FINANCIAL STABILITY MONETARY POLICY AND GROWTH

AN EMPIRICAL INVESTIGATION OF MACROFINANCIAL LINKAGES

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Abstract

In the aftermath of the global financial crisis, financial stability has captured the attention of scholars and central bankers and has become a prominent topic in the financial and economic literature. In this dissertation, we empirically examine the association between financial stress co-movements and spillovers among several economies using financial stress indices. Furthermore, we examine the interdependence of banking, securities and foreign exchange markets for the major advanced economies. In addition to examining the linkages of financial stress among countries and markets, we examine the relationship between financial stability and several macroeconomic fundamentals. In this dissertation, by conducting empirical macroeconomic and financial analysis, we seek to contribute to the continuously growing literature on financial stability.

Keywords: Financial Stability; Monetary Stability; Growth; Financial Stress Index; Government Deficit; Housing Prices; Impulse Responses; Granger Causality; Dynamic Conditional Correlations; Stress Spillover Index; Stress Spillover Plots; Financial Crises; GIRs.

Περίληψη

Μετά την παγκόσμια χρηματοπιστωτική κρίση του 2007, η χρηματοπιστωτική σταθερότητα έλαβε την προσοχή των μελετητών και των κεντρικών τραπεζών και κατέστη ένα εξέχον θέμα στη χρηματοοικονομική και οικονομική βιβλιογραφία. Κατά τον ορισμό της Τραπέζης της Ελλάδος, χρηματοπιστωτική σταθερότητα είναι μια κατάσταση στην οποία το συνολικό χρηματοπιστωτικό σύστημα διαθέτει ισχυρές αντοχές και επαρκείς αντιστάσεις στους απροσδόκητους κραδασμούς ή διορθώσεις ανισορροπιών, ώστε να ελαχιστοποιείται η πιθανότητα αποδιοργάνωσης του συστήματος σε βαθμό που θα διακύβευε την αποτελεσματική λειτουργία του χρηματοπιστωτικού συστήματος. Σε αυτή τη διατριβή, εξετάζουμε εμπειρικά τις συνεργατικές κινήσεις και διάχυση του χρηματοπιστωτικού στρες μεταξύ αρκετών οικονομιών, χρησιμοποιώντας δείκτες χρηματοπιστωτικού στρες. Επιπλέον, εξετάζουμε την αλληλεξάρτηση των τραπεζικών αγορών, των αγορών κινητών αξιών και των αγορών συναλλάγματος για τις προηγμένες οικονομίες. Εκτός από την εξέταση των δεσμών οικονομικού στρες μεταξύ χωρών και αγορών, εξετάζουμε τη σχέση μεταξύ χρηματοπιστωτικής σταθερότητας και πολλών μακροοικονομικών θεμελιωδών μεγεθών. Σε αυτή τη διατριβή, με τη διενέργεια εμπειρικής ανάλυσης, επιδιώκουμε να συμβάλουμε στην συνεχώς αυξανόμενη βιβλιογραφία για τη χρηματοπιστωτική σταθερότητα.

Λέξεις κλειδιά: Χρηματοπιστωτική σταθερότητα; Νομισματική σταθερότητα; Ανάπτυξη; Δείκτης χρηματοοικονομικού στρες; Κυβερνητικό έλλειμμα; Τιμές στέγασης; Impulse responses; Αιτιότητα κατά Granger; Dynamic conditional correlations; Δείκτης διάχυσης στρες; Διασπορά στρες; Χρηματοπιστωτικές κρίσεις; Generalized impulse responses.

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1. Introduction

Research on financial stability has taken a different pace since the global financial crisis of 2007. Many central banks have started to pay more attention to safeguarding financial stability. Together with monetary policy, financial stability and macroprudential policy are the main tasks of central banks.

We find several definitions of financial stability in the literature, indicating that there is no consensus.[1] In general, Smaga (2013), who compares definitions of financial stability, argues that the emphasis is mainly placed on whether the financial system can properly fulfill its functions, particularly the efficient allocation of resources and the impact of financial instability on the real economy; however, the risks arising from misalignments in asset prices and the interrelationships between various elements of the financial system, through which contagion may spread, receive little attention. Smaga (2014, p. 13) defines systemic risk as the risk that a shock will result in such a significant materialization of (e.g., macro-financial) imbalances that it will spread on a scale that impairs the functioning of the financial system and to such an extent that it adversely affects the real economy (e.g., economic growth). For example, the European Central Bank (ECB), which includes financial stability and macroprudential policy as one of its mains tasks together with banking supervision,

[1] In Chapter 2, we provide a brief exploration of definitions of financial stability.

banknotes, statistics, and international and European cooperation, defines financial stability as the state whereby the build-up of systemic risk is prevented.[2] According to the ECB, systemic risk can derive from i) an endogenous build-up of financial imbalances, possibly associated with a booming financial cycle, ii) large aggregate shocks hitting the economy or the financial system, and iii) contagion effects across markets, intermediaries or infrastructures.

From a theoretical perspective, the groundbreaking works of Bernanke and Gertler (1995), Bernanke et al. (1999) and Kiyotaki and Moore (1997) introduced credit market frictions and emphasized the role of the financial accelerator mechanism in amplifying the effects of financial cycles on the real economy. Kiyotaki and Moore (1997) show that in a scenario of a negative shock to the economy where output declines, collateral values fall, which means borrowing falls, which depresses output even further. Thus, the collateral constraint is a mechanism that amplifies and propagates the effects of temporary shocks on the economy. Expanding on the model of Kiyotaki and Moore, (1997), Brunnermeier and Sannikov (2014) explain that when an economic boom increases bank capital levels so high enough that credit is amply available to borrowers, the volatility of both output and asset prices is lowered. This lower volatility induces banks to increase their leverage and lend even more, so much so that the system is now vulnerable to a negative shock.

1.1 Contagion effects and the linkages of financial stress

The global financial and economic crisis revealed the importance of international financial spillovers. Financial stress co-movements and the risk of contagion increase during periods

[2] ECB (2018)

of extreme turbulence because financial markets have gradually become more interconnected.

One strand of the literature examines the transmission mechanisms and the channels of contagion of financial stress. Stress spillovers can be transmitted mainly via trade and financial channels (Diebold and Yilmaz, 2009; Forbes and Chinn, 2004; Forbes and Rigobon, 2002; Glick and Rose, 1999). Scholars have examined the transmission of financial distress along financial markets and examined the likelihood that such stressful episodes engender economic downturns using a financial stress index (Balakrishnan et al., 2009; Cardarelli et al., 2011). Balakrishnan et al. (2009) examine financial transmission from advanced to emerging market economies. Cardarelli et al. (2011) assess the impact of financial stress on the real economy and intensified episodes of financial turmoil that can lead to slowdowns or even recessions.

1.2 Financial stability and macroeconomic fundamentals

The global financial crisis relaunched the debate over whether monetary policy should counter the volatility of and change in financial variables as well as the expected inflation and output (Borio, 2014; Mishkin, 2011). Furthermore, the conventional view prior to the crisis was also that there is no general tradeoff between monetary and financial stability and that there is only a positive correlation between price stability and financial stability (Bordo et al., 2002; Issing, 2003; Schwartz, 1995).

Schwartz (1995) finds that achieving price stability over the medium term is sufficient to prevent financial crises. Borio and Lowe (2002) argue that there is the possibility of financial instability even in conditions of low inflation and growth when there is a combination of supply shocks and asset price booms with overoptimistic assessments of risk.

De Graeve et al. (2008) find evidence of a tradeoff between financial stability and monetary stability by incorporating a measure of banking distress. Granville and Mallick (2009) examine the nexus between monetary stability and financial stability and find a pro-cyclical relationship between these measures over the long run.

Another strand of the literature addresses the relationship between growth and financial stability (Cevik et al., 2013; Hakkio and Keeton, 2009; Mallick and Sousa, 2013). Bloom (2009) argues that uncertainty shocks lead to drops in output because higher uncertainty causes firms to temporarily halt investment plans. However, the causal relationship between financial stability and growth might run in the other direction. Scholars have found evidence of a reverse relationship in which growth negatively affects financial instability (Beck et al., 2006; Demirgüç-Kunt and Detragiache, 1998; Klomp and De Haan, 2009).

