0.82	4.10	3.35	1.28	1.30	9.57	8.19
IND	0.28	0.31	0.43	0.43	1.14	1.22	9.10	7.31
CHN	0.08	0.06	0.11	0.02	1.57	1.15	6.86	6.18
KOR	0.59	0.59	5.15	2.98	1.14	1.33	6.50	8.89
IDN	0.59	0.57	3.06	1.73	0.95	1.15	4.67	7.25
MAL	0.27	0.27	0.31	0.33	0.61	0.74	1.73	3.80

Notes: 1. Volatilities are measured by standard deviations.
2. 'Up' indicates periods during which daily currency rates and stock returns increase and 'down' indicates the opposite conditions.

Table 3.3: Standard deviations of currency and stock returns of EM and advanced countries

(unit: %)	currency rates			stock price index		
period	Normal(A)	Crisis(B)	C=B/A	Normal(A)	Crisis(B)	C=B/A
EM countries	0.35	1.00	2.88	1.36	3.20	2.37
BRA	0.83	2.45	2.95	1.62	4.17	2.57
RUS	0.19	1.00	5.26	1.91	6.86	3.59
IND	0.25	0.77	3.08	1.42	3.15	2.21
PHL	0.27	0.56	2.07	1.24	2.51	2.02
HKG	0.03	0.04	1.33	1.63	4.72	2.89
THA	0.34	0.34	1.00	1.33	2.51	1.88
MEX	0.49	1.71	3.49	1.13	3.05	2.69
TUR	0.85	1.88	2.21	1.92	3.04	1.58
TWN	0.24	0.40	1.67	1.17	2.45	2.09
SGP	0.26	0.60	2.31	0.94	2.77	2.94
USA	-	-	-	0.74	3.37	4.55
Euro	0.58	1.26	2.15	1.00	3.68	3.68
Japan	0.51	1.30	2.53	1.16	3.67	3.16

Notes: 1. Currency rates per US Dollar.
2. EM countries are based on the average of 14 EM countries.
3. The normal period is from January 2003 to June 2007.
4. The crisis period is from September 2008 to March 2009.
5. Stock price index for advanced economies include Dow Jones (US), Eurostoxx50 (Euro), and Nikkei (Japan).
6. All variables are analyzed after being transformed into the first differences of the log levels.

Table 3.4: Degree of financial development index

Country	HKG	SGP	KOR	MAL	CHN	BRA	RUS	IND	TUR	MEX	PHP	IDN
Rank	1	4	15	18	23	32	39	40	42	43	49	50

Note: Orders out of 60 developed/developing countries.
Source: World Economic Forum (2012)

Table 3.5: Lists of daily data

country	sample period	observations	currency rates	stock price index
BRA	7/4/1994 - 11/30/2012	4,561	BRL	IBOV
CHI	3/1/1994 - 11/30/2012	4,559	CNY	SHASHR
HKG	7/16/1993 - 11/30/2012	4,793	HKD	HSCEI
IND	1/8/1980 - 11/30/2012	7,286	INR	SENSEX
IDN	11/7/1991 - 11/30/2012	5,137	IDR	JCI
KOR	2/22/1984 - 11/30/2012	6,344	KRW	KOSPI
MEX	1/20/1994 - 11/30/2012	4,711	MXN	MEXBOL
MYS	1/20/1994 - 11/30/2012	6,630	MYR	FBMKLCI
PHL	1/5/1987 - 11/30/2012	6,431	PHP	PCOMP
RUS	12/15/1993 - 11/30/2012	4,474	RUB	ROS
SGP	9/1/1999 - 11/30/2012	3,332	SGD	FSSTI
THA	7/6/1987 - 11/30/2012	6,233	THB	SET
TWN	2/24/1984 - 11/30/2012	5,775	TWD	TWSE
TUR	1/5/1988 - 11/30/2012	6,218	TRY	XU100

Source: Bloomberg

Table 3.6: Summary statistics on daily currency returns of EM countries

Country	Mean	STD	Skewness	Kurtosis	Jarque-Bera	(prob)
BRA	0.017	1.485	2.475	40.75	55,715.9	(<0.01)
CHI	0.021	0.120	5.108	93.20	310,099.1	(<0.01)
HKG	0.000	0.032	-2.648	51.91	425,548.2	((<0.01)
IND	0.001	0.728	1.840	31.46	58,720.2	(<0.01)
IDN	-0.003	0.400	-0.449	9.508	1,924.4	(<0.01)
KOR	0.012	0.401	0.022	6.030	676.8	(<0.01)
MEX	0.038	0.983	2.804	98.59	1,612,135.0	(<0.01)
MYS	0.016	0.581	-1.243	138.9	3,248,945.0	(<0.01)
PHP	-0.005	0.334	-0.287	17.03	34,711.2	(<0.01)
RUS	-0.067	1.267	1.402	215.1	7,873,628.0	(<0.01)
SGP	-0.009	0.335	0.172	7.834	3,258.0	(<0.01)
THA	-0.009	0.598	-3.401	131.5	29,144.5	(<0.01)
TWN	-0.006	0.266	0.101	34.63	175,892.9	(<0.01)
CHI	0.086	1.157	12.87	457.3	36,410,458.0	(<0.01)

Table 3.7: Summary statistics on daily stock returns of EM countries

Country	Mean	STD	Skewness	Kurtosis	Jarque-Bera	(prob)
BRA	0.064	2.338	0.200	8.036	980.5	(<0.01)
CHI	0.104	2.128	-0.276	5.032	166.9	(<0.01)
HKG	0.057	2.519	0.461	8.553	5,572.1	((<0.01)
IND	0.073	1.801	-0.150	7.819	1,662.2	(<0.01)
IDN	0.137	2.053	3.512	55.54	125,783.6	(<0.01)
KOR	-0.011	0.401	0.038	5.996	662.0	(<0.01)
MEX	0.077	1.659	0.187	6.150	6,579.9	(<0.01)
MYS	0.030	1.561	0.324	26.62	98,191.0	(<0.01)
PHP	0.041	1.797	0.580	14.06	21,768.0	(<0.01)
RUS	0.152	3.167	0.445	13.73	20,379.4	(<0.01)
SGP	0.018	1.277	-0.128	7.204	2461.1	(<0.01)
THA	0.034	1.831	0.149	8.607	5,544.7	(<0.01)
TWN	0.016	1.753	-0.120	5.129	807.6	(<0.01)
CHI	0.158	2.626	0.379	8.770	5,955.7	(<0.01)

Table 3.8: Stock market liberalization of EM countries

BRA	IND	IDN	KOR	MYS	MEX	PHL	THA
05/1991	11/1992	09/1989	01/1992	12/1988	06/1991	05/1989	09/1987

Source: Bekaert and Harvery (2003)

Table 3.9: Breaking-point Test results with foreign portfolio investments of EM countries

Country	Testing sample period (number of breakpoints tested)	Suggested Break Point	LR statistics (p-value)
IND	1999m01 - 2012m10 (148)	2007m06	568.9 (0.01)
IDN	1998m11 - 2012m01 (159)	2008m11	1,516.1 (0.01)
KOR	1998m02 - 2012m10 (159)	2007m09	302.7 (0.01)
MEX	1999m02 - 2012m10 (147)	2009m02	528.4 (0.01)
THA	1999m02 - 2012m10 (147)	2006m06	326.2 (0.01)

Notes: 1. Quandt-Andrews unknown breakpoint test results from least squares with portfolio investments (dependent variable) and time trends (explanatory variable).
2. The null hypothesis is no insignificant breaking point.

Table 3.10: Explanatory power (R^2) of mean equations

Model	Benchmark model		Alternative model 2-1-1 or 2-2-1		Alternative model 2-1-2 or 2-2-2	
Independent variables	Bi-variate VAR(2)		Bi-variate VAR(2), global variables		Bi-variate VAR(2), regional variables	
Dependent variable	Currency	Stock	Currency	Stock	Currency	Stock
BRA	1.2	3.7	44.0	66.0	58.7	80.3
CHI	1.1	6.7	58.6	50.9	64.3	70.8
HKG	2.4	2.0	10.7	40.9	13.9	82.9
IDN	1.9	2.9	20.3	40.4	27.3	69.7
IND	1.2	2.3	31.6	36.3	47.0	69.7
KOR	3.7	2.6	32.8	41.2	59.9	77.4
MEX	0.7	2.7	51.9	67.3	61.8	76.4
MYS	0.9	3.7	38.1	37.5	56.2	69.7
PHL	1.8	14.1	55.9	38.2	62.5	70.9
RUS	3.4	2.1	43.7	55.0	48.2	71.0
SGP	1.1	6.7	58.6	50.9	64.3	70.8
THA	0.5	2.1	27.1	36.6	32.3	49.2
TUR	2.0	8.1	55.0	43.1	65.0	50.1
TWN	1.2	2.4	32.7	38.0	49.6	69.7

Note: Alternative models 2-1-1 and 2-1-2 are variations of Benchmark model 2-1, which introduces crisis dummy variables in the variance equation. Alternative model 2-1-1 deviates from Benchmark model 2-1 in that explanatory variables in the mean equation include vector autoregressive terms of dependent variables and global market variables. Alternative model 2-1-2 then also includes regional variables in addition to the VAR terms and global variables. Alternative models 2-2-1 and 2-2-2 are similarly variations of Benchmark model 2-2 which have asymmetric dummy variables in the variance equation, with mean equations with explanatory variables of the VAR terms and global variables (Alt. model 2-2-1) or VAR terms, global and regional market variables (Alt. model 2-2-2).

Table 3.11: Indicators for global and regional financial markets

Category	Variables	Description
global financial market variables	$MWXO$	MSCI index on weighted average world stock prices
	$MXGX$	MSCI index on G7 stock prices
	$USDJPY$	spot exchange rates between US Dollar and Japan Yen
	DXY	dollar (DXY) index
regional financial market variables	$MXEF$	MSCI composite index on emerging market stock prices
	$FXMX$	MSCI composite index on emerging market currencies
	$MXMS$	MSCI composite index on Asian composite stock prices
	$MXLA$	MSCI composite index on Latin America stock prices

Source: Bloomberg

Table 3.12: Cross-correlations between residuals series in mean equations

Model	Benchmark model	Alternative model 2-1-1 and 2-2-1	Alternative model 2-1-2 and 2-2-2
Independent variables	Bi-variate VAR(2)	Bi-variate VAR(2), global variables	Bi-variate VAR(2), regional variables
BRA	0.60	0.21	0.02
CHI	0.29	0.05	0.11
HKG	-0.13	0.00	0.03
IDN	0.47	0.31	0.22
IND	0.51	0.34	0.20
KOR	0.61	0.41	-0.03
MEX	0.58	-0.09	0.03
MYS	0.44	0.20	-0.02
PHL	-0.09	-0.06	0.00
RUS	0.55	0.30	0.29
SGP	-0.29	-0.05	0.11
THA	0.32	0.19	0.15
TUR	-0.49	-0.22	-0.17
TWN	0.48	-0.31	-0.01

Note: Alternative models 2-1-1 and 2-1-2 are variations of Benchmark model 2-1, which introduces crisis dummy variables in the variance equation. Alternative model 2-1-1 deviates from Benchmark model 2-1 in that explanatory variables in the mean equation include vector autoregressive terms of dependent variables and global market variables. Alternative model 2-1-2 then also includes regional variables in addition to the VAR terms and global variables. Alternative models 2-2-1 and 2-2-2 are similarly variations of Benchmark model 2-2 which have asymmetric dummy variables in the variance equation, with mean equations with explanatory variables of the VAR terms and global variables (Alt. model 2-2-1) or VAR terms, global and regional market variables (Alt. model 2-2-2).