Finally, a third strand of the literature examines the relationship of sovereign debt and financial stability (Corsetti et al., 2013; Das et al., 2010; Proaño et al., 2014; Taylor et al., 2012). Das et al. (2010) examine the channels and the linkages of public debt to financial stability. They argue that poor debt management can raise sovereign risks, deteriorating financial stability via a feedback loop. Taylor et al. (2012) examine the linkages between primary deficits, interest rates and economic growth. They find that low GDP growth rates are the cause of high debt-to-GDP ratios. Corsetti et al. (2013) examine how the sovereign risk channel affects macroeconomic dynamics and stabilization policy. They argue that the risk channel can become a critical determinant of macroeconomic outcomes in the case of an environment in which the monetary policy is constrained. Examining the relationship among growth, the level of debt, and the stress level, Proaño et al. (2014) find that debt impairs economic growth in the European Monetary Union during times of high financial stress. Tagkalakis (2013) finds a significant deterioration in debt ratios during financial crises and an increase in the stock of debt. Furthermore, a fragile and inadequately performing banking system poses risks to the soundness of public finances (Tagkalakis, 2014). Finally, Magkonis and Tsopanakis (2014) find that financial and fiscal shocks negatively affect growth and inflation rates.

1.3 Measures of financial stability

There are several measures of financial stability in the literature. Gadanecz and Jayaram (2009) provide a review of such measures from single indicators (e.g., IMF Financial Soundness Indicators) and composite indicators (bank credit related to GDP) to single aggregate measures of financial stability (e.g., the financial stress index of Illing and Liu (2006)). These aggregate measures reflect the conditions of a key sector such as banking or key financial market conditions. In this dissertation, to have a reliable measure of financial stability, we use financial stress indices.

Several scholars propose measures of measuring systemic risk, using financial stress indices (FSIs). In this regard, the literature dates back to the seminal study of Illing and Liu (2006). They develop an FSI for the Canadian financial system and propose several approaches to aggregate individual stress indicators into a composite stress index. Other relevant papers are Nelson and Perli (2007), Kritzman et al. (2010), Caldarelli et al. (2009), and Holló et al. (2012). Louzis and Vouldis (2011) make a first effort to categorize the academic efforts of building an FSI.

1.4 Methods

To examine the correlations of financial stress among the G7 nations during the 1981-2009 period, we use the dynamic conditional correlations (DCC) model of Engle (2002). Furthermore, we use the vector autoregressive (VAR) framework of Diebold and Yilmaz (2009, 2012), which involves generalized variance decompositions to explore the stress linkages i) among the G7 nations and ii) among five Asian countries in 1997 and 2009, iii) and to measure the interdependence of three financial stress sub-indices (banking, securities and foreign exchange) for the G7 economies. We calculate financial stress spillovers and indices, and we provide financial spillover stress plots (total-directional-net pairwise). Additionally, to examine the relationship among financial stability, monetary stability, and output growth, we utilize the VAR framework to estimate impulse response functions (IRFs). We implement the generalized framework of Koop et al. (1996) and Pesaran and Shin (1998) to calculate the IRFs, and we use the pure sign restriction and the penalty function approaches developed by Uhlig (2005). We also examine the Granger causation of financial stress, the CPI and GDP using VAR methods. Finally, we use a panel vector autoregressive (PVAR) generalized method of moments (GMM) estimator, as in Love and Zicchino (2006), to explore the relationship between financial stress and the macroeconomic variables of 19 OECD economies during 1999-2016. We proceed to the panel Granger causality examination, and we implement panel impulse responses and panel variance decompositions.

Overall, this dissertation aims to contribute to the growing stream of literature on financial stability by employing an FSI as a measure of financial stability and by examining the dynamics of financial stress among countries, markets and macroeconomic fundamentals.

1.5 Structure

The remainder of this dissertation is structured as follows. In Chapter 2, we examine financial stress co-movements and spillovers among the advanced economies of the G7 by employing an FSI as a proxy variable for financial stability and by considering the global financial crisis. In Chapter 3, we study the interdependence of three financial markets, and we examine the relationship between financial stability and macroeconomic fundamentals by investigating the effects of financial stress on growth and price levels. In Chapter 4, we examine financial stress spillovers in Asian financial markets by employing an FSI appropriate for emerging economies. In Chapter 5, we examine the relationship among financial stress, inflation and growth in advanced economies over the 1999-2016 period using panel data and a newly constructed FSI and considering the European sovereign debt crisis. Chapter 6 presents the discussion and conclusion of this dissertation.

Financial Stress Spillovers in Advanced Economies

Abstract

In this study, we examine financial stress co-movements and spillovers among the G7 economies by employing a financial stress index as a proxy variable and accounting for financial instability. To examine the interdependence of financial stress, we parse the dynamic conditional correlations of financial stress among these countries for the 1981-2009 period. In addition, we present spillover indices and plots of financial stress that indicate financial stress innovations and spillover dynamics, respectively. Our empirical results suggest a positive association of financial stress co-movements and spillovers with both financial crises and uncertainty. In general, our findings provide a clear view of the transmission of financial stress during important stressful episodes, suggesting the existence of an increased interplay among the financial markets.

Keywords: Financial stability; Financial stress indices; Dynamic conditional correlations; Stress spillover index; Stress spillover plots; Financial crises.

JEL classification: C32, C43, F30, G15.

2. Financial Stress Spillovers in Advanced Economies

2.1 Introduction

In recent years, financial stability has increasingly gained the interest of the scientific community, especially after the 1990s, when the banking and currency crises were enhanced by financial deregulation and integration (Stiglitz, 2003). The need for policy measures oriented toward safeguarding and strengthening the financial system motivated us to conduct this research. The field of financial stability is still nascent, but it is growing fast. Nevertheless, a unique acceptable definition of financial stability does not exist (Crockett, 1996; Schinasi, 2004; Allen and Wood, 2006a). The current study is consistent with the descriptions of instability outlined by Mishkin (1999) and De Graeve et al. (2008). Mishkin (1999) relates the ability of financial systems to allocate funds to productive investment opportunities. De Graeve et al. (2008) argue the existence of a trade-off between financial stability and monetary stability by incorporating a measure of banking distress. Therefore, we proxy financial stability using a Financial Stress Index (FSI) developed by International Monetary Fund (IMF) economists. A level of distress in the financial system that is higher than normal is regarded as an indication of financial instability.

The main objective of this study is to study the underlying dynamic relationship of financial stress episodes between the advanced countries of the G7. The literature on how stress spillovers are transmitted through countries is still nascent. Financial stress episodes are frequently connected with economic downturns, as they destabilize the financial system and hinder its ability to operate smoothly. Recent research has focused on the transmission of financial stress and the likelihood of these stressful episodes to lead to economic downturns (Cardarelli et al., 2009; Balakrishnan et al., 2009).

To the best of our knowledge, this study is the first to use dynamic conditional correlations (DCCs) and spillover indices to examine co-movements and spillovers of financial stress. Our first contribution comes from the examination of stress co-movements among the G7 countries. We examine the conditional correlations using the two-stage DCC multivariate GARCH model developed by Engle (2002). Using this approach, we investigate the pattern of financial stress interdependencies among the G7 countries. The second contribution comes from the examination of stress spillover effects. We study the linkages of financial stress using the vector autoregressive (VAR) framework developed by Diebold and Yilmaz (2009, 2012). Our last contribution to the relevant literature comes from an examination of the stress spillovers of each of the FSI subcomponents—namely, banking sector, securities markets and foreign exchange rate subindices—and an analysis of the volatility stress spillovers among the G7 countries.

The newly developed version of the spillover index, which involves generalized variance decompositions, has recently been applied to the investigation of the interconnectedness of volatility in financial markets (Yilmaz, 2010; Antonakakis and Vergos, 2013). Furthermore, our paper adds to the evolving stream of financial stability literature by employing an FSI as a measure of financial instability and by examining the transmission of stress. A similar FSI has been used to examine the crisis of 2007 in the foreign exchange market (Melvin and Taylor, 2009) and to measure the relationship between monetary and financial instability (Baxa et al., 2013; Martin and Milas, 2013).

The results of our models suggest policy measures oriented toward safeguarding and strengthening financial stability. Several important findings stem from the analysis of the DCC and the generalized spillover indices. In summary, our findings suggest, first, the existence of a positive association between stress co-movements and periods of financial turmoil, such as the Asian and Russian crises, the dot-com crisis and the most recent global financial crisis. The panel regression analysis of the conditional correlations with the conditional volatility provides further evidence of the positive association of stress co-movements with periods of increased uncertainty, particularly for the US, the UK and Canada. Second, cross-country stress spillovers explain a substantial proportion of the forecast error variance beyond own-country stress spillovers. The US is the main transmitter of stress spillovers to other countries, whereas the UK is the main stress receiver. The net directional and pairwise stress spillover plots verify the role of the US as a major transmitter of stress to other countries. In addition, our results indicate that 19.9% of the forecast error variance in the examined countries is derived from stress spillovers.

The examination of the three subcomponents of financial stress provides further evidence of stress spillovers. The total stress spillover index of the securities markets explains a higher proportion of the forecast error variance than banking and exchange total stress spillover indices. This finding indicates that the securities markets are the most important factor in the transmission of financial stress through spillovers among the G7 countries. Finally, results similar to those for stress spillovers stem from the analysis of the volatility spillovers of financial stress, where the total volatility spillover index indicates that, on average, 20.9% of the volatility forecast error variance comes from spillovers. Our findings provide evidence of the transmission of financial stress during significant stressful episodes, suggesting interplay among the financial markets. Overall, our results suggest that the interdependence of financial uncertainty between the G7 countries is positively related to crisis periods and that spillovers of financial stress among these countries have increased during the last three decades.

The remainder of this study is structured as follows. In section 2.2, we present our review of the literature on financial (in)stability and its importance to economic activity. In section 2.3, we provide a brief description of the financial stress indices and the methods used for their construction. In sections 2.4 and 2.5, we describe the methods and the data used in this study. In section 2.6, we present our empirical findings. Finally, we summarize and conclude the study in section 2.7.

2.2 Literature review

On theoretical grounds, we may distinguish the work of Kiyotaki and Moore (1997) Bernanke et al. (1999) and Goodhart et al. (2004). Kiyotaki and Moore (1997) argue that minor shocks to the economy may be exacerbated by credit restrictions, leading to large output fluctuations. In the work of Bernanke et al. (1999), financial frictions allow for the effect of financial factors on investments and the real interest rate. In this manner, the authors suggest a channel through which changes in financial variables influence economic activity. Goodhart et al. (2004) analyze financial fragility using a finite horizon general equilibrium (FHGE) model.

In recent years, there is a continuous effort to identify the consequences of financial imbalances in economic activity primarily during stress episodes. Recently, Cardarelli et al. (2011) conduct a search for common patterns of economic crises and increased periods of financial distress. Scholars have identified two factors that contribute to stress spillovers, largely through the trade and financial channels. For instance, Glick and Rose (1999) examine trade and exchange linkages, and Forbes (2002) examine trade linkages during crises. In addition to the trade channel, financial linkages are a second important channel of stress, as highlighted by Kaminsky and Reinhart (2000), Van Rijckeghem and Weder (2001), Forbes and Chinn (2004), and Caramazza et al. (2004). In addition to the two important country-specific factors above, the transmission of financial stress may be attributed to common factors, such as global shocks, cross-country contagion and common-lender effects. These factors may manifest through investors' herding behavior and are likely related to the financial integration of the financial markets (Balakrishnan et al., 2009).

It is necessary for the analysis of financial stability to cover all the sources of risks and vulnerabilities although this effort requires the systematic monitoring of individual parts of the financial system as well as their relationships (Schinasi, 2006). Thus, a suitable measurement of financial stability should include a wide range of quantitative variables capturing cross-border contagion risks and financial system vulnerabilities. The quantification of financial distress is a rudimentary challenge that many scholars encounter in their research. In general, in our review of relevant research, we found empirical studies employing the probability of default (PD) as a single measure of financial stability. PD is typically calculated as a function of the distance to default (DD) based on the theory and practice of contingent claims analysis (CCA) and the Merton Model.[3] Nevertheless, the accuracy of such predictions is subject to criticism Bharath and Shumway, (2008). In this study, we utilize the FSI developed by IMF economists (Balakrishnan et al., 2009) as a measure of financial stress and increased instability in the economy. The construction of such financial stress indices has been developed by several researchers (Hanschel and Monnin, 2005; Illing and Liu, 2006; Van den End, 2006). Next, we provide information regarding the compilation of such FSIs and their applicability to scientific research.

[3] $DD_t = \frac{\ln(V_{A_t}/D_t)+(r+0.5\sigma_A^2)T}{\sigma_A\sqrt{T}}$. With the use of market data on equity and annual accounting data, the market value V_A and the volatility of assets σ_A are typically estimated using the (Black and Scholes, 1973) options pricing model and (Merton, 1973) (1974). The theoretical probability of default is obtained using DD_t as $PD_t = N(-DD_t)$, where N is the cumulative probability distribution function (CDF) for a variable that is normally distributed with a mean of zero and a standard deviation of 1, and μ measures the mean growth of V_A.

2.3 Financial stress indices

Various stress indices, including different indicators combined into a single composite index, are found in the literature. In a seminal paper, Illing and Liu (2006) explore several different ways of combining financial variables into a composite index and examine three different weighting methods. The first method incorporates the factor analysis approach based on the techniques of Stock and Watson (1989). This approach was used in the construction of the Chicago Fed National Activity Index (CFNAI), the Kansas City Financial Stress Index (KCFSI) and the St. Louis Financial Stress Index (STLFSI). The second method, referred to as credit weights, weights variables by the relative market size. The weight is assigned by the relative market share of total credit in the economy, with high market shares having higher weight. Finally, the last method, the variance-equal weighting method, generates an index that gives equal importance to each variable. This approach is followed in the works of Cardarelli et al. (2009, 2011) and Balakrishnan et al. (2009). The use of this method allows for an investigation of subindices rather than an overall index through a simple decomposition of its components (Balakrishnan et al., 2009). Illing and Liu (2006) postulate that the variance-equal weighting method performs as well as the credit weight method in signaling stress episodes. Balakrishnan et al. (2009) and Park and Mercado Jr. (2013) posit that the factor and equal variance methods yield similar weights and comparable patterns of financial stress.

As such, FSIs are used for several purposes and for different scopes. Illing and Liu (2006) compile an index that includes a number of variables that are more important to a small open economy, such as corporate bond spreads, a measure of liquidity in the treasury market and a measure of volatility in the overall stock market. An alternative method for the construction of an FSI has been proposed by Van den End (2006), whose financial stability condition index is based on several financial indicators, such as interest rates, the effective exchange rate, real estate prices, stock prices, the solvency of financial institutions and the volatility of financial institutions' stock index.

Cardarelli et al. (2009, 2011) use an FSI to answer the question of why some financial stress episodes lead to economic downturns. In the same vein, Balakrishnan et al. (2009) use an FSI to study how financial stress, defined as periods of impaired financial intermediation, is transmitted from advanced to emerging economies.[4] Davig and Hakkio (2010) explore the linkages between financial stress and economic activity using an FSI to find evidence of the link between the index and economic activity employing impulse responses. Finally, Baxa et al. (2013) examine the relationship between financial instability and monetary policy using the FSI developed by Cardarelli et al. (2011), and similarly to Balakrishnan et al. (2009), Park and Mercado Jr., (2013) construct an FSI to examine the transmission of stress in emerging economies.

2.4 Empirical method

First, we examine the conditional correlation using the framework developed by Engle (2002).[5] The covariance matrix is decomposed into the product of dynamic conditional standard deviations and DCCs. We define the DCC model as follows:

$$s_t = \mu_t(\theta) + \epsilon_t, \text{ where } \varepsilon_t | \Omega_{t-1} \sim N(0, H_t) \quad (2.1)$$

[4] Balakrishnan et al. (2009) use the same method as Cardarelli et al. (2009) to construct the FSI for advanced economies but compile a different FSI for emerging economies.