Table 3.13: Scenarios for sources of volatility spillovers

	Significance of spillovers parameters in the alternative model 2-1-1 through 2-2-2		Role of each source of volatility spillover		
Scenario	normal	crisis	Common information	Information transmission	Contagion
1	o	o	yes	yes	yes
2	x	o	yes	no	yes
3	o	x	yes	yes	no
4	x	x	yes	no	no

Notes: 1. 'o' means spillover parameters are significant; 'x' means they are not significant.
2. 'Yes' indicates a role for a spillover source and 'No' indicates no role.

Table 3.14: Estimated parameters (Benchmark model 1)

	a_{11}	a_{12}	a_{21}	a_{22}	b_{11}	b_{12}	b_{21}	b_{22}
BRA	0.38***	0.04	0.02*	0.30***	0.93***	-0.00	-0.01**	0.95***
	(0.05)	(0.08)	(0.01)	(0.04)	(0.02)	(0.03)	(0.00)	(0.02)
CHI	0.54	0.43	0.00	0.28**	0.84***	-0.27	0.00	0.96***
	(0.02)	(1.09)	(0.00)	(0.05)	(0.07)	(0.71)	(0.00)	(0.01)
HKG	1.06***	0.01	0.003**	0.20***	0.73***	0.01	0.00	0.97***
	(0.31)	(0.30)	(0.001)	(0.04)	(0.12)	(0.04)	(0.001)	(0.01)
IDN	0.31***	0.01	0.02	0.33***	0.96***	0.00	-0.00	0.94***
	(0.07)	(0.02)	(0.04)	(0.05)	(0.02)	(0.01)	(0.01)	(0.02)
IND	0.22	0.03	0.01***	0.31***	0.98***	0.01	-0.002**	0.94***
	(0.04)	(0.15)	(0.002)	(0.03)	(0.01)	(0.01)	(0.001)	(0.01)
KOR	0.36***	0.09**	-0.01	0.23***	0.95***	-0.02	0.001	0.97***
	(0.02)	(0.05)	(0.004)	(0.02)	(0.01)	(0.01)	(0.001)	(0.01)
MEX	0.59***	-0.14	0.11*	0.18***	0.80***	0.07**	-0.04**	0.98***
	(0.12)	(0.08)	(0.06)	(0.03)	(0.07)	(0.04)	(0.02)	(0.01)
MYX	0.47***	0.43	0.00	0.28**	0.84***	-0.27	0.00	0.96***
	(0.04)	(1.09)	(0.00)	(0.04)	(0.07)	(0.71)	(0.00)	(0.01)
PHL	0.21***	-0.04	0.003	0.35***	0.97***	-0.001	-0.001	0.92***
	(0.02)	(0.13)	(0.003)	(0.03)	(0.01)	(0.015)	(0.001)	(0.02)
RUS	0.37	-0.11	-0.004	0.37***	0.93***	0.05**	0.003	0.92***
	(0.04)	(0.06)	(0.004)	(0.04)	(0.01)	(0.02)	(0.002)	(0.01)
SGP	0.22***	0.04	0.03*	0.30***	0.93***	-0.003	-0.01**	0.95***
	(0.02)	(0.08)	(0.01)	(0.04)	(0.02)	(0.032)	(0.003)	(0.02)
THA	0.34***	-0.26	-0.001	0.32***	0.93***	0.08*	0.000	0.92***
	(0.03)	(0.15)	(0.005)	(0.03)	(0.01)	(0.05)	(0.002)	(0.02)
TUR	0.63***	-0.44**	0.08**	0.10***	0.81***	0.15	-0.01**	0.99***
	(0.12)	(0.17)	(0.03)	(0.04)	(0.06)	(0.08)	(0.00)	(0.00)
TWN	0.56***	-0.57***	-0.02**	0.24***	0.81***	0.28***	0.01**	0.97***
	(0.08)	(0.12)	(0.01)	(0.02)	(0.04)	(0.06)	(0.00)	(0.00)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

Table 3.15: Likelihood-ratio Test results (Alternative models 1-1, 1-2, and 1-3)

	Alternative model 1-1	Alternative model 1-2	Alternative model 1-3
BRA	-	862.7***	12.1**
CHI	-	22,119.7***	19391.1***
HKG	-	48.3***	344.0***
IDN	-	11.4**	25.5***
IND	340.6***	185.5***	80.3***
KOR	7.5	1905.4***	48.7***
MEX	-	343.8***	66.2***
MYS	53.1***	80.4***	60.4***
PHL	6.3	4.9	21.5***
RUS	-	20.4***	35.8***
SGP	-	-	35.0***
THA	-	8.43	10.6**
TUR	-	164.1***	11.3**
TWN	146.8***	52.9***	80.1***

Notes: 1.Testing the null hypothesis of no volatility spillovers ($a_{12d}= a_{21d}=b_{12d}=b_{21d}=0$).

2. Displayed numbers are chi-squared (4) values.

3. *** and ** indicate rejecting the null hypothesis at confidence levels of 99% and 95%, respectively.

4. - indicates that the LR test is not executed for a given country due to the lack of data.

5.Alternative models 1-1, 1-2, and 1-3 are variations of Benchmark model 1 with time dummies for post- 1990, 1998, and 2008, respectively, in the variance equations. .

Table 3.16: Estimated parameters (Alternative model 1-1)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
IND	0.26*	0.03**	-0.22***	-0.02*	0.01	-0.01**	0.00	0.01**
	(0.14)	(0.01)	(0.10)	(0.01)	(0.05)	(0.01)	(0.04)	(0.005)
KOR	-0.01	-0.01	0.10***	0.01	0.001	0.001	-0.02	-0.001
	(0.02)	(0.01)	(0.04)	(0.02)	(0.04)	(0.002)	(0.03)	(0.003)
MYX	-0.02	-0.03**	-0.15	0.03*	-0.02	0.01*	0.06***	-0.01*
	(0.07)	(0.02)	(0.05)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)
PHL	-0.64	0.005	0.59	-0.002	0.18	-0.002	-0.18	0.002
	(1.93)	(0.003)	(1.94)	(0.01)	(0.46)	(0.002)	(0.45)	(0.006)
TWN	-0.32	-0.02***	-0.08	0.04***	0.14***	0.003**	0.01	-0.01***
	(0.17)	(0.009)	(0.29)	(0.01)	(0.04)	(0.002)	(0.07)	(0.003)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative model 1-1 is a variation of the Benchmark model 1with time dummy for post 1990 period in the variance equation.

Table 3.17: Estimated parameters (Alternative model 1-2)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
BRA	0.77***	-0.004	-0.81	-0.04**	-0.23*	0.002	0.24*	0.02***
	(0.65)	(0.004)	(0.71)	(0.02)	(0.12)	(0.003)	(0.14)	(0.006)
IDN	-0.003	0.03***	0.14	0.01	0.003	-0.007	-0.03	-0.004
	(0.06)	(0.01)	(0.13)	(0.02)	(0.02)	(0.004)	(0.03)	(0.01)
IND	0.20***	0.02	-0.20	-0.02	-0.04*	-0.007	0.05	0.005
	(0.07)	(0.02)	(0.12)	(0.02)	(0.03)	(0.004)	(0.05)	(0.005)
KOR	0.02	-0.008	0.09	-0.001	0.003	0.000	-0.03	0.001
	(0.05)	(0.005)	(0.09)	(0.03)	(0.01)	(0.001)	(0.02)	(0.007)
MEX	-0.05	0.17**	-0.09	-0.16***	0.02	-0.03***	0.04	0.03***
	(0.07)	(0.07)	(0.13)	(0.06)	(0.03)	(0.01)	(0.05)	(0.008)
MYX	-0.35***	-0.02**	0.18	0.02*	0.10***	0.01**	-0.06*	-0.01**
	(0.11)	(0.008)	(0.12)	(0.01)	(0.03)	(0.002)	(0.03)	(0.002)
PHL	-0.21*	0.003	0.22	-0.002	0.04	-0.001	-0.05	0.001
	(0.11)	(0.003)	(0.13)	(0.01)	(0.03)	(0.001)	(0.04)	(0.005)
RUS	-0.08**	-0.002	-0.04	-0.003	0.04	0.002	0.01	0.002
	(0.19)	(0.003)	(0.08)	(0.005)	0.03	(0.001)	(0.01)	(0.002)
THA	-0.26	0.00	-0.07	-0.004	0.08*	-0.001	0.02	0.003
	(0.19)	(0.01)	(0.17)	(0.01)	(0.05)	(0.006)	(0.04)	(0.003)
TUR	-0.15	-0.005	-0.20	0.10*	0.15	-0.002	-0.04	-0.01***
	(0.37)	(0.03)	(0.40)	(0.06)	(0.13)	(0.005)	(0.13)	(0.003)
TWN	-0.32*	-0.02***	-0.08	0.04***	0.14***	0.003**	0.01	-0.01***
	(0.17)	(0.009)	(0.29)	(0.01)	(0.04)	(0.002)	(0.06)	(0.003)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative model 1-2 is a variation of the Benchmark model 1 with time dummies for the post-1998 period in the variance equation.

Table 3.18: Estimated parameters (Alternative model 1-3)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
BRA	0.03***	0.02	0.03	0.01	-0.001	-0.01**	-0.02	0.002
	(0.07)	(0.01)	(0.08)	(0.02)	(0.03)	(0.004)	(0.03)	(0.004)
CHI	2.52	0.00	-3.00	0.003	-2.22	0.00	2.73	-0.002
	(1.85)	(0.00)	(1.97)	(0.004)	(1.64)	(0.00)	(1.71)	(0.002)
HKG	4.40	0.004**	-2.66	-0.004**	1.56	0.00***	0.34	0.00***
	(3.13)	(0.002)	(2.76)	(0.002)	(0.96)	(0.00)	(0.82)	(0.00)
IDN	0.03	0.02**	-0.04	0.003	-0.007	-0.006**	0.05	-0.003
	(0.02)	(0.01)	(0.24)	(0.03)	(0.007)	(0.003)	(0.05)	(0.007)
IND	0.15***	0.01***	-0.20***	0.02	-0.02**	-0.002***	0.06***	-0.005
	(0.04)	(0.002)	(0.06)	(0.01)	(0.01)	(0.001)	(0.01)	(0.003)
KOR	0.09***	-0.007	-0.03	-0.06***	-0.02	0.001	0.01	0.02***
	(0.06)	(0.004)	(0.07)	(0.02)	(0.02)	(0.001)	(0.02)	(0.004)
MEX	-0.08	0.12*	0.00	-0.16	0.05**	-0.04***	-0.01	0.01
	(0.06)	(0.07)	(0.04)	(0.10)	(0.02)	(0.01)	(0.01)	(0.01)
MYX	-0.23***	-0.003**	0.12**	0.08***	0.07***	0.00**	-0.04**	-0.02***
	(0.05)	(0.002)	(0.06)	(0.02)	(0.02)	(0.00)	(0.02)	(0.01)
PHL	-0.18*	0.003	0.26**	-0.03**	0.02	-0.001	-0.07**	0.01***
	(0.10)	(0.003)	(0.12)	(0.01)	(0.02)	(0.001)	(0.03)	(0.004)
RUS	-0.12**	-0.004	0.02	-0.03**	0.03**	0.003	0.03	0.01**
	(0.06)	(0.004)	(0.02)	(0.01)	(0.02)	(0.002)	(0.03)	(0.01)
SGP	-0.15**	-0.004	0.36***	-0.04***	0.05*	0.001	-0.07**	0.01**
	(0.08)	(0.01)	(0.12)	(0.01)	(0.03)	(0.001)	(0.03)	(0.003)
THA	-0.28**	0.003	0.37**	-0.007	0.09**	-0.003	-0.13*	0.004
	(0.14)	(0.008)	(0.18)	(0.01)	(0.05)	(0.004)	(0.07)	(0.004)
TUR	-0.45**	0.09	0.04	-0.02	0.16**	-0.01**	-0.01	0.00
	(0.18)	(0.04)	(0.06)	(0.03)	(0.08)	(0.003)	(0.02)	(0.004)
TWN	-0.36***	-0.02**	-0.04	0.04**	0.16***	0.004**	-0.01	-0.01***
	(0.11)	(0.01)	(0.09)	(0.02)	(0.06)	(0.002)	(0.02)	(0.005)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative model 1-2 is a variation of the Benchmark model 1 with time dummies for the post-2008 period in the variance equation.

Table 3.19: Likelihood-ratio Test results (Alternative models 1-4 , 1-5, and 1-6)

	Alternative model 1-4	Alternative model 1-5	Alternative model 1-6
BRA	155.4***	369.9***	845.7***
CHI	20,343.4***	22,601.0***	19,293.4***
HKG	446.0***	94.8***	487.3***
IDN	35.3***	15.3***	2,390.9***
IND	71.5***	4,758.4***	10,443.9***
KOR	9.9**	193.5***	2,368.1***
MEX	329.7***	215.0***	90.5***
MYS	9.8**	8.5*	8,835.0***
PHL	9.4*	9.4**	2,877.8***
RUS	126.2***	24.6***	45.0***
SGP	9.0*	2.2	63.3***
THA	24.9**	91.7**	1,677.7***
TUR	240.6***	176.3***	625.6***
TWN	64.3***	89.7***	2,148.6***

Notes: 1.Testing the null hypothesis of no volatility spillovers ($a_{12d}= a_{21d}=b_{12d}=b_{21d}=0$).

2. Displayed numbers are chi-squared (4) values.

3. *** and ** indicate rejecting the null hypothesis at confidence levels of 99% and 95%, respectively.

4. - indicates that the LR test is not executed for a given country due to the lack of data.

5.Alternative models 1-4 and 1-5 are variations of benchmark model 1 with dummy variables for currency depreciating days and stock return decreasing days, respectively, in the variance equations.

Table 3.20: Estimation results for cross-market spillover parameters (Alternative model 1-4)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
BRA	0.13*	0.003	0.06	0.03*	-0.05	0.004	0.02	-0.01**
	(0.07)	(0.003)	(0.11)	(0.02)	(0.09)	(0.003)	(0.23)	(0.01)
CHI	-0.24	0.00	-1.48	0.004	-1.22	0.001	2.97	-0.003
	(0.39)	(0.00)	(2.96)	(0.001)	(1.30)	(0.001)	(1.87)	(0.001)
HKG	-1.45	0.00*	-2.55*	0.004**	0.25	0.00	0.91	-0.001**
	(1.95)	(0.00)	(1.41)	(0.002)	(0.95)	(0.00)	(1.41)	(0.000)
IDN	-0.04	0.01	0.15***	0.03	0.02	-0.003	-0.06***	-0.01
	(0.54)	(0.03)	(0.03)	(0.97)	(0.11)	(0.01)	(0.01)	(0.20)
IND	0.11*	0.002	-0.006	0.006	-0.001	-0.001	-0.02***	-0.002
	(0.07)	(0.003)	(0.005)	(0.14)	(0.03)	(0.001)	(0.002)	(0.04)
KOR	0.12	-0.006	-0.06	-0.005	-0.06	0.00	0.06	0.001
	(0.39)	(0.004)	(0.57)	(0.02)	(0.10)	(0.001)	(0.14)	(0.004)
MEX	-0.06	0.19***	-0.08**	-0.16***	0.03	-0.06***	0.05	0.06***
	(0.06)	(0.05)	(0.04)	(0.05)	(0.02)	(0.01)	(0.04)	(0.02)
MYS	-0.17***	-0.002	0.03	-0.001	0.03	0.001*	0.03	-0.001*
	(0.03)	(0.002)	(0.05)	(0.001)	(0.03)	(0.00)	(0.05)	(0.001)
PHL	0.006	0.002	-0.18	0.00	-0.08	0.001	0.16	-0.004
	(0.02)	(0.004)	(0.23)	(0.006)	(0.05)	(0.003)	(0.87)	(0.004)
RUS	-0.03	0.004*	-0.08	-0.02***	0.05	-0.002	-0.05	0.01
	(0.35)	(0.003)	(1.04)	(0.004)	(0.42)	(0.004)	(0.87)	(0.01)
SGP	-0.03	-0.01*	0.08	0.01	-0.03	0.005*	0.06	-0.01
	(0.07)	(0.006)	(0.09)	(0.01)	(0.03)	(0.003)	(0.05)	(0.007)
THA	-0.36	0.006	0.22	-0.01*	0.17	-0.006	-0.13*	0.004
	(0.33)	(0.01)	(0.32)	(0.005)	(0.15)	(0.006)	(0.07)	(0.004)
TUR	-0.23***	0.11**	-0.04	-0.10**	0.07***	-0.01**	0.02	0.005
	(0.08)	(0.04)	(0.03)	(0.04)	(0.02)	(0.006)	(0.05)	(0.01)
TWN	-0.68***	-0.03***	0.16	0.02	0.22***	0.009***	0.15*	-0.01***
	(0.16)	(0.01)	(0.13)	(0.02)	(0.07)	(0.003)	(0.08)	(0.004)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative models 1-4 is a variation of benchmark model 1 with dummy variables for currency depreciating days in the variance equations.

Table 3.21: Estimation results for cross-market spillover parameters (Alternative model 1-5)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
BRA	0.16**	0.00	-0.01	0.04***	-0.07***	0.003***	0.08***	-0.01***
	(0.06)	(0.002)	(0.01)	(0.01)	(0.02)	(0.001)	(0.02)	(0.004)
CHI	-0.99	-0.001	-1.48	0.004***	-1.22	0.001**	2.97	-0.00***
	(1.77)	(0.001)	(2.96)	(0.001)	(1.30)	(0.001)	(1.88)	(0.00)
HKG	-1.30	0.00	-1.52*	0.004**	0.07	0.00**	1.09*	0.00***
	(1.07)	(0.001)	(0.97)	(0.002)	(0.06)	(0.00)	(0.61)	(0.00)
IDN	-0.05	0.02*	0.11	0.02	-0.003	-0.01*	0.004	0.001
	(0.07)	(0.01)	(0.08)	(0.02)	(0.04)	(0.004)	(0.086)	(0.007)
IND	0.10***	0.001	-0.01	-0.03	-0.05***	0.00	0.06**	0.004*
	(0.04)	(0.002)	(0.01)	(0.01)	(0.01)	(0.001)	(0.03)	(0.002)
KOR	0.08*	0.00	-0.02	-0.02	-0.05***	0.001	0.09***	0.002
	(0.04)	(0.002)	(0.01)	(0.02)	(0.01)	(0.001)	(0.03)	(0.002)
MEX	-0.09***	0.15**	0.00	-0.24***	0.12***	-0.04**	0.16***	0.04***
	(0.03)	(0.07)	(0.007)	(0.09)	(0.03)	(0.02)	(0.05)	(0.02)
MYX	-0.17***	-0.004	0.007	0.001	0.04***	0.00	0.01	0.001*
	(0.03)	(0.002)	(0.01)	(0.002)	(0.01)	(0.00)	(0.01)	(0.001)
PHL	0.01	0.002	-0.17	0.00	-0.07	0.001	0.16	-0.004
	(0.08)	(0.15)	(0.43)	(0.02)	(0.40)	(0.65)	(0.41)	(0.46)
RUS	-0.08	-0.005	-0.06	0.004	0.07	0.001	-0.04	0.004
	(0.07)	(0.005)	(0.10)	(0.006)	(0.05)	(0.001)	(0.06)	(0.003)
SGP	0.005	-0.008*	-0.01	0.00	0.04	-0.002	-0.07	0.008
	(0.01)	(0.006)	(0.03)	(0.01)	(0.09)	(0.006)	(0.18)	(0.01)
THA	-0.36***	0.006	0.22	-0.009*	0.17***	-0.006**	-0.17**	0.009*
	(0.09)	(0.006)	(0.25)	(0.005)	(0.05)	(0.002)	(0.08)	(0.005)
TUR	-0.30	0.10	-0.04	-0.10	0.11	-0.02	-0.01	0.02
	(-3.10)	(2.53)	(-1.13)	(-2.83)	(2.44)	(-2.210)	(-0.42)	(1.76)
TWN	-0.44	-0.04***	-0.05	0.04**	0.33***	0.002	-0.20	0.003
	(0.28)	(0.01)	(0.39)	(0.02)	(0.07)	(0.002)	(0.140)	(0.004)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative model 1-5 is a variation of benchmark model 1 with dummy variables for stock return decreasing days in the variance equations.

Table 3.22: Estimation results for cross-market spillover parameters (Alternative model 1-6)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
BRA	-0.02	-0.004	0.003	0.05**	0.02	0.001	0.01	-0.02**
	(0.08)	(0.004)	(0.06)	(0.01)	(0.02)	(0.001)	(0.01)	(0.01)
CHI	0.61	0.00	-0.37	0.002	-0.41	0.00	1.41	-0.002
	(1.17)	(0.00)	(2.22)	(0.005)	(0.87)	(0.00)	(2.656)	(0.004)
HKG	0.01	0.004**	0.01	-0.004**	0.09	-0.001***	0.04	0.001**
	(0.19)	(0.002)	(0.55)	(0.002)	(1.76)	(0.00)	(5.00)	(0.00)
IDN	-0.05	0.02	-0.08	0.02	0.01	-0.01	0.03	-0.005
	(0.53)	(0.03)	(0.97)	(0.03)	(0.10)	(0.10)	(0.20)	(0.01)
IND	-0.05	-0.004	0.08	-0.006	-0.01	0.002***	-0.05	0.002
	(0.07)	(0.003)	(0.15)	(0.005)	(0.03)	(0.001)	(0.044)	(0.002)
KOR	0.12***	-0.001	-0.09*	-0.04**	-0.03**	-0.09	0.02*	0.01***
	(0.04)	(0.003)	(0.05)	(0.02)	(0.01)	(0.05)	(0.01)	(0.005)
MEX	-0.06	0.12*	-0.14	-0.15**	0.04*	-0.03***	0.04	0.03***
	(0.05)	(0.07)	(0.09)	(0.06)	(0.02)	(0.01)	(0.03)	(0.009)
MYS	-0.24***	-0.002*	0.001	-0.002*	0.06***	0.00**	-0.002	0.00*
	(0.04)	(0.001)	(0.007)	(0.002)	(0.01)	(0.00)	(0.02)	(0.00)
PHL	-0.06	-0.001	0.20	-0.02**	0.006	0.00	-0.05	0.007**
	(0.07)	(0.004)	(0.16)	(0.008)	(0.01)	(0.002)	(0.035)	(0.003)
RUS	-0.01*	0.005**	-0.08	-0.02***	0.03**	-0.001	-0.01	0.006***
	(0.007)	(0.002)	(0.15)	(0.006)	(0.02)	(0.001)	(0.05)	(0.002)
SGP	-0.04	-0.005	0.39	-0.01	0.005	0.001	-0.06	0.003
	(0.07)	(0.005)	(0.24)	(0.01)	(0.02)	(0.001)	(0.066)	(0.01)
THA	-0.24	-0.004	-0.24	0.00	0.08	0.001	0.10	0.00
	(0.20)	(0.02)	(0.40)	(0.01)	(0.06)	(0.01)	(0.099)	(0.004)
TUR	-0.30***	-0.01**	0.33***	0.19***	0.14***	0.004***	-0.13***	-0.05***
	(0.09)	(0.006)	(0.12)	(0.06)	(0.05)	(0.002)	(0.05)	(0.02)
TWN	-0.46***	-0.02***	-0.34	0.02*	0.23***	0.005**	0.12	-0.004**
	(0.11)	(0.01)	(0.23)	(0.01)	(0.06)	(0.002)	(0.11)	(0.002)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative model 1-6 is a variation of Benchmark model 1 with dummy variables for crisis periods in the variance equations.