[5] See McAleer et al. (2009) for a comparison between different GARCH models, including that closely related to the DCC model of VCCs of Tse and Tsui (2002).

$$\epsilon_t = H_t^{1/2} u_t, \text{ where } u_t \sim N(0, I) \quad (2.2)$$

$$H_t = D_t R_t D_t, \quad (2.3)$$

where $s_t = (s_{i,t}, \dots \dots s_{N,t})'$ is a N x 1 vector of financial stress (N=7), $\mu_t(\theta) = (\mu_{i,t}, \dots \dots \mu_{N,t})'$ is the conditional 7 x 1 mean of s_t, H_t is the conditional covariance matrix, $D_t = diag\left(h_{ii,t}^{1/2}, \dots .., h_{NN,t}^{1/2}\right)'$ is a diagonal matrix of square root conditional variances, and h_{iit} is a univariate GARCH-type model.[6][7]

In the first step, the conditional variances $h_{ii,t}$ are modeled via the GARCH model, and in the second step, the estimated conditional variances are used to estimate the standardized residuals. In the second step, the residuals are transformed by their estimated standard deviations from the first step. The evolution of the correlation in the DCC model is given by the following:

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha u_{t-1} \acute{u}_{t-1} + \beta Q_{t-1}, \quad (2.4)$$

where $u_t = (u_{1,t}, u_{2,t}, \dots, u_{N,t})'$ is the N x 1 vector of standardized residuals, Q_t is the N x N unconditional variance matrix of u_t, and α and β satisfy the stability constraint of $\alpha + \beta < 1$. We scale Q_t to obtain a correlation matrix R_t with ones on the diagonal.

$$R_t = diag\left(q_{ii,t}^{-1/2}, \dots .., q_{NN,t}^{-1/2}\right) Q_t diag(q_{ii,t}^{-1/2}, \dots .., q_{NN,t}^{-1/2})$$

$$\text{or } \rho_{ij,t} = \rho_{ji,t} = q_{ij,t} / \sqrt{q_{ii,t} q_{jj,t}}, \quad (2.5)$$

Next, we use the method developed by (Diebold and Yilmaz, 2009, 2012) to explore the stress linkages among the major advanced economies (G7). As a starting point, we take the N-variable, pth order VAR:

[6] $s_t = \mu + \sum_{p=1}^{p} \gamma_p s_{t-p} + \varepsilon_t, for\ p = 3$

[7] $h_{ii,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \beta_i h_{ii,t-1}, for\ i = 1,2,..,7.$

$$x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \varepsilon_t,\ \varepsilon_t \sim iid\ (0, \Sigma) \tag{2.6}$$

where $x_t = (x_{1,t},..,x_{N,t})'$, Φ is a N x N parameter matrix, ε_t is a vector of independently and identically distributed errors, and Σ is the covariance matrix. The moving average representation is given by $x_t = \sum_{i=1}^{\infty} A_i \varepsilon_{t-i}$, where the N × N coefficient matrices A_i are estimated by the recursion $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \cdots + \Phi_p A_{i-p}$, with A_0 being an N × N identity matrix and with $A_i = 0$ for $i < 0$. The recent work of Diebold and Yilmaz (2012) employs the generalized VAR framework of (Koop et al., 1996; Pesaran and Shin, 1998), in which variance decompositions are invariant in terms of the variable ordering. In this case, the H-step-ahead forecast error variance decomposition is defined as follows:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)}, \tag{2.7}$$

where Σ is the variance matrix for the error vector ε, σ_{jj} is the standard deviation of the error term for the j^{th} equation, and e_i is the selection vector, with one as the i^{th} element and zero otherwise.

In the generalized VAR framework, the shocks to each variable are not orthogonalized; therefore, the sum of each row of the variance decomposition matrix does not add to unity. In this case, each element of the decomposition matrix is normalized by dividing it by the row sum:

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)}, \tag{2.8}$$

where $\sum_{j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = 1$ and $\sum_{i.j}^{N} \tilde{\theta}_{ij}^{g}(H) = N$ by construction. Using the normalized elements of the decomposition matrix of Eq. 2.8, we construct the total stress spillover index (TSI). This index captures the level of cross-country spillovers by measuring the contribution of the spillovers of shocks across all countries to the total forecast error variance. The TSI, based on H-step-ahead forecasts, is given by the following:

$$S^g(H) = \frac{\sum_{\substack{i,j=1 \\ i\neq j}}^{N} \tilde{\theta}_{ij}^g(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^g(H)} \cdot 100 = \frac{\sum_{\substack{i,j=1 \\ i\neq j}}^{N} \tilde{\theta}_{ij}^g(H)}{N} \cdot 100. \qquad (2.9)$$

To examine the spillover effects from and toward a specific country, we use directional stress spillovers. Because the generalized impulse responses and variance decompositions are invariant to the ordering of variables, we calculate the directional stress spillovers using normalized elements of the generalized variance decomposition matrix. Specifically, the directional stress spillovers received by variable i from all other variables j are defined as follows:

$$S_{i\cdot}^g(H) = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\theta}_{ij}^g(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^g(H)} \cdot 100 = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\theta}_{ij}^g(H)}{N} \cdot 100. \qquad (2.10)$$

Accordingly, the directional stress spillovers transmitted by variable i to all other variables j are defined as follows:

$$S_{\cdot i}^g(H) = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\theta}_{ji}^g(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ji}^g(H)} \cdot 100 = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\theta}_{ji}^g(H)}{N} \cdot 100. \qquad (2.11)$$

The net directional stress spillovers provide information on whether a country is a receiver or a transmitter of shocks in net terms. The net value is simply the difference between the gross stress shocks transmitted to and those received from all other countries, with positive values indicating that country i is transmitting spillover effects to all other countries and with the reverse inference for negative values (i.e., country i is a receiver of spillover effects). We obtain the net stress spillover from country i to all other countries j by subtracting Eq. 2.11 from Eq. 2.10. Thus, the net directional stress spillover is given by the following:

$$S_i^g(H) = S_{\cdot i}^g(H) - S_{i\cdot}^g(H) \qquad (2.12)$$

The net pairwise stress spillover between countries i and j is simply the difference between the gross financial stress shocks transmitted from country i to country j and those transmitted from j to i. The net pairwise stress spillovers are defined as follows:

$$S_{ij}^{g}(H) = \left(\frac{\tilde{\theta}_{ji}^{g}(H)}{\sum_{i,k=1}^{N} \tilde{\theta}_{ik}^{g}(H)} - \frac{\tilde{\theta}_{ij}^{g}(H)}{\sum_{j,k=1}^{N} \tilde{\theta}_{jk}^{g}(H)}\right) \cdot 100$$
$$= \left(\frac{\tilde{\theta}_{ji}^{g}(H) - \tilde{\theta}_{ij}^{g}(H))}{N}\right) \cdot 100. \qquad (2.13)$$

2.5 Data

We examine financial stress spillovers between the major advanced economies (the US, the UK, Canada, Japan, Germany, France and Italy) measured by the FSI, as described. To our knowledge, no empirical study to date has provided comprehensive evidence of the stress spillovers among these countries. For the purpose of our analysis, we use the FSI provided by Balakrishnan et al. (2009), which is an appropriate measure of financial stress for a variety of countries. The construction of the FSI follows the third method indicated by Illing and Liu (2006). Thus, it is a variance-equal weighted average of seven components grouped into three subindices: banking sector, securities markets and foreign exchange rate. In detail:

i. The banking sector subindex is compiled by the beta of the banking sector (a 12-month rolling beta), which is a measure of the correlation of banking stock returns to total returns in line with the CAPM, the TED or interbank spread (the difference between the three-month short-term government debt (T-bill) interest rate and the three-month interbank offered rate), which is an indicator of perceived credit risk in the general economy, and the inverted term spread, which is measured as the difference between the short-term rate and long-term yields of government-issued securities.

ii. The securities market subindex is compiled with corporate bond spreads, stock market returns and stock market volatility. The corporate bond spreads are the corporate bond yield minus the long-term government bond yield. Moreover, the stock market returns are measured as the inverted month-over-month change in the stock index; for example, a decrease in stock prices is listed as an increase in the index. A third variable for measuring securities markets is the measure of stock market volatility.

iii. Finally, the foreign exchange market subindex is measured by exchange market volatility. The volatility of the stock market and the volatility of the exchange rate are measured by a GARCH (1,1) model according to Bollerslev et al. (1992).

To yield the aggregate FSI for an individual country, the seven components are standardized and summed:

$$\begin{aligned} FSI_t = beta\ &+\ TED\ spread\ +\ Inverted\ term\ spread \\ &+\ Corporate\ dept\ spread \\ &+\ Stock\ market\ returns \\ &+\ Stock\ market\ volatility \\ &+\ Exchange\ market\ volatility \end{aligned} \tag{2.14}$$

The summary statistics of the input data spanning from the beginning of 1981 to early 2009 and covering several episodes of financial stress over an approximately 28-year period are presented in Table 2-1. As shown in the table, the maximum value of financial stress is observed for Germany, the US and the UK (19.9, 18.0 and 17.6 points, accordingly). Descriptive statistics support the existence of serial correlation and ARCH effects in our series, according to the Ljung-Box Q tests on raw and squared series and Engle's ARCH-LM test, respectively. Another noteworthy statistic of the FSI series shown in Table 2-1 is a high value of kurtosis and the presence of positive skewness, which contribute to the strong rejection of the null hypothesis of normality from the Jarque-Bera statistics. Thus, we use the first difference of the FSI series for our DCC and VAR-spillover models throughout this study.