Table 3.23: Estimation results for cross-market spillover parameters (Benchmark model 2-1)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
BRA	-0.23	-0.01	-0.36**	0.08	0.27	0.00	0.15***	-0.02
	(0.16)	(0.07)	(0.17)	(0.06)	(0.18)	(0.04)	(0.06)	(0.02)
CHI	0.05	0.00	-0.37	0.002**	0.02	0.00	1.53***	0.00
	(0.18)	(0.00)	(2.22)	(0.01)	(0.08)	(0.00)	(0.611)	(0.00)
HKG	0.00	0.00	0.001	0.00	-0.01	0.00	0.003	0.00
	(2.62)	(0.00)	(1.83)	(0.00)	(0.70)	(0.00)	(1.62)	(0.00)
IDN	0.08	0.01	0.17	0.06**	-0.01	-0.01	-0.02	-0.02**
	(0.22)	(0.02)	(0.23)	(0.03)	(0.09)	(0.01)	(0.087)	(0.01)
IND	-0.08	0.03	-0.35	-0.06***	0.01	-0.01	0.16***	0.01**
	(0.08)	(0.02)	(0.60)	(0.01)	(0.02)	(0.01)	(0.05)	(0.004)
KOR	0.15**	-0.11***	0.02	-0.14***	-0.06***	0.04**	0.01	0.03*
	(0.07)	(0.02)	(0.11)	(0.05)	(0.02)	(0.02)	(0.05)	(0.01)
MEX	0.12	-0.16**	0.04	-0.01	-0.03	0.03	-0.06*	0.005
	(0.11)	(0.07)	(0.11)	(0.03)	(0.06)	(0.03)	(0.03)	(0.02)
MYS	-0.16*	0.04	0.01	-0.27	0.07	-0.03	0.006	0.09
	(0.09)	(0.05)	(0.05)	(0.18)	(0.05)	(0.03)	(0.018)	(0.07)
PHL	0.29	-0.005	0.64**	-0.02	-0.09**	0.009	0.08	-0.01
	(0.25)	(0.03)	(0.30)	(0.03)	(0.05)	(0.02)	(0.12)	(0.02)
RUS	0.07	0.03	0.68***	-0.05	-0.05	-0.002	-0.20*	0.01*
	(0.16)	(0.03)	(0.27)	(0.03)	(0.05)	(0.01)	(0.10)	(0.007)
SGP	-0.01	0.01	-0.64	-0.005	0.05	0.003	0.49***	-0.02**
	(0.17)	(0.02)	(0.45)	(0.021)	(0.06)	(0.01)	(0.08)	(0.01)
THA	0.07	-0.002	0.86	0.01	-0.02	0.001	-0.13	-0.006***
	(0.64)	(0.01)	(0.74)	(0.01)	(0.22)	(0.002)	(0.155)	(0.003)
TWN	-0.32**	0.02	0.50	-0.05***	0.13*	-0.01	-0.25	0.01
	(0.17)	(0.01)	(0.56)	(0.02)	(0.08)	(0.01)	(0.158)	(0.01)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Benchmark model 2-1 is a variation of Benchmark model 1 with a variance equation with explanatory variables of crisis dummy variables.

Table 3.24: Estimation results for cross-market spillover parameters (Alternative model 2-1-1)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
BRA	-0.08	-0.01	-0.13*	0.18**	0.01	-0.01	0.04	-0.003
	(0.06)	(0.06)	(0.07)	(0.08)	(0.04)	(0.02)	(0.06)	(0.03)
CHI	0.02	0.00	-2.47	0.006*	0.02	0.00	1.67***	-0.001
	(0.18)	(0.002)	(1.92)	(0.003)	(0.18)	(0.00)	(0.48)	(0.001)
IDN	-0.03	0.03	-0.33	-0.09**	0.001	-0.01	0.06	0.04***
	(0.41)	(0.03)	(0.39)	(0.04)	(0.19)	(0.02)	(0.19)	(0.01)
IND	-0.001	0.02	-0.72***	-0.06***	0.01	-0.01	0.16***	0.01**
	(0.01)	(0.02)	(0.17)	(0.02)	(0.01)	(0.01)	(0.06)	(0.004)
KOR	-0.11	-0.03	0.19	-0.25***	0.05	0.01	-0.004	0.03*
	(0.14)	(0.04)	(0.16)	(0.08)	(0.07)	(0.03)	(0.05)	(0.02)
PHL	-0.11	0.003	-0.69**	0.03	0.007	-0.01	0.61***	-0.02***
	(0.18)	(0.02)	(0.36)	(0.03)	(0.07)	(0.01)	(0.10)	(0.01)
RUS	0.08	0.02	-0.77**	0.04	-0.07	-0.02	0.52***	0.01
	(0.15)	(0.03)	(0.31)	(0.03)	(0.10)	(0.01)	(0.14)	(0.01)
SGP	0.32	-0.04	-1.16***	0.02	-0.05	0.003	0.30***	-0.005
	(0.51)	(0.04)	(0.34)	(0.05)	(0.15)	(0.01)	(0.10)	(0.01)
THA	0.42	0.00	0.56	-0.01	-0.12	-0.001	-0.39***	0.01**
	(0.32)	(0.007)	(0.38)	(0.01)	(0.11)	(0.003)	(0.13)	(0.004)
TWN	0.02	-0.006	-0.90**	-0.05***	-0.006	-0.003	0.08	0.02**
	(0.12)	(0.008)	(0.36)	(0.02)	(0.05)	(0.01)	(0.09)	(0.01)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative model 2-1-1 is a variation of Benchmark model 2-1 with explanatory variables in the mean equation of vector autoregressive terms of dependent variables and global market variables.

Table 3.25: Estimation results for cross-market spillover parameters (Alternative model 2-1-2)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
CHI	-0.51	0.003	0.63	0.00	0.05	-0.001	2.43**	-0.001
	(0.85)	(0.003)	(4.83)	(0.002)	(0.25)	(0.001)	(1.16)	(0.001)
IDN	0.07	-0.004	0.20	-0.08***	-0.03	0.003	-0.02	0.02***
	(0.11)	(0.02)	(0.15)	(0.03)	(0.03)	(0.01)	(0.04)	(0.01)
IND	-0.02	0.002	1.06***	-0.01	0.01	0.001	-0.14	0.00
	(0.04)	(0.02)	(0.24)	(0.02)	(0.01)	(0.005)	(0.10)	(0.005)
KOR	-0.16	0.06	0.41***	-0.30***	0.09	-0.05	-0.19*	0.14**
	(0.11)	(0.05)	(0.16)	(0.12)	(0.10)	(0.05)	(0.11)	(0.06)
MYS	0.01	0.01	-0.75***	0.03	0.03	-0.01	0.05	0.01
	(0.07)	(0.02)	(0.21)	(0.03)	(0.08)	(0.02)	(0.129)	(0.03)
RUS	0.001	0.02	-0.34*	0.07	-0.07	-0.01	0.31***	-0.001
	(0.05)	(0.04)	(0.19)	(0.05)	(0.05)	(0.01)	(0.088)	(0.011)
THA	0.42	0.01	0.70***	-0.02	-0.10	-0.004	-0.40***	0.01***
	(0.26)	(0.007)	(0.33)	(0.01)	(0.06)	(0.004)	(0.09)	(0.005)
TWN	-0.02*	-0.01	0.43*	-0.01	0.071	0.018	-1.140***	0.05***
	(0.05)	(0.01)	(0.25)	(0.03)	(0.06)	(0.01)	(0.13)	(0.01)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative model 2-1-2 is a variation of Benchmark model 2-1 with explanatory variables in the mean equation of vector autoregressive terms of dependent variables and global and regional market variables.

Table 3.26: Estimation results for cross-market spillover parameters (Alternative model 2-2)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
BRA	0.11	-0.01	-0.04	0.03	-0.06	0.01	0.10*	-0.03
S	(0.12)	(0.04)	(0.15)	(0.05)	(0.04)	(0.02)	(0.06)	(0.02)
CHI	0.63	0.00	-0.52	-0.01**	0.15	-0.00	-0.42	0.002**
S	(0.73)	(0.00)	(0.47)	(0.00)	(0.19)	(0.00)	(0.62)	(0.001)
HKG	-0.06	0.00	-0.03	0.00**	-0.21	0.00	-0.08	0.00
S	(1.60)	(0.00)	(3.64)	(0.00)	(1.08)	(0.00)	(2.09)	(0.00)
IDN	0.27***	0.01	0.03	0.04**	-0.13**	0.004	0.18*	-0.04***
C	(0.11)	(0.01)	(0.12)	(0.02)	(0.06)	(0.005)	(0.10)	(0.01)
IND	0.08	0.01	0.17	0.06	-0.01***	-0.01*	-0.02***	-0.02***
C	(0.21)	(0.02)	(0.23)	(0.03)	(0.10)	(0.01)	(0.09)	(0.01)
KOR	0.14	-0.09**	-0.16	-0.01	-0.11**	0.03	0.20***	-0.00
S	(0.10)	(0.04)	(0.10)	(0.02)	(0.04)	(0.01)	(0.02)	(0.01)
MEX	0.11	-0.21***	-0.16	0.11	0.00	0.03	0.03	-0.02
C	(0.10)	(0.07)	(0.17)	(0.07)	(0.02)	(0.02)	(0.04)	(0.04)
MYS	-0.13***	0.09*	-0.09*	-0.03	0.11***	-0.06***	-0.07	0.07***
S	(0.04)	(0.05)	(0.05)	(0.06)	(0.03)	(0.02)	(0.07)	(0.02)
PHL	0.47**	-0.04	0.44	0.07***	-0.17	0.02	0.28	-0.06*
C	(0.20)	(0.03)	(1.12)	(0.02)	(0.28)	(0.04)	(0.28)	(0.03)
RUS	0.08	-0.01	0.03	0.03***	-0.02	0.003	-0.03	-0.01
C	(0.12)	(0.01)	(0.22)	(0.01)	(0.07)	(0.01)	(0.10)	(0.01)
SGP	0.21	-0.02	0.17	-0.03*	-0.19**	0.02**	0.26**	-0.01
C	(0.17)	(0.01)	(0.18)	(0.02)	(0.09)	(0.01)	(0.12)	(0.01)
THA	0.19	0.00	-0.05	-0.01	-0.21	0.004	0.31	-0.004
S	(1.03)	(0.02)	(5.05)	(0.03)	(0.70)	(0.02)	(2.12)	(0.04)
TWN	-0.04	0.03*	-0.35	-0.02	0.36**	-0.03***	-0.51***	-0.04***
S	(0.15)	(0.02)	(0.22)	(0.02)	(0.17)	(0.007)	(0.17)	(0.01)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Benchmark model 2-2 is a variation of Benchmark model 1 with a variance equation with explanatory variables of asymmetric dummy variables.

4. 'S' represents the model with dummy variables for stock return decreases and 'C' for FX rate depreciation.

Table 3.27: Estimation results for cross-market spillover parameters (Alternative model 2-2-1)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
BRA	-0.11	0.01	0.02	0.03	-0.05	0.04	0.18	-0.08
S	(0.22)	(0.04)	(0.27)	(0.22)	(0.10)	(0.04)	(0.20)	(0.14)
CHI	0.05	0.00	-0.37*	0.002	0.02	0.00	-0.20	0.00
S	(0.18)	(0.00)	(0.22)	(0.005)	(0.08)	(0.00)	(0.59)	(0.00)
HKG	-0.00	-0.01	0.07	0.07	0.04***	0.03*	-0.07***	-0.07***
S	(0.02)	(0.01)	(0.04)	(0.04)	(0.01)	(0.02)	(0.02)	(0.02)
IDN	0.17	0.01	-0.04	0.04**	-0.10	0.00	0.16	-0.04*
C	(0.16)	(0.01)	(0.76)	(0.02)	(0.09)	(0.01)	(0.20)	(0.03)
IND	-0.20**	0.02**	0.34**	0.02*	0.17***	-0.02***	-0.32***	0.03*
C	(0.09)	(0.01)	(0.15)	(0.01)	(0.04)	(0.01)	(0.08)	(0.02)
KOR	0.08	-0.03	-0.37***	0.09	-0.07*	0.01	0.21***	-0.03
S	(0.08)	(0.04)	(0.09)	(0.10)	(0.04)	(0.02)	(0.06)	(0.04)
PHL	-0.14	-0.003	0.16	0.02	0.01	-0.004	0.06	-0.01
C	(0.53)	(0.02)	(0.71)	(0.03)	(0.02)	(0.01)	(0.12)	(0.02)
RUS	-0.04	0.02	0.08	0.05	-0.10	-0.00	0.00	-0.01
C	(0.13)	(0.03)	(0.08)	(0.03)	(0.13)	(0.01)	(0.09)	(0.01)
SGP	-0.05	-0.02	0.32*	-0.02	-0.18	0.02	0.35	-0.03
C	(0.24)	(0.03)	(0.19)	(0.05)	(0.41)	(0.04)	(0.76)	(0.07)
THA	0.69	-0.02	0.25	0.02	-0.59	-0.01	-0.20	-0.004
S	(0.69)	(0.02)	(0.78)	(0.03)	(0.75)	(0.01)	(0.82)	(0.03)
TWN	0.02	-0.00	0.22	-0.02	0.01	-0.00	-0.04	0.01
S	(0.12)	(0.02)	(0.18)	(0.02)	(0.08)	(0.00)	(0.14)	(0.01)

Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative model 2-2-1 is a variation of Benchmark model 2-2 with explanatory variables in the mean equation of vector autoregressive terms of dependent variables and global market variables.

4.'S' represents the model with dummy variables for stock return decreases and 'C' for FX rate depreciation.

Table 3.28: Estimation results for cross-market spillover parameters (Alternative model 2-2-2)

	a_{12}	a_{21}	a_{21d}	a_{21d}	b_{12}	b_{21}	b_{12d}	b_{21d}
CHI	0.25	0.003**	-0.14	0.00	-1.09	0.00	2.07*	-0.004***
S	(0.73)	(0.001)	(0.78)	(0.00)	(0.64)	(0.00)	(1.25)	(0.002)
IDN	0.18	0.05	0.02	0.003	-0.09	0.01	0.14	-0.05
C	(0.17)	(0.04)	(0.20)	(0.10)	(0.01)	(0.02)	(0.18)	(0.07)
IND	-0.04	0.01	0.09	0.02	0.14***	-0.01	-0.27**	0.03
C	(0.04)	(0.01)	(0.17)	(0.02)	(0.05)	(0.01)	(0.11)	(0.03)
KOR	-0.12	-0.01	0.13	-0.12	-0.01	0.03	0.07	-0.02
S	(0.10)	(0.03)	(0.15)	(0.21)	(0.36)	(0.16)	(0.77)	(0.33)
MYS	0.05	0.05***	-0.06	-0.05***	-0.41***	0.02***	0.86***	-0.05***
S	(0.12)	(0.02)	(0.40)	(0.02)	(0.11)	(0.01)	(0.28)	(0.01)
SGP	0.18	-0.01	-0.08	0.07	0.23***	-0.03***	-0.51***	0.05***
C	(0.12)	(0.07)	(0.19)	(0.07)	(0.05)	(0.01)	(0.08)	(0.01)
THA	0.15	-0.00	0.48	0.01	-0.03	-0.01*	-0.23	0.02
S	(0.45)	(0.01)	(0.64)	(0.01)	(0.15)	(0.01)	(0.20)	(0.01)
TWN	0.05	0.05***	-0.06	-0.05**	-0.41***	0.02**	0.86***	-0.05***
S	(0.12)	(0.02)	(0.40)	(0.02)	(0.11)	(0.01)	(0.28)	(0.03)

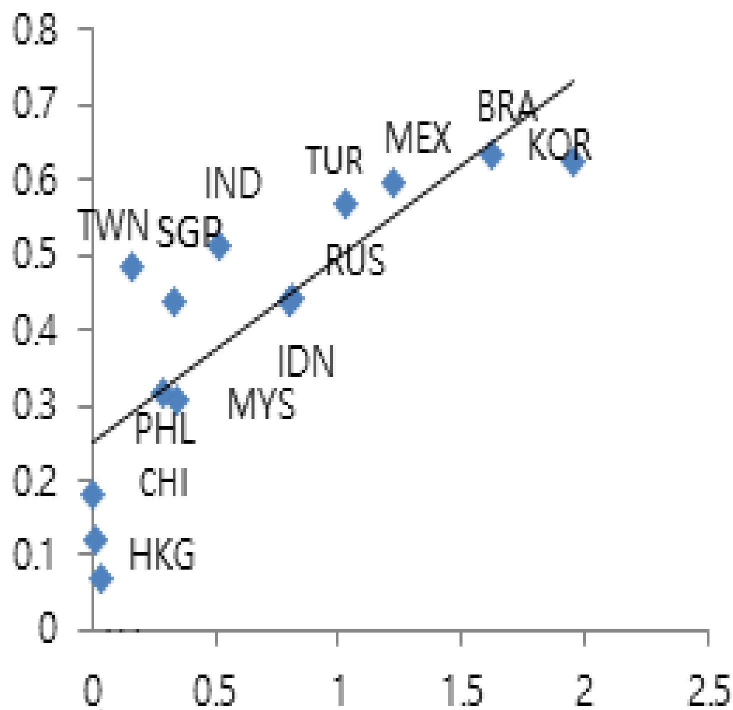
Notes: 1. ***, **, and * indicate significant coefficients at the 99%, 95%, and 90% confidence levels, respectively.

2. ( ) indicates robust standard errors used for the estimated parameters in the variance equations.

3. Alternative model 2-2-2 is a variation of Benchmark model 2-2 with explanatory variables in the mean equation of vector auto-regressive terms of dependent variables and global and regional market variables.

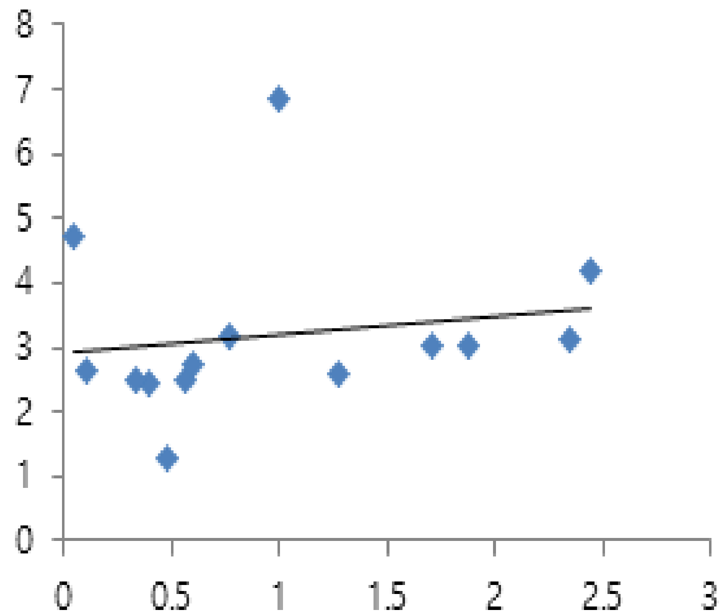
4.'S' represents the model with dummy variables for stock return decreases and 'C' for FX rate depreciation.

Figure 3.1: Currency rate volatility and market dependence between stock and FX market



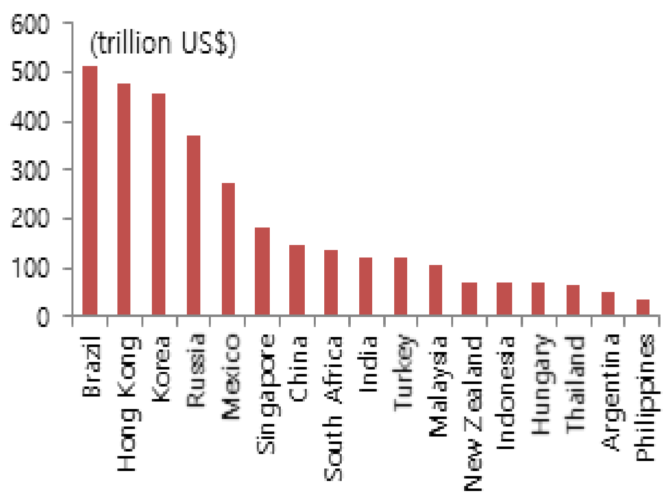
Notes: 1. The vertical axis measures the cross-correlation between two returns.
2. Horizontal axis is standard deviation of currency rate (%).
3. Sample periods: September 2008 - March 2009

Figure 3.2: Currency and stock return volatility of EM countries



Notes: 1. The vertical axis measures standard deviations of stock price index.
2. The horizontal axis measures standard deviations of currency rates (%).
3. Sample period: September 2008 - March 2009

Figure 3.3: Portfolio investment liabilities



Note: IIF liabilities of portfolio investment (debt securities + portfolio securities).

Figure 3.4: Accumulated foreign portfolio investments in selected EM countries

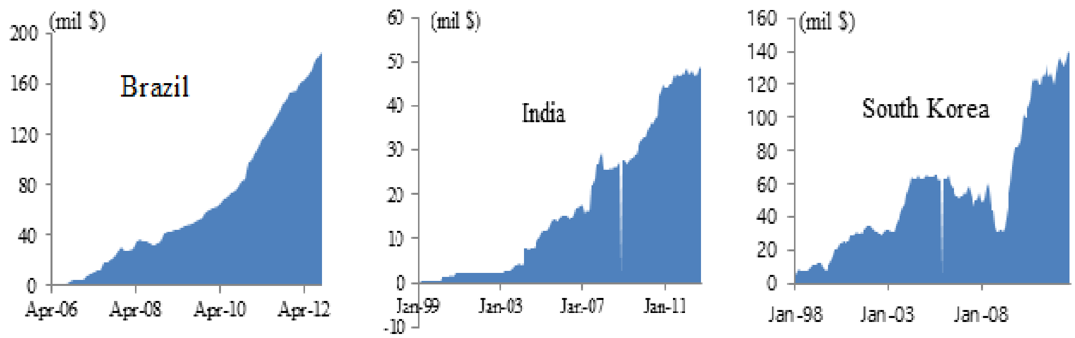
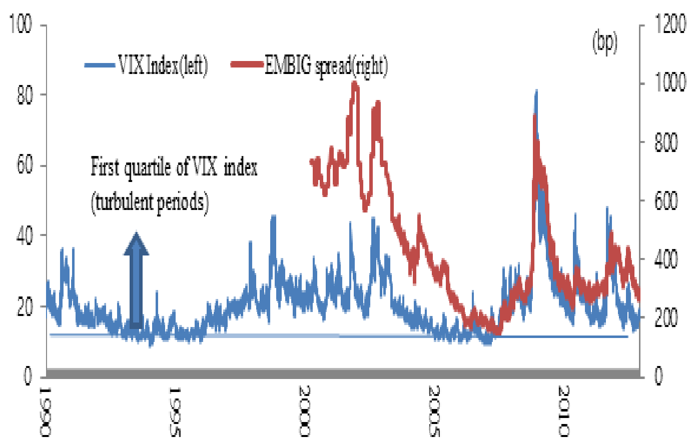


Figure 3.5: VIX and EMBIG spread



Note: EMBIG indicates Emerging market bond index by JP Morgan.