To visualize the financial stress of each country, we depict the FSI series in Fig. 2-1. The FSI captures the major episodes of financial distress from the last two decades, with higher numbers indicating more stressful periods. The financial turbulence following the collapse of Lehman Brothers is strongly reflected in the plot, as shown in the spike in mid-2008. The highest levels of financial stress are observed during the last global financial crisis for the US, the UK, Canada and Japan, whereas the highest levels for Germany are depicted in early 1991, for Italy at the end of 1992 (the ERM crisis) and for France in mid-1982 (the Latin American debt crisis). Additionally, the financial stress indices move closely together, although this phenomenon is more pronounced during the last decade for the US, the UK, Canada and Japan. This observation is supported by the unconditional correlations shown in Table 2-2. The highest correlations of stress are observed for Canada and the UK (0.76) and for the US and the UK (0.72). The unconditional correlations of the differenced series are lower in magnitude than the series in terms of levels, with the highest correlations evident for the US-Japan and US-UK pairs. Overall, the FSI is able to identify and capture the most important financial stress episodes that followed the financial deregulation at the end of the 1990s in most countries and the globalization of the capital markets.

Table 2-1. Summary statistics.

Variable	USA	UK	CAN	JPN	GER	FRA	ITA
Mean	-0.20988	-0.14217	0.0093228	0.051421	-0.087219	-0.033955	-0.078464
Minimum	-5.2293	-5.6455	-4.6264	-6.2075	-6.9095	-5.7262	-5.5879
Maximum	17.965	17.599	16.813	14.076	19.91	13.309	10.209
Std.dev.	3.1174	3.0954	3.2096	2.7302	3.2943	3.3139	2.8244
Skewness	1.6294**	1.9307**	2.0299**	0.97157**	1.2911**	1.1617**	0.78683**
	(12.248)	(14.513)	(15.258)	(7.3029)	(9.7050)	(8.7320)	(5.9143)
Kurtosis	5.5479**	7.2672**	5.9032**	2.5791**	4.2279**	2.4309**	0.52751*
	(20.911)	(27.392)	(22.250)	(9.7213)	(15.936)	(9.1625)	(1.9883)
JB	579.59**	948.13**	718.62**	145.99**	343.61**	158.30**	38.565**
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Q(20)	1200.81**	1023.43**	1058.03**	711.963**	1227.54**	126.08**	1293.00**
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$Q^2(20)$	354.784**	430.645**	743.920**	81.9384**	83.9867**	2396.80**	345.375**
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ARCH (1-5)	114.04**	307.30**	157.70**	14.314**	11.874**	971.566**	53.717**
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

Notes: () and [] denote t-values and the actual probability values, respectively. JB is the Jarque-Bera test for normality, and Q(20) and $Q^2(20)$ are the Ljung–Box statistics for serial correlation in raw series and squared series, respectively. First-differenced financial stress series are used. The sample size is 336 monthly observations spanning from 03-01-1981 to 02-01-2009.

* 5% significance

** 1% significance

Table 2-2. Unconditional correlations.

	1	2	3	4	5	6
Panel A: FSI series						
USA	1					
UK	0.7183**	1				
CAN	0.7025**	0.7640**	1			
JPN	0.3583**	0.5619**	0.5400**	1		
GER	0.5255**	0.6286**	0.6498**	0.4384**	1	
FRA	0.4261**	0.3004**	0.3484**	0.1411**	0.2495**	1
ITA	0.3958**	0.3937**	0.3977**	0.2548**	0.3250**	0.6352**
Panel B: First differenced series						
dUSA	1					
dUK	0.3013**	1				
dCAN	0.2252**	0.1102*	1			
dJPN	0.3242**	0.0393	0.1264*	1		
dGER	0.0591	0.1803**	0.1277	0.0417	1	
dFRA	0.2160**	0.1585**	0.1258*	0.1334*	0.2582**	1
dITA	0.1269*	0.1494**	0.0259	0.0038	0.1349*	0.0842

Notes: d denotes series in first differences.

* 5% significance

** 1% significance

Fig. 2-1. Monthly financial stress indices of the G7 countries.
Note: Higher numbers indicate greater financial stress.

Table 2-3. Unit root tests.

Country	ADF intercept	ADF intercept and trend	PP Intercept	PP intercept and trend
Panel A: FSI series				
USA	-1.189396	-0.961208	-2.839630	-2.721841
UK	-1.682565	-1.649293	-2.988364*	-2.950863
CAN	-3.081217*	-3.206646	-4.123027**	-4.251717**
JPN	-3.913383**	-3.917285*	-8.693973**	-8.744519**
GER	-2.638578	-3.018468	-5.108492**	-5.459332**
FRA	-3.077677*	-3.328930	-4.766727**	-6.870810**
ITA	-4.134248**	-4.342718**	-5.370624**	-6.117858**
Panel B: First differenced series				
dUSA	-17.08416**	-17.20752**	-23.08321**	-23.59421**
dUK	-24.26917**	-24.31920**	-24.74944**	-25.08811**
dCAN	-10.65547**	-10.76457**	-32.34402**	-34.13788**
dJPN	-11.29510**	-8.299087**	-47.42005**	-47.30835**
dGER	-18.02537**	-18.08363**	-28.94807**	-29.75022**
dFRA	-14.62957**	-7.081465**	-29.41034**	-29.39757**
dITA	-16.35039**	-16.35404**	-33.15002**	-34.26451**

Notes: d denotes series in first differences. ADF and PP denote augmented Dickey-Fuller and Phillips-Perron tests, respectively. AIC max lags=16 and Newey-West bandwidth for the ADF and PP tests, respectively.
* 5% significance, ** 1% significance

Prior to the estimation of the VAR, we checked the stationarity of our series. Two different tests for the probability of unit root existence were used: the Augmented Dickey-Fuller (ADF) and Phillips and Perron (PP) tests. The results given in Table 2-3 indicate that most of the FSI series are stationary in levels, and all are stationary in first differences, as they reject the hypothesis of the existence of unit roots.

Empirical results

2.6.1 DCC estimation results

In this section, we parse the DCC to identify the stress co-movements among the G7 countries. In Table 2-4, we present the results of an AR(3)-MGARCH (1,1) model based on Engle 2002) two-stage DCC model.[8] The use of 3 lags is sufficient to avoid any serial correlation and to correct for heteroskedasticity. We use two additional tests, the Tse (2000) and Engle and Sheppard (2001) tests, to examine the appropriateness of using a dynamic correlation model. The rejection of the null hypothesis supports the hypothesis of time-varying correlations rather than constant correlations.

We present the results of the first step in Table 2-4, Panel A. The constant term in the mean equation is not statistically significant for all countries. The AR(1) term in the mean equation (γ_1) statistically significant and negative for all countries. The coefficients of the lagged conditional volatility (β) in the variance equation are significant for the US, Canada and France, with France's beta being more persistent than other countries, whereas the coefficients of the squared error terms (α) are significant for the US, Canada and Italy.

[8] The lag length was determined by the AIC criterion.

Table 2-4. DCC estimation results and diagnostics.

	Mean equations				Variance equations				
	μ	γ_1	γ_2	γ_3	ω	α	β	Q(20)	$Q^2(20)$
PANEL A: Univariate diagnostics. Step 1									
USA	0.0103	-0.3001**	-0.2408**	-0.0770	0.3860	0.1651*	0.6635**	114.031	980.935
	(0.2313)	(-5.130)	(-3.895)	(-1.367)	(1.595)	(2.552)	(4.841)	[0.9351]	[0.9715]
UK	0.0201	-0.3118**	-0.0161	-0.0637	0.9871	0.1879	0.3715	160.577	106.434
	(0.0371)	(-4.730)	(-0.2326)	(-0.9765)	(0.6961)	(0.9590)	(0.4755)	[0.7130]	[0.9550]
CAN	0.0272	-0.4488**	-0.0593	-0.0462	0.2178*	0.2617**	0.6962**	156.845	118.474
	(0.6053)	(-6.826)	(-0.7937)	(-0.7235)	(2.350)	(2.968)	(14.64)	[0.7360]	[0.9212]
JPN	0.0413	-0.4050**	-0.2813**	-0.1424	1.4539	0.3426	0.3189	176.708	172.728
	(0.8086)	(-6.299)	(-4.811)	(-1.962)	(1.5450)	(1.679)	(0.9564)	[0.6091]	[0.6352]
GER	0.0496	-0.3273**	-0.1004	0.0463	2.3167**	0.0788	0.1484	239.237	0.824421
	(0.7621)	(-4.734)	(-1.721)	(0.9294)	(2.751)	(1.868)	(0.7981)	[0.2457]	[1.0000]
FRA	0.0039	-0.3827**	-0.2424**	-0.0768	0.0337	0.0806	0.9048**	161.198	236.779
	(0.1002)	(-5.929)	(-2.989)	(-1.220)	(0.6982)	(0.9568)	(10.28)	[0.7092]	[0.2568]
ITA	-0.0392	-0.2037*	-0.1068	0.0122	1.1782**	0.5280*	0.0955	202.705	153.807
	(-0.6642)	(-2.063)	(-1.684)	(0.1881)	(3.974)	(1.967)	(0.5511)	[0.4411]	[0.7542]