APPENDIX A

APPENDIX TO CHAPTER 1: IV SELECTION AND TEST

A.1 IV candidates for MP shocks

A.1.1 Daily short-term spot rate changes on MP decision dates: IV 1 through 4

Following Cochrane and Piazessi (2002) and others, we test daily movements of short-term interest rates around MP decision announcements, by defining an MP shock as the daily change in the spot rates on that day. Financial market participants anticipate MP decisions before actual policy announcements, and short-term rates may have already been adjusted beforehand. If on the contrary the MP announcement is a mere surprise, market rates will adjust only after the announcements. We test the following four short-term interest rates: overnight rates (IV1), market interest rates with maturity of 1 month (IV2), Treasury bill rates with maturity of 3 months (IV3), and daily exchange rates per U.S. dollar (IV4).

A.1.2 Daily futures prices of financial instruments on MP decision dates: IV 5 through 9

A variety of futures assets, even though the underlying instrument is not directly related to MP, exist in financially developed SOEs. Like spot rates, futures prices also retain meaningful information about market expectations regarding future paths of MP. We test here the following five futures contracts under financial assets: futures prices under short-term (IV5), medium-term (IV6), and long-term (IV7) fixed-income (bond) instruments,[1] currency futures rates per USD (IV8), and national stock price futures rates (IV9). [2,3]

A.1.3 Beveridge-Nelson decomposed overnight rates: IV10

If there is no other economic news except MP announcements on MP decision dates, we may define MP shocks as deviations of MP instruments on that day from the expected future paths. What is an 'expected future path'? Here we use an econometric technique of Beveridge and Nelson (1981) ('BN' hereafter) and seek to provide potential instruments for unexpected MP shocks.

BN propose a definition of the permanent component of an $I(1)$ time series with drift as the limiting forecast as the horizon goes to infinity, adjusted for the mean rate of growth over the forecast horizon, as shown in (A.1).

[1]Although the relationship with the MP instrument is not as close as those with short-term instruments, there are also good reasons to regard movements of futures prices under long-term fixed-income instruments as embedding market expectations for MP announcements. If we follow the expectation hypothesis regarding the term structure, long-term rates can be explained by expectations for short-term rates and the liquidity premium, assuming there is no credit risk with the financial instruments.

[2]Theoretical and empirical studies have suggested a relationship between currency or equity prices and MP surprises. For example, a representative theory of the relationship between MP and currency would be the uncovered interest rate parity (UIP) theory. According to UIP, risk-neutral investors are indifferent between the interest rates in two countries since the exchange rate between those countries is expected to be adjusted such that the return on deposits in each country equalizes, thereby eliminating the potential for uncovered interest arbitrage profits. However, as is well-known in international macroeconomics, many empirical studies report that high-interest-rate currencies tend to appreciate (the UIP puzzle). Therefore, we need to use these carefully.

[3]Following Gertler and Karadi (2015), because the day of an FOMC meeting varies from month to month, we take the following step in constructing daily MP instruments. First, for each day of the month, we cumulate the surprise on any FOMC days during the last 31 days; and second, we create cumulative daily surprise series by cumulating all MP decision-day surprises.

$$
\begin{aligned}
x_t = r_t - z_t = r_t + \psi^*(L)e_t = r_t + \psi_0^* e_t + \psi_1^* e_{t-1} + \ldots \\
= r_t + \sum_{j=1}^{\infty} E(\Delta r_{t+j} - \mu | I_t) = \lim_{j \to \infty} r_{t+j|t} - \mu j
\end{aligned}
\tag{A.1}
$$

where x_t is the (adjusted) permanent component of r_t and z_t is the transitory component. According to the Box-Jenkinss method, we find that daily MP instruments in each country follow the ARIMA process, as reported in (A.2).

$$
\begin{aligned}
&\text{US [ARIMA(1,1,2)]} : \triangle\, r_t = \underset{(25.41)}{0.58}\ \triangle\, r_{t-1} + e_t - \underset{(-32.00)}{0.77}\ e_{t-1} - \underset{(-4.30)}{0.06}\ e_{t-2} \\
&\text{AU [ARIMA (2,1,2)]} : \triangle\, r_t = \underset{(47.64)}{0.61}\ \triangle\, r_{t-1} - \underset{(-64.98)}{0.95}\ \triangle\, r_{t-2} + e_t - \underset{(-38.33)}{0.61}\ e_{t-1} + \underset{(49.48)}{0.92}\ e_{t-2} \\
&\text{CA [ARIMA (1,1,0)]} : \triangle\, r_t = -\underset{(-11.67)}{0.17}\ \triangle\, r_{t-1} + e_t \\
&\text{KO [ARIMA(1,1,2)]} : \triangle\, r_t = \underset{(25.41)}{0.58}\ \triangle\, r_{t-1} + e_t - \underset{(-32.00)}{0.77}\ e_{t-1} - \underset{(-4.30)}{0.06}\ e_{t-2} \\
&\text{UK [ARIMA (1,1,0)]} : \triangle\, r_t = \underset{(4.96)}{0.05}\ \triangle\, r_{t-1} + e_t
\end{aligned}
\tag{A.2}
$$

where Δr_t is the first difference of the overnight rate, e_t is the residual, and the numbers in parenthesis are t-values. Following Morley (2002), we can transform this result into a state-space representation, $R_t = FR_{t-1} + \varepsilon_t$, and implement BN decomposition. For example, for the US case, state space representation can be expressed as (A.3):

$$
\begin{bmatrix} \triangle\, r_t \\ e_t \\ e_{t-1} \end{bmatrix} = \begin{bmatrix} \phi_1 & \theta_1 & \theta_2 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \triangle\, r_{t-1} \\ e_{t-1} \\ e_{t-2} \end{bmatrix} + \begin{bmatrix} e_t \\ e_t \\ 0 \end{bmatrix}
\tag{A.3}
$$

Then, the BN trend is r_t + (1,1) element of $F\,(I(n) - F)^{-1} R_t$ where n denotes a dimension of the state-space matrix, and the transitory component, an MP shock, is the (1,1) element of $-F\,(I(n) - F)^{-1} R_t$. Assuming that there is no economic news on an MP decision day and that overnight financial markets behave consistently with the market efficiency hypothesis, the BN trend on an MP decision date is the market participants' long-run forecast conditional on information up to the date, and the transitory component on the day is the unexpected MP shock.[4]

A.1.4 Residuals from forward-looking Taylor-rule estimation: IV11

Following Clarida et al. (2000) and many others, we estimate the forward-looking Taylor rule as equation (A.4) assuming that the policy rate adjusts to gaps between expected inflation and output and their respective target levels. Residuals from the policy rule estimation can be interpreted as the difference between actual policy rates and the rates implied by the rule had monetary authorities followed it. Roughly speaking, the residuals indicate the unintended policy shocks caused by a central bank that strictly obeys the rule.

$$r_t = \rho r_{t-1} + (1-\rho)\left[rr^* + (\beta - 1)\,\pi^* + \beta \pi_{t,k} + \gamma x_{t,q}\right] + \upsilon_t \tag{A.4}$$

where r^*, $\pi_{t,k}$, $x_{t,q}$, ρ are the target interest rate, the inflation rate at time $t+k$,

[4]We assume market efficiency in the overnight interest rate market, so the market price may be determined based on the entire information set available up to time $t(I_t)$.

the output gap in period $t + q$,[5] and the degree of smoothing of interest rate changes, respectively. The real rate and its long-run equilibrium are $rr_t^* \equiv r_t^* - E[\pi_{t,k} | \Omega_t]$ and $rr^* \equiv r^* - \pi^*$, where Ω_t is the information set at the time that the interest rate is set. Note that the residual from the rule is the form $\upsilon_t = -(1-\rho)\left[\beta\left[\pi_{t,k} - E(\pi_{t,k} | \Omega_t)\right] + \gamma\left[x_{t,q} - E\left(x_{t,q} | \Omega_t\right)\right]\right]$.

Unless $\pi_{t,k} = E[\pi_{t,k} | \Omega_t]$ and $x_{t,q} = E\left[x_{t,q} | \Omega_t\right]$, the explanatory variables and the error term become correlated. In order to solve this orthogonality problem, we estimate with the Generalized Method of Moments, which utilizes an optimal weight matrix that accounts for the possible serial correlation in υ_t.[6] The estimation results are summarized in Table A.1.

[5]The output gap is measured by the difference between industrial production and its HP filtered series.

[6]We use instrument sets, which include four lags of policy rates, inflation, the output gap, and the spread between long-term and TB (3-month) rates.

Table A.1: Estimation results for forward-looking policy rule

	β	γ	ρ	π^*
US [1980~2013]	3.46	0.44	0.90	4.08
	(0.55)	(0.56)	(0.03)	(0.27)
CA [1982~2013]	3.63	-0.64	0.57	2.58
	(0.40)	(0.64)	(0.13)	(0.16)
AU [1991~2013]	3.24	-2.68	0.83	2.60
	(0.56)	(0.71)	(0.03)	(0.17)
KO [1996~2013]	1.77	-0.21	0.85	4.60
	(0.51)	(0.17)	(0.02)	(1.12)
UK [1989~2013]	1.84	1.13	0.44	0.68
	(0.17)	(0.27)	(0.14)	(0.48)

Note: Numbers in parentheses are standard errors.

A.2 IV test results

A.2.1 IVs for U.S. MP shocks

Table A.2 summarizes the results of the weak IV test, for each suggested IV for U.S. MP shocks. Each row displays the t-value and R^2 for the first-stage least square. We find that almost all the IV candidates have strong relationships with the residual series of the MP instrument. Spot short-term rates (IV1~3) have significant explanatory power at the 95% significance level through all sample periods tested. As already shown clearly in other studies, intraday movements of Federal Fund Futures rates and Eurodollar futures rates (IV5a~5e) are significantly relevant to the MP instruments, reporting the highest t-values and R^2. The BN decomposed rate (IV10) also shows high relevancy while the residual from the Taylor rule estimation (IV11) shows mixed results, which are significant for the full sample but not for the sub-samples.

Table A.3 exhibits over-identification test results for the proposed U.S. IVs. The IV set consisting of intraday FFFRs (IV5 series) shows very low Sargan statistics, indicating that they are sufficiently orthogonal to residual series of other endogenous variables in the VAR system. Spot short-term rates (IV1~4) show mixed results; through the 1980~2008 sample, the IVs cannot reject the null hypothesis that the IVs are endogenous with other residual series of other financial instruments (3-month, 3-year, and 10-year TBs) at the 5% significance level, but through other sub-samples the null hypothesis is not rejected.

A.2.2 IVs for SOE MP shocks

We summarize the relevancy of IVs for each of the focal SOEs in Table A.4. Above all, spot overnight rates (IV1) turn out to be the most highly relevant to the residual of the MP instruments, in line with Cochrane and Piazessi (2002). In all analyzed SOEs, IV1 is significant at the 5% level and the explanatory power of the IV (R^2) ranges from 0.07 to 0.23. Short-term rates (with 3-month maturity, IV2) have a close relationship with the MP instruments that is significant at the 10% level in all SOEs. Daily innovation of overnight rates through BN decomposition (IV10) produces almost the same results as were obtained for IV1. However, the results for the remaining IVs are mixed by country: residuals from Taylor rule estimation (IV11) show significant relevancy except in the UK. Spot market rates (3-month maturity, IV3) and futures rates for fixed-income or bond instruments (IV5~7) are significantly relevant to MP shocks in Canada and the UK. Spot FX rates per US dollar (IV4) and futures rates under FX rates (IV8) or under a sovereign stock price index (IV9) offer little explanation of the portions of the MP instruments.

The evidence in Table A.4 leads us to select the best combination of multiple IVs in terms of relevancy. The selected IV sets for each country and their F-values in the first-stage least square are displayed at the bottom row of Table A.4. This allows us to establish a set of results for our analysis in a setting where there is unlikely to be a weak instruments problem.

Finally, in Table A.5, the over-identification test results are summarized for the selected IV combinations for both the focal SOEs and U.S. MP shocks. At the 5% significance level, almost none of the residual series rejects the null hypothesis. This indicates that the selected IV combinations for each country are exogenous to residual series of other variables.

Table A.2: Explanatory power of suggested IVs for U.S. MP shocks

	1980~2008	1984~2008	1989~2008
IV1	1.82*[0.01]	**2.84***[0.03]**	**2.36**[0.03]**
IV2	**3.95***[0.04]**	**2.65***[0.02]**	-0.97[0.00]
IV3	**4.04***[0.05]**	**5.00***[0.08]**	**4.89***[0.10]**
IV5a	-		**6.73***[0.17]**
IV5b	-	-	**6.08***[0.15]**
IV5c		**3.38***[0.04]**	**4.00***[0.07]**
IV5d	-	**3.79***[0.05]**	**3.67***[0.06]**
IV5e	-	**3.30***[0.04]**	**3.29***[0.05]**
IV5f	-	**2.59***[0.02]**	**2.83***[0.04]**
IV10	**7.58***[0.14]**	**5.59***[0.09]**	**2.75***[0.03]**
IV11	**2.41**[0.02]**	1.28[0.01]	1.34[0.01]

Notes: 1) t-values and R^2 (parentheses) of each IV in the first-stage regression of the VAR residual of MP and each IV.
2) '-' indicates that the selected IV is not available.
for a given sample period.
3) Bold results are significant at the 95% confidence level.

Table A.3: Sargan statistics for selected U.S. IVs

Sample	1980~2008	1984~2008	1984~2008	1989~2008		
	[IV1~3,10]	[IV1~3,10]	[IV5c~5f]	[IV1~3,10]	[IV5c~5f]	[IV5a~5b]
Y	6.75	2.19	1.79	5.03	1.29	3.57
P	2.49	2.29	0.22	8.07	0.89	0.39
$R3m$	15.90	3.11	0.06	0.24	1.73	2.87
$R3y$	15.90	0.84	1.06	2.67	6.44	7.57
$R10y$	20.50	2.76	1.54	4.60	4.32	4.74
$Lend$	5.10	2.80	0.79	3.25	8.28	1.82
L	1	1	1	1	1	1
K	4	4	4	4	4	2
$\chi^2_{0.99(0.95)} > K - L$	9.21(5.99)			9.21(5.99)		6.64(3.84)

Note: Reject H_0 at the 1% (5%) significance level if $\chi^2_{0.99(0.95)} > K - L$, where K and L are the number of IVs and endogenous variables, respectively.

Table A.4: Explanatory power of SOE IVs on the first-stage residual of MP shock

	Australia	Canada	Korea	U.K.
IV1	**3.47*****	**7.66*****	**5.78*****	**4.71*****
	[0.14]	**[0.23]**	**[0.19]**	**[0.11]**
2	1.90*	**5.39*****	**3.59*****	**5.85*****
	[0.05]	**[0.13]**	**[0.08]**	**[0.17]**
3	1.44	**6.88*****	**-2.25****	**4.56*****
	[0.03]	**[0.20]**	**[0.03]**	**[0.11]**
4	0.60	1.73*	-	1.42
	[0.00]	[0.02]		[0.01]
5	-1.59	**-10.70‘*****	-	**-7.38*****
	[0.03]	**[0.37]**		**[0.24]**
6	-0.26	-	1.13	-
	[0.00]		[0.01]	
7	-0.12	**-2.69*****	-	-0.62
	[0.00]	**[0.04]**		[0.00]
8	0.40	1.94*	-1.47	1.86*
	[0.00]	[0.02]	[0.01]	[0.02]
9	-	-1.53	-0.76	0.18
		[0.01]	[0.00]	[0.00]
10	**4.12*****	**7.66*****	**5.71*****	**-4.71*****
	[0.18]	**[0.23]**	**[0.18]**	**[0.11]**
11	**2.09****	**2.50****	**2.73*****	0.21
	[0.06]	**[0.03]**	**[0.05]**	[0.00]
IV combinations	**[IV1,5, 10,11]** (F-value 7.4)	**[IV 1,2,11]** (F-value 34.6)	**[IV1,8,10,11]** (F-value 14.3)	**[IV1,2,3,5]** (F-value 23.7)

Notes: 1) t-values and R^2 (parentheses) of each IV in the first-stage regression of the VAR residual of MP and each IV.
2) '-' indicates that the selected IV is not available for a given sample period.
3) Bold results are significant at the 95% confidence level.

Table A.5: Over-identification Test results for selected IVs

Residuals	Australia	Canada	Korea	UK
Y	6.70	9.68	9.70	2.19
P	4.83	7.95	5.77	5.40
$R3m$	1.49	4.41	4.13	8.77
$R3y$	3.83	11.66	6.99	5.90
$R10y$	3.37	10.89	7.98	3.86
$LEND$	2.71	1.05	14.33	0.13
FX	5.62	15.75	25.13	6.83
K	9	8	9	9
L	1	1	1	1
$\chi^2_{0.99(0.95)} > K - L$	15.5	14.1	15.5	15.5

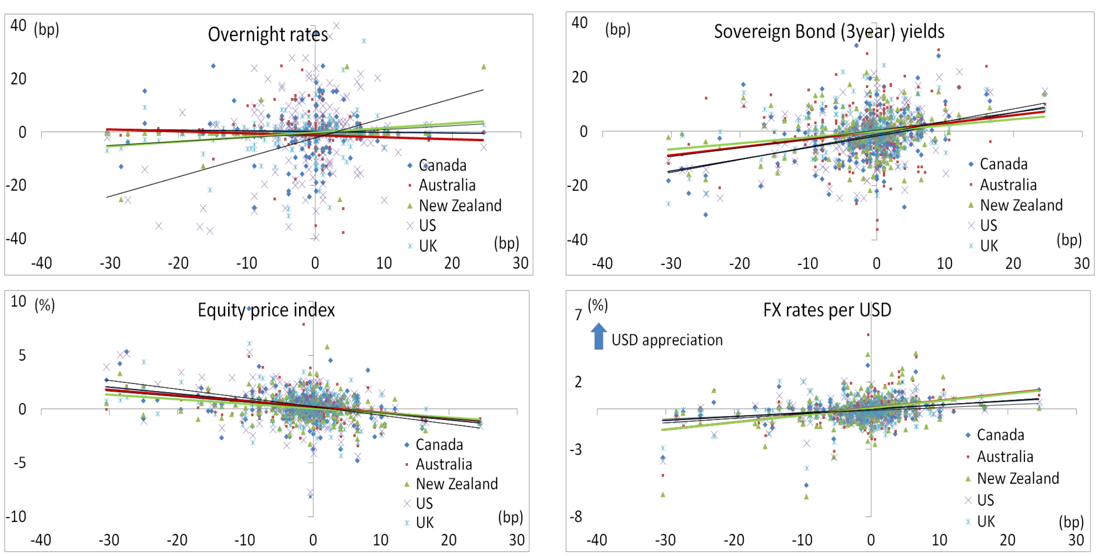
Note: Reject H_0 at the 1% (5%) significance level if $\chi^2_{0.99(0.95)} > K - L$, where K and L are the number of IVs and endogenous variables.

APPENDIX B

APPENDIX TO CHAPTER 2: EXTENDED EVENT STUDY RESULTS

Figure B.1 displays scatterplots of the MP shocks in ED4 and daily asset returns in the focal economies on FOMC announcement dates between 1990 and 2014, with the lines indicating linear trends. Equity price indexes decrease following a positive MP shock, which can explained by increased discount rates and/or adverse future cash flows. Currencies of the focal open economies depreciate, or the U.S. dollar appreciates, following positive MP shocks, as the Overshooting theory by Dornbusch (1976) predicts. Interestingly, while overnight rates in open economies do not respond to the shocks, medium-term bond yields show a clear positive relationship.

Figure B.1: Scatter plots of U.S. MP shocks and daily asset returns



Note: MP shocks are shown along the horizontal axis and daily asset returns are shown along the vertical axis.

Based on equation (2.5) in Section 2.2.3, I further test the contemporaneous impact of U.S. shocks on open asset returns with alternative measures of such shocks: the target and path factors. As shown in Table B.1, responses of asset returns to the factors are generally consistent with the responses that I find when I choose the ED4 rates as a proxy for MP shocks. An additional finding here is that sovereign bond yields are explained primarily by the path factor, indicating that bond markets in the focal open economies are influenced mostly by the forward guidance of the Fed rather than actual movements of the Federal Funds rates. For the equity prices and FX rates of the focal economies, both factors generate statistically significant impacts, but the target factor shows a slightly stronger influence than the path factor.

Next, I analyze the non-linear feature of U.S. transmissions. To test the state dependency of the spillovers, I divide the sample periods into two parts based on the following criteria:

(i-a) U.S. business cycle: Following Jensen et al. (1997) and many others, I divide the samples into periods of U.S. economic expansions and recessions.

(i-b) U.S. financial cycle: Following Chen (2007) and others, state-dependent spillovers based on the phase of financial asset prices are tested. D_t is defined as 1 if an MP shock occurs during the upward phase of dependent variables, and 0 otherwise. When testing responses of equity prices, for instance, the samples are divided into bull and bear stock markets, respectively.

(i-c) Financial market turbulence: Another group of studies alternatively focuses on financial market conditions measured by overall market volatilities. I use the CBOE volatility (VIX) index to proxy variable for the volatilities. D_t is 1 if the VIX index at time t is greater than the median value of long-time series at the time of the shock and 0 otherwise.

Table B.1: Regression coefficients of asset returns on U.S. MP shocks

	MP	R(3y)	R(10y)	S	FX	MP	R(3y)	R(10y)	S	FX
			[US]					[CA]		
$ED4$	0.73***	0.47***	0.38***	-8.14***	3.29***	-0.03	0.43***	0.26***	-6.14***	2.90***
	(0.26)	(0.08)	(0.08)	(1.41)	(0.72)	(0.12)	(0.08)	(5.65)	(1.31)	(0.70)
TS	1.08***	0.33***	0.12	-5.49***	2.03***	0.03	0.31***	0.09	-5.09***	1.26*
	(0.23)	(0.07)	(0.08)	(1.29)	(0.66)	(0.11)	(0.07)	(0.07)	(1.19)	(0.41)
PS	0.07	0.20***	0.22***	-3.36***	1.51***	-0.07	0.18***	0.15***	-2.05***	1.46***
	(0.14)	(0.04)	(0.05)	(0.81)	(0.42)	(0.07)	(0.05)	(0.04)	(0.75)	(0.40)
			[AU]					[NZ]		
$ED4$	-0.07	0.30***	0.23***	-5.27***	5.38***	0.28	0.22***	0.11	-4.23***	5.26***
	(0.09)	(0.09)	(0.09)	(1.51)	(1.08)	(0.19)	(0.07)	(0.07)	(1.17)	(1.07)
TS	0.16*	0.14	-0.01	-6.14***	1.94**	0.24	0.09	-0.03	-3.75***	-1.57
	(0.09)	(0.09)	(-0.08)	(1.42)	(1.00)	(0.17)	(0.07)	(0.07)	(1.13)	(0.98)
PS	-0.09	0.16***	0.17***	-1.36*	2.88***	0.11	0.12***	0.08**	-1.47**	-3.00***
	(0.05)	(0.05)	(0.05)	(0.81)	(0.63)	(0.10)	(0.04)	(0.04)	(0.65)	(0.65)
			[KO]					[UK]		
$ED4$	-0.14	0.20*	0.15	-9.98***	4.60***	0.15***	0.36**	0.29***	-5.15***	2.08***
	(0.10)	(0.11)	(0.11)	(2.70)	(1.28)	(0.06)	(0.08)	(0.08)	(1.34)	(0.79)
TS	-0.17*	0.19	0.19**	-12.0***	2.38*	0.17***	0.20**	0.04	-3.16**	1.30*
	(0.09)	(0.10)	(0.10)	(2.45)	(1.21)	(0.06)	(0.07)	(0.07)	(1.23)	(0.72)
PS	-0.04	0.04	0.16*	-2.19	2.33***	0.03	0.19***	0.18***	-2.01***	0.94**
	(0.06)	(0.06)	(0.09)	(1.45)	(0.72)	(0.04)	(0.05)	(0.05)	(0.77)	(0.46)

Notes: 1. Regression coefficients(β_i) of the OLS: $R_{i,t} = \alpha_i + \beta_i^M SMS_t + XZ_t + \varepsilon_{i,t}$.
2. $'ED4'$, $'TS'$, and $'PS'$ indicate the coefficients for U.S. MP shocks measured by the movements of ED4 rates, the target factor, and path factor, respectively. $R(10y)$ stands for sovereign bond yields with 10-year maturity.
3. In the U.S. case, the notations are instead MP*, R(3y)*, R(10y)*, S*, DXY.
4. Numbers in parentheses are standard errors. *** and ** indicate significance at the 1% and 5% levels, respectively.