PANEL B: Multivariate diagnostics. Step 2

ρ_{USA-UK}	0.360251**	(4.769)	$\rho_{CANADA-JAPAN}$	0.205382**	(3.202)
$\rho_{USA-CANADA}$	0.311957**	(4.806)	$\rho_{CANADA-GERMANY}$	0.178130	(1.381)
$\rho_{USA-JAPAN}$	0.293620**	(5.278)	$\rho_{CANADA-FRANCE}$	0.174171*	(2.372)
$\rho_{USA-GERMANY}$	0.147761	(0.842)	$\rho_{CANADA-ITALY}$	0.133477	(1.798)
$\rho_{USA-FRANCE}$	0.276323**	(3.381)	$\rho_{JAPAN-GERMANY}$	0.117129	(1.039)
$\rho_{USA-ITALY}$	0.165542*	(2.327)	$\rho_{JAPAN-FRANCE}$	0.145864	(1.825)
$\rho_{UK-CANADA}$	0.241666**	(3.694)	$\rho_{JAPAN-ITALY}$	0.104290	(1.604)
$\rho_{UK-JAPAN}$	0.174202*	(2.292)	$\rho_{GERMANY-FRANCE}$	0.288289**	(3.332)
$\rho_{UK-GERMANY}$	0.201124*	(2.048)	$\rho_{GERMANY-ITALY}$	0.173911*	(2.112)
$\rho_{UK-FRANCE}$	0.202465**	(2.643)	$\rho_{FRANCE-ITALY}$	0.192145**	(2.898)
$\rho_{UK-ITALY}$	0.169757	(1.945)			
α	0.028112*	(2.444)			
β	0.838629**	(9.897)			
Ho(20)	948.571	[0.7370753]			
$Ho^2(20)$	956.663	[0.6811467]			
Li-Mc(20)	951662	[0.7133233]			
Li-$Mc^2(20)$	958269	[0.6678832]			
Log likelihood	-4209.467				

Notes: Q() and Q^2() are the Ljung–Box portmanteau tests statistics for serial correlation in the univariate standardized and squared standardized residuals, respectively. Ho(), Ho^2( ) and Li − McLc( ), Li−Mc^2( ) are the multivariate Ljung–Box test statistics. ( ) and [ ] are t-values and the actual probability values, respectively.
* 5% significance
** 1% significance

More interestingly, the results of the DCC model shown in Panel B indicate that the highest conditional correlations are between the financial stress of the US and those of the UK, Canada and Japan and between Germany and France. By contrast, we do not find evidence of a conditional correlation between US and German financial stress. The conditional correlations are higher in magnitude than the unconditional pairwise stress correlations presented in Table 2-4, Panel B. As in Table 2-2, the conditional correlations in Table 2-4 are significant at the 5% level for most of the country pairs. Both the alpha and beta of the second step are positive and significant, indicating a high persistence in the volatility, implying a mean-reverting variance process and reflecting time-varying correlations, as both summed ($\alpha + \beta$) approach 1 (0.87).

2.6.2 Analysis of the conditional correlation coefficients

In this section, we investigate the change in the conditional correlations over time by regressing them on a constant and a time trend. In Table 2-5, we report the summary statistics of the regressions of the conditional correlations. First, the volatility of the conditional correlations ranges from 14.05% to 57.48%; this result highlights the significant divergence in the volatilities. Second, the coefficients of the time trend are positive and significant for the US-UK, US-Canada, US-France and UK-France pairs at the 1% level. The term $\Delta\rho$ indicates the increase in the correlations over the estimated period. For these country pairs, the increase in the correlations ranges from 38% to 55%, suggesting that financial stress has become more interrelated in these countries over the analyzed period. Therefore, based on these findings, we argue that the interdependence between the US, UK and French economies in terms of financial stress has increased over the analyzed period owing to the greater financial integration and higher degree of financial openness.

Fig. 2-2 shows the evolution of the conditional correlations obtained from the DCC model. The plots clearly show that the correlations do not remain constant over time but significantly fluctuate over time. The conditional correlations range from -0.38 for the US-Germany pair to 0.58 for the US-UK pair, and higher correlations are found for 1988-1989, 1990-1994, 1997-2000, 2001-2004 and 2007-end. The conditional correlations are significantly higher during stressful periods and may be associated with crisis periods: the European exchange rate mechanism (ERM) crisis of 1992-1993, the Asian financial crisis of 1997-1998, the dot-com bubble of 2000-2002 and the most recent global financial crisis in 2007-2008. Moreover, the pairwise conditional correlation coefficients for the US and the UK, Canada, Japan, Germany and France peaked during the last financial crisis. Examination of the conditional covariance plots reveals similar evidence.[9] After having demonstrated the stress co-movements between the G7 countries by a graphical analysis, we proceed to the examination of whether these stress co-movements are related to increased periods of economic uncertainty.

Fig. 2-2. Dynamic conditional correlations.

[9] Available upon request.

Table 2-5. Dynamic conditional correlations.

	Average	St.dev. %	Trend (*1000)	t-statistic	R^2	Δρ%
ρ_{USA-UK}	0.357686**	17.76%	0.3390	3.256308	0.27	37.66%
$\rho_{USA-CANADA}$	0.308550**	19.92%	0.3300	3.128802	0.27	43.58%
$\rho_{USA-JAPAN}$	0.292073	16.87%	-0.0478	-0.505027	0.01	-5.31%
$\rho_{USA-GERMANY}$	0.153417	54.62%	0.1970	1.426728	0.05	54.46%
$\rho_{USA-FRANCE}$	0.276459**	22.13%	0.3450	4.539334	0.30	52.61%
$\rho_{USA-ITALY}$	0.163596	36.21%	0.1380	1.349944	0.05	32.91%
$\rho_{UK-CANADA}$	0.239715	24.98%	0.1370	1.446601	0.05	21.03%
$\rho_{UK-JAPAN}$	0.168995	33.91%	0.1320	1.100905	0.05	29.97%
$\rho_{UK-GERMANY}$	0.204799*	23.24%	0.2170	2.169987	0.19	43.03%
$\rho_{UK-FRANCE}$	0.205019**	29.78%	0.2660	2.772840	0.18	55.33%
$\rho_{UK-ITALY}$	0.168759	43.95%	0.0841	1.175306	0.01	21.69%
$\rho_{CANADA-JAPAN}$	0.206286	29.38%	-0.0774	-0.663898	0.01	-11.79%
$\rho_{CANADA-GERMANY}$	0.180730*	40.95%	0.2770	2.453453	0.13	68.66%
$\rho_{CANADA-FRANCE}$	0.178764	32.93%	0.1240	1.637382	0.04	26.28%
$\rho_{CANADA-ITALY}$	0.128239	40.28%	0.1120	1.202554	0.04	34.23%
$\rho_{JAPAN-GERMANY}$	0.114006	57.48%	0.0773	0.413465	0.01	25.54%
$\rho_{JAPAN-FRANCE}$	0.149700	40.65%	0.1610	1.869905	0.06	43.81%
$\rho_{JAPAN-ITALY}$	0.099554*	55.22%	0.2600	2.498636	0.21	155.03%
$\rho_{GERMANY-FRANCE}$	0.295690	14.05%	-0.0126	-0.178140	0.00	43.81%
$\rho_{GERMANY-ITALY}$	0.176270	26.20%	0.0734	0.854665	0.02	-1.42%
$\rho_{FRANCE-ITALY}$	0.193897	28.26%	0.2100	1.933276	0.14	44.05%

Notes: "Trend" is the slope coefficient of a regression of conditional correlations s_t on a constant and a time trend. Δρ is the difference between the last and first fitted values of a regression of conditional correlations on a constant and a zero-mean time trend. Robust standard errors (HAC standard errors and covariance (Pre-Whitening with lags estimated according to AIC)).
 * 5% significance
** 1% significance

2.6.3 Conditional correlations, volatilities and crises

In this section, we examine the time-series behavior of the correlation coefficients and the effect of external shocks on their movements. Thus, we estimate a panel regression to examine the dynamic feature of the correlation changes associated with crises. We use four dummy variables to provide additional insight into the potential explanatory factors that drive the countries' stress correlations. Our panel regression takes the following form:

$$\Delta\rho_{ij,t} = \mu_{ij,t} + \sum_{\kappa=1}^{4} a_{\kappa}\, DM_{k,t} + \beta_1 Trend + \varepsilon_{ij,t} \qquad (2.15)$$

where $\Delta\rho_{ij,t}$ is the first difference of the estimated DCC between the financial stress of countries i and j, μ_{ij} are country-specific effects, $DM_{1,t}$ is a dummy variable for the ERM crisis (08/1992-10/1993), $DM_{2,t}$ is a dummy variable for the Asian and Russian crises (10/1997-10/1998), $DM_{3,t}$ is a dummy variable for the dot-com bubble (03/2000-10/2002), $DM_{4,t}$ is a dummy variable for the 2008 global financial crisis (09/2008-end) and Trend is a time trend. The value of the dummy variables is equal to one for a crisis period and zero otherwise. In the next stage of our analysis, we examine the links between the conditional volatility and the conditional correlations. Thus, we regress the conditional correlations on the conditional volatility to estimate the effect of the increased volatility of financial stress on the correlations in the following form:

$$\Delta\rho_{ij,t} = \mu_{ij,t} + \sum_{\kappa=1}^{7} \varphi_{\kappa}\, h_{k,t} + \zeta_1 Trend + \varepsilon_{ij,t} \qquad (2.16)$$

where $h_{k,t}$ is the conditional volatility of each country. In Table 2-6, Panel A, we present the results for the dummy variables, which confirm that correlations increased during the last three crisis events examined, as the dummy variables are significantly positive. By contrast, the ERM has a nonsignificant effect on the pairwise correlations; thus, during the ERM crisis, the correlations increase, but the increase is nonsignificant. The result in the last column for the dummy variable indicating all four crisis events (dummy = 1 for crisis periods and 0 otherwise) confirms that the conditional correlations increase during times of financial turmoil.

Table 2-6. Tests of changes in dynamic correlations.

	(I)				(II)
	ERM crisis	Asian and Russian crises	Dot-com bubble crisis	Global financial crisis	Financial crises
Panel A: Dynamic correlations and crisis periods					
$DM_{r,t}$	0.001269	0.006857**	0.003076**	0.009269**	0.003802**
	(1.907806)	(6.518176)	(5.230754)	(3.421915)	(8.938906)
Trend	-2.95E-06**				4.49E-07
	(-3.217997)				(-1.300404)
Panel B: Dynamic correlations and volatilities					
	USA	UK	CAN	JPN	Conditional volatility
$h_{k,t}$	0.003207**	0.003598**	0.001383**	-0.000303	0.058685**
	(6.580490)	(6.677981)	(3.462509)	(-0.997973)	(19.70569)
	GER	FRA	ITA		
$h_{k,t}$	-0.001897	-0.000227	-0.000103		
	(-1.774654)	(-0.415530)	(-0.771142)		
Trend	8.27E-07				2.37E-07
	(1.081044)				(0.343835)

Notes: All specifications include cross-country specific effects. ( ) indicate absolute t-values, estimated with robust standard errors. The first-difference estimator is used.
* 5% significance
** 1% significance

In Table 2-6, Panel B, we present the results for the conditional correlations and the conditional volatility. The positive φ_k in Eq. 2.16 suggests that the conditional correlations increase with the volatility of financial stress. In contrast, the negative φ_k indicates that the correlations decrease during periods of high volatility in these countries. The evidence suggests that the increased volatilities of financial stress in the US, the UK and Canada have a significant and positive effect on the conditional correlations. By contrast, the higher volatility of financial stress in Japan, Germany, France and Italy results in lower correlations over time, but the decrease is nonsignificant. The results in the last column indicate that the conditional correlations increase during periods of uncertainty, as the volatility is significantly positive. The time trend is positive but nonsignificant, indicating a nonsignificant increase in stress co-movements during the examined period. Overall, these findings demonstrate the important stress co-movements occurring during crucial stressful events of the last decade, largely because of the amplified interconnection of the financial markets during times of increased uncertainty.

2.6.4 Spillover indices and spillover tables

Table 2-7 presents the spillover table, which provides an input-output decomposition of the spillover index of the G7 countries following the VAR framework of Diebold and Yilmaz (2012). The outcome of this table is based on the VAR(2) model, and the 10-months-ahead stress forecast errors are based on generalized variance decompositions.[10] The ijth entry is the estimated contribution to the forecast error variance of country i coming from innovations to country j. The off-diagonal column sums (labeled directional to others) and row sums (labeled directional from others) are the directional spillovers, and the net stress spillovers are the differences between each off-diagonal column sum with each off-diagonal row sum. The TSI index is the fraction of the grand off-diagonal column sum (or the row sum, numerator) to the grand column sum including diagonals (or the row sum including diagonals, denominator) expressed as a percentage.

In greater detail, the own-country stress spillovers (i=j) shown on the diagonal elements explain the highest share of forecast error variance. The own-country stress spillovers explaining the forecast error variance range from 71.2% for the US to 84.8% for Italy. In addition to own-country spillovers, the off-diagonal elements (i≠j) provide important information. Table 2-7 shows that innovations to US financial stress are responsible for 7.7% of the error variance in forecasting 10-month-ahead UK stress but for only 1.8% of the error variance in forecasting 10-month-ahead Italian financial stress. In addition, the UK and Canada are responsible for 7.3% and 7.1%, respectively, of the error variance of US financial

[10] The lag order was selected according to the Akaike information criterion (AIC).

stress.

Moreover, the US, Canada and the UK are the major transmitters of stress as shown in the directional-to-others row (28.9%, 26.8% and 20.8%, respectively), whereas Italy has the lowest contribution to other countries, at 6.5%. Furthermore, the US, the UK and Canada are the major gross receivers, as shown in the directional-from-others column. The gross directional stress spillovers to these three countries from other countries are relatively high, with these spillovers explaining approximately 20.7% to 28.8% of the forecast error variance. These results are supported by the net stress spillovers, which measure the net stress spillovers from country i to all other countries j, reported in the last row of Table 2-7. Specifically, positive net stress spillovers are evident for the US, Canada, Japan, Germany and France, with the largest observed for Canada (6.1%).

In general, we find total and directional stress spillovers to be important. By combining all of the various cross-country stress spillovers into a single index, we find that approximately 19.9% of the forecast error variance comes from spillovers (the lower right corner of Table 2-7, TSI).

Table 2-7. Stress spillover index.

	USA	UK	CAN	JPN	GER	FRA	ITA	Directional *from* others
USA	71.2	7.3	7.1	7.1	2.8	3.8	0.6	28.8
UK	7.7	77.2	6.6	1.3	4.5	1.9	0.8	22.8
CAN	6.3	4.3	79.3	4.6	2.0	2.7	0.8	20.7
JPN	7.9	1.7	5.3	83.3	0.6	0.8	0.3	16.7
GER	1.2	4.6	2.1	0.9	82.0	7.0	2.2	18.0
FRA	3.9	1.4	2.5	1.5	5.7	83.3	1.7	16.7
ITA	1.8	1.4	3.2	3.3	3.1	2.5	84.8	15.2
Directional *to* others	28.9	20.8	26.8	18.6	18.8	18.7	6.5	139.0
Directional including own	100.1	97.9	106.1	101.9	100.7	102.0	91.2	TSI
Net spillovers	0.08	-2.06	6.11	1.88	0.75	2.00	-8.76	19.9%

Notes: Spillover indices for seven advanced economies. The VAR lag length of order 2 was selected according to the AIC. The table's indices were calculated from variance decompositions based on 10-step-ahead forecasts.

We extend our analysis by decomposing the FSI into its three subcomponents—namely, banking sector, securities market and foreign exchange rate subindices—and by examining the stress spillovers among the G7 countries. The breakdown of the FSI provides us with the opportunity to examine each market contribution separately. We observe from Table 2-8 the FSI banking subindex that the UK and Germany have the greatest contribution of stress spillovers to other countries, at approximately 19.8% and 19.1%, respectively (Table 2-9). Interestingly, with regard to the securities market subindex, the gross directional stress spillovers from the US and the UK to other countries are high in magnitude, explaining approximately 60% of the forecast error variance (Table 2-10). The following table shows that the US is the major transmitter of foreign exchange stress to other countries, according to the FSI exchange rate subindex (Table 2-11). On average, securities market spillovers explain the highest percentage of the volatility forecast error variance at 48.4%, whereas 12.1% of the volatility forecast error variance stems from banking stress spillovers, and 32.6% comes from exchange spillovers. However, the spillover tables provide only a static image of the average stress spillovers. Next, we include a dynamic representation of the stress spillovers using 10-year rolling samples.