As discussed in section 2.2.3, U.S. monetary spillovers seem to be conditional on U.S. business cycles. Specifically, the international transmission into market interest rates in our open economies occurs to a statistically significant extent only during expansions. On the other hand, equity prices and FX rates exhibit much greater impact during economic downturns, although they show significant results during both periods. Conditioned instead on phases of financial asset prices, as shown in Table B.2, the estimation yields results that are similar to those found in the business cycle case. Bond yields are more responsive when the variables are on upward (restrictive) trend while equity exhibits clear evidence of stronger MP effects during downturns (bear markets) in the U.S., Canada, and Korea. FX rates respond only when the U.S. dollar appreciates, indicating that the expectations of economic agents in currency markets respond more sensitively when their local currencies are expected to depreciate. Finally, when I choose financial market turbulence to test state dependency, the results are especially noticeable for sovereign bond yields. As seen in Table B.3, U.S. MP surprises work on sovereign bond yields of the focal open countries (except Korea) only during normal periods. Equity returns respond significantly during both periods, with greater sensitivity during turbulent periods for the U.S. and Canada. The responses of FX rates to surprises are clearly seen to increase during times of turbulence.

Finally, I test asymmetric U.S. MP spillovers. Similarly, I divide the full sample into two parts based on the type of shock involved. Two types of asymmetries are tested:
(ii-a) Shock direction: one possibility for explaining the asymmetry is the sign of surprises, i.e., $D_t = 1$ if an MP shock is contractionary and 0 if it is expansionary.
(ii-b) Shock size: D_t =1 if an MP shock is aggressive and 0 otherwise. I define aggressive shocks as those the squared sums of which are above the median value of all observations.

As shown in section 2.2.3, the results display coefficients on two directional (positive and negative) MP surprises. U.S. bond yields are more sensitive to contractionary shocks and the yields in the focal open economies also show a similar pattern (except in Korea). Equity returns show mixed results; expansionary shocks seem to matter much more for the U.S., Canada, Korea, and the U.K., while MP tightening works more distinctly for Australia and New Zealand.

The U.S. dollar shows significant results with respect to both directional shocks while expansionary shocks seem to matter more for our open economies (except for the U.K.).[1] On the other hand, the spillovers apparently show size dependence. Table B.4 exhibits the regression results from two exclusive sub-samples divided by the magnitudes of the shocks. All the asset returns respond only to aggressive shocks at the 5% significance level. On small MP shocks, no asset returns react in an obvious way.

Table B.2: Non-linear regression coefficients of asset returns on U.S. MP shocks (U.S. financial asset-price phases)

coefficients	MP	R(3y)	R(10y)	S	FX	MP	R(3y)	R(10y)	S	FX
			[US]					[CA]		
Upward	0.73	0.67***	0.63***	-5.10***	4.70***	0.08	0.70***	0.50***	-3.83**	4.31***
(β_i^D)	(0.58)	(0.13)	(0.12)	(1.69)	(0.94)	(0.28)	(0.13)	(0.11)	(1.59)	(0.91)
Downward	0.74**	0.35***	0.18	-13.9***	1.46	-0.05	0.28***	0.06	-10.5***	1.07
(β_i^{ND})	(0.29)	(0.09)	(0.11)	(2.31)	(1.07)	(0.14)	(0.10)	(0.09)	(2.17)	(1.04)
			[AU]					[NZ]		
Upward	-0.00	0.47***	0.47***	-5.32***	8.03***	0.63	0.46***	0.25**	-3.46**	7.80***
(β_i^D)	(0.21)	(0.16)	(0.13)	(1.98)	(1.40)	(0.58)	(0.13)	(0.11)	(1.50)	(1.39)
Downward	-0.09	0.20*	0.03	-5.20**	1.91	0.23	0.09	0.00	-5.45***	1.93
(β_i^{ND})	(0.10)	(0.12)	(0.12)	(2.35)	(1.60)	(0.19)	(0.09)	(0.10)	(1.88)	(1.59)
			[KO]					[UK]		
Upward	-0.02	0.24	0.22	-9.66***	7.02***	0.12	0.37**	0.37**	-4.89***	3.53***
(β_i^D)	(0.17)	(0.17)	(0.15)	(2.73)	(1.62)	(0.14)	(0.13)	(0.12)	(1.64)	(1.03)
Downward	-0.21	0.17	0.09	-23.9	0.93	0.15**	0.36**	0.21*	-5.62**	0.20
(β_i^{ND})	(0.12)	(0.14)	(0.15)	(17.0)	(1.99)	(0.07)	(0.11)	(0.11)	(2.25)	(1.17)

Notes: 1. Regression coefficients (β_i^D and β_i^{ND}) of the OLS: $R_{i,t} = \alpha_i + \beta_i^D MS_t D_t + \beta_i^{ND} MS_t (1 - D_t) + XZ_t + \varepsilon_{i,t}$.
2. MS_t indicates shocks measured by movements in ED4 rates. D_t indicates dummy variables of interest, i.e., $D_t = 1$ when the phase of U.S. financial asset prices is on an upward trend and 0 otherwise. .
3. In the U.S. case, the notations are instead MP*, R(3y)*, R(10y)*, S*, DXY.
4. Numbers in parentheses are standard errors. *** and ** indicate significance at the 1% and 5% levels, respectively.

[1] When tested with target and the path factors, the currency rates respond only to expansionary MP shocks.

Table B.3: Non-linear regression coefficients of asset returns on U.S. MP shocks (Financial market turbulence)

coefficients	MP	R(3y)	R(10y)	S	FX	MP	R(3y)	R(10y)	S	FX
			[US]					[CA]		
Turbulence	0.88*	0.31**	0.40**	-13.7***	5.50***	-0.12	0.39***	0.24*	-11.9***	6.18***
(β_i^D)	(0.47)	(0.14)	(0.15)	(2.51)	(1.29)	(0.23)	(0.15)	(0.13)	(2.32)	(1.25)
Normal times	0.67**	0.53***	0.38***	-5.80***	2.36***	0.01	0.45***	0.27***	-3.69**	1.52*
(β_i^{ND})	(0.31)	(0.09)	(0.10)	(1.65)	(1.29)	(0.15)	(0.10)	(0.09)	(1.52)	(0.81)
			[AU]					[NZ]		
Turbulence	-0.06	0.12	0.23	-5.50**	10.4***	0.04	0.08	-0.07	-4.13**	9.85***
(β_i^D)	(0.17)	(0.17)	(0.17)	(2.57)	(1.92)	(0.33)	(0.14)	(0.14)	(2.05)	(1.91)
Normal times	-0.08	0.37***	0.23**	-5.16***	3.27**	0.39	0.28***	0.19**	-4.29***	3.32***
(β_i^{ND})	(0.11)	(0.11)	(0.11)	(1.87)	(1.26)	(0.22)	(0.09)	(0.09)	(1.43)	(1.25)
			[KO]					[UK]		
Turbulence	-0.18	0.31*	0.32	-11.1***	8.57***	0.18*	0.41***	0.22	-5.92**	3.49***
(β_i^D)	(0.15)	(0.18)	(1.78)	(4.20)	(1.95)	(0.11)	(0.14)	(0.14)	(2.42)	(1.43)
Normal times	-0.13	0.14	0.08	-9.06**	1.85	0.13*	0.34***	0.32***	-4.82***	1.49
(β_i^{ND})	(0.13)	(0.13)	(0.60)	(3.51)	(1.63)	(0.07)	0.10)	(0.10)	(1.59)	(0.93)

Notes: 1. Regression coefficients (β_i^D and β_i^{ND}) of the OLS: $R_{i,t} = \alpha_i + \beta_i^D MS_t D_t + \beta_i^{ND} MS_t(1 - D_t) + XZ_t + \varepsilon_{i,t}$.
2. MS_t indicates shocks measured by movements in ED4 rates. D_t indicates dummy variables of interest, i.e., D_t = 1 when international financial market is turbulent and 0 otherwise.
3. In the U.S. case, the denotations are instead MP*, R(3y)*, R(10y)*, S*, DXY.
4. Numbers in parentheses are standard errors. *** and ** indicate significance at the 1% and 5% levels, respectively.

Table B.4: Non-linear regression coefficients of asset returns on U.S. MP shocks (Magnitude of U.S. MP shocks)

coefficients	MP	R(3y)	R(10y)	S	FX	MP	R(3y)	R(10y)	S	FX
			[US]					[CA]		
Big	0.66***	0.48***	0.40***	-8.29***	3.40***	-0.06	0.45***	0.29***	-6.20***	2.91***
(β_i^D)	(0.22)	(0.08)	(4.67)	(1.43)	(0.73)	(0.13)	(0.08)	(0.07)	(1.33)	(0.72)
Small	3.24**	0.10	-0.08	-3.38	-0.36	1.20	-0.36	-0.54	-4.11	2.65
(β_i^{ND})	(1.62)	(0.44)	(-0.15)	(8.09)	(4.15)	(0.70)	(-0.47)	(0.42)	(-7.53)	(4.04)
			[AU]					[NZ]		
Big	-0.04	0.30***	-5.28***	5.34***	0.25	0.22***	0.11	-4.44***	5.20***	
(β_i^D)	(0.09)	(0.09)	(0.09)	(1.54)	(1.10)	(0.18)	(0.07)	(0.07)	(1.19)	(1.09)
Small	-1.09**	0.34	-0.23	-4.94	6.51	1.26	0.15	0.18	3.03	7.16
(β_i^{ND})	(0.53)	(0.54)	(0.52)	(8.92)	(6.24)	(1.15)	(0.44)	(0.43)	(7.09)	(6.17)
			[KO]					[UK]		
Big	-0.03	0.14	0.22	-12.0***	7.97***	0.15**	0.38***	0.26***	-5.03***	2.00**
(β_i^D)	(0.14)	(0.14)	(0.14)	(3.86)	(1.79)	(0.06)	(0.08)	(0.08)	(1.37)	(0.82)
Small	-0.26	0.26	0.06	-8.08**	1.46	0.05	-0.48	0.77	-1.96	1.52
(β_i^{ND})	(0.14)	(0.15)	(0.16)	(3.72)	(1.73)	(0.37)	(-0.51)	(0.48)	(7.89)	(4.73)

Notes: 1. Regression coefficients(β_i^D and β_i^{ND}) of the OLS: $R_{i,t} = \alpha_i + \beta_i^D MS_t D_t + \beta_i^{ND} MS_t(1 - D_t) + XZ_t + \varepsilon_{i,t}$.
2. MS_t indicates shocks measured by movements in ED4 rates. D_t indicates dummy variables of interest, i.e., $D_t = 1$ when when the MP shock is big (aggressive) and 0 otherwise.
3. In the U.S. case, the denotations are instead MP*, R(3y)*, R(10y)*, S*, DXY.
4. Numbers in parentheses are standard errors. *** and ** indicate significance at 1% and 5% levels, respectively.