Table 2-8. Stress spillover table: banking market stress subindex.

	USA	UK	CAN	JPN	GER	FRA	ITA	Directional from others
USA	83.8	6.5	3.7	1.3	3.2	0.4	1.1	16.2
UK	4.6	84.4	0.3	0.6	6.5	1.4	2.2	15.6
CAN	3.0	2.6	87.4	0.6	2.9	1.8	1.7	12.6
JPN	1.7	2.3	0.7	89.9	3.1	1.9	0.3	10.1
GER	4.0	6.3	3.1	2.2	81.1	1.2	2.0	18.9
FRA	1.1	0.7	1.3	0.2	1.4	95.1	0.2	4.9
ITA	0.6	1.4	1.9	0.8	1.9	0.2	93.2	6.8
Directional to others	15.1	19.8	10.8	5.7	19.1	7.0	7.6	85.0
Directional including own	98.9	104.1	98.2	95.7	100.2	102.2	100.8	TSI
Net spillovers	-1.1	4.1	-1.8	-4.3	0.2	2.2	0.8	12.1%

Notes: The table's indices were calculated from variance decompositions based on 10-step-ahead forecasts. The VAR lag length of order 2 was selected according to the AIC.

Table 2-9. Stress spillover table: securities market stress subindex.

	USA	UK	CAN	JPN	GER	FRA	ITA	Directional from others
USA	42.0	13.7	14.4	8.5	7.9	8.6	4.9	58.0
UK	14.1	43.8	10.4	5.8	8.4	8.6	8.8	56.2
CAN	13.2	10.9	49.1	4.8	10.0	7.6	4.4	50.9
JPN	10.4	7.6	5.5	64.3	4.1	7.2	0.9	35.7
GER	8.9	8.6	10.9	3.6	47.6	11.8	8.6	52.4
FRA	9.0	9.7	6.5	6.7	10.8	51.3	6.0	48.7
ITA	6.1	9.2	4.4	1.8	9.0	6.9	62.7	37.3
Directional to others	61.8	59.6	52.2	31.2	50.1	50.7	33.5	339.1
Directional including own	103.9	103.4	101.3	95.5	97.8	102.0	96.2	TSI
Net spillovers	3.9	3.4	1.3	-4.5	-2.2	2.0	-3.8	48.4%

Notes: The table's indices were calculated from variance decompositions based on 10-step-ahead forecasts. The VAR lag length of order 2 was selected according to the AIC.

Table 2-10. Stress spillover table: exchange market stress subindex.

	USA	UK	CAN	JPN	GER	FRA	ITA	Directional from others
USA	52.0	1.4	17.1	13.6	5.2	9.5	1.3	48.0
UK	1.9	66.0	14.9	2.3	1.6	4.1	9.2	34.0
CAN	20.3	0.5	63.8	10.3	1.8	2.8	0.5	36.2
JPN	22.2	0.7	12.3	62.4	0.2	1.0	1.2	37.6
GER	0.6	2.2	2.9	1.0	81.0	10.1	2.2	19.0
FRA	12.9	3.7	4.7	1.7	7.1	66.4	3.5	33.6
ITA	1.2	10.4	1.0	1.2	2.1	3.7	80.4	19.6
Directional to others	59.1	18.9	53.0	30.1	17.9	31.3	17.8	228.0
Directional including own	111.1	84.8	116.8	92.5	98.9	97.7	98.2	TSI
Net spillovers	11.1	-15.2	16.8	-7.5	-1.1	-2.3	-1.8	32.6%

Notes: The table's indices were calculated from variance decompositions based on 10-step-ahead forecasts. The VAR lag length of order 3 was selected according to the AIC.

2.6.5 Spillover plots of financial stress

2.6.5.1 Total spillovers

We estimate our model using a rolling-window analysis to obtain time-varying estimates of spillover indices. This approach allows us to evaluate the evolution of the stress spillovers of G7 countries over time. Hence, we estimate stress spillovers using 120-month rolling samples.[11]

[11] Our findings are robust to changes in the model specification. We found similar results with alternate-month horizons (6 and 8) and different lag selections.

Fig. 2-3 provides a dynamic image of the stress spillover variation via the corresponding time series of spillover indices. Several stress episodes are evident in the total financial stress plots, as indicated by the presence of bursts, including the Asian currency crisis and the Russian crisis, the stressful period of the tech-stock bubble and the most recent financial turmoil followed by the collapse of Lehman Brothers in mid-2008. The plot displays a moderate increase in stress spillovers until the financial turmoil of 2001, which reflects a gentle increase in the linkages among the G7. As evident from the plot, during the 1991-2001 period, the total stress spillover plots fluctuated between 20% and 30%. Subsequently, a higher level of interdependence is shown, reaching its highest point during the recent global financial crisis. During this period, the total stress spillover fluctuated at an increasingly higher level, ranging from approximately 35% to 45%, which reached a peak after the collapse of Lehman Brothers and the subsequent outbreak of the global financial crisis with economic turmoil.

Fig. 2-3. Total stress spillovers.

Note: Plot estimated using 120-month rolling windows.

2.6.5.2 Directional spillovers

In Fig 2-4, we present the directional stress spillovers from each country to all other countries (corresponding to the "directional to others" row in Table 2-7), and in Fig 2-5, we illustrate the directional stress spillovers from all other countries to each individual country (corresponding to the "directional from others" column in Table 2-7), which are the off-diagonal column and row sums of the estimated 120-month rolling windows.

In Fig 2-4 and Fig 2-5, the directional stress spillover plots vary a great deal over time. These two figures indicate the bidirectional and asymmetric nature of stress spillovers between the G7 countries. In particular, directional stress spillovers from each of the seven countries to others are higher than the directional stress spillovers from other countries to each individual country, except for Italy. Most of the plots indicate a significant increase in stress fluctuations during the last decade. Furthermore, we observe that before 2001, the directional stress spillovers to others fluctuated between 10% and 35%, but subsequently, the directional stress spillovers increased significantly and reached nearly 75%, as evident in the US plot.

Following the analysis of the directional stress spillovers from and to each country, we proceed to the examination of the net directional stress spillovers. Each point in Fig 2-6 corresponds to S_i^g(H) (Eq. (2.12) and is the difference between the sum of the "directional from" column and the sum of the "directional to" row. According to Fig 2-6 which plots the time-varying net directional spillovers, we notice that the US is largely a net transmitter of financial stress, whereas Japan and Italy are typically net stress receivers, as they had little effect on the financial stress of other countries, particularly during the last decade. As shown in the plot, the US was a net stress receiver until 2001, but subsequently, the reverse trend appears, as the US became a net stress transmitter.

2.6.5.3 Net pairwise spillovers

In this section, we calculate the net pairwise stress spillovers between two countries (Eq. 2.13) and present these plots in Fig 2-7. Positive values of this index indicate that country i is a net transmitter of stress spillovers to market j. These plots provide a clearer representation of the bilateral spillovers between the G7 countries. Fig 2-7 supports our previous findings

Fig. 2-4. Directional stress spillovers from each country to all other countries.

Note: Plots estimated using 120-month rolling windows.

Fig. 2-5. Directional stress spillovers *from* all other countries *to* each country.

Note: Plots estimated using 120-month rolling windows.

Fig. 2-6. Net stress spillovers.
Note: Plots estimated using 120-month rolling windows.

Fig. 2-7. Net pairwise stress spillovers.
Note: Plots estimated using 120-month rolling windows.

with regard to the directional stress spillovers presented in the previous figures. The US was a net transmitter of stress during the most recent financial crisis. The effect of the recent financial crisis has been depicted as positive stress spillovers from the US to the other countries, with the most prominent spillover to France.

2.6.6 Volatility stress spillovers

As a robustness check, we examine the spillovers of the volatility of financial stress. The estimated conditional volatility parameters for the seven financial stress series obtained from the DCC model in the previous section are used as the x_{it} variables in Eq. 2.6, in which i is each country's conditional volatility. Several interesting results emerge from Table 2-8. As in Table 2-7, we observe that own-country volatilities explain the highest share of the forecast error variance. Similarly, the highest volatility spillovers are between the US, the UK and Canada. The US is the dominant country in terms of volatility transmission, according to the "directional to others" row, whereas the UK is the major receiver of volatility. In addition, the US has the largest positive net volatility stress spillover (50.7% - 33.7% = 16.9%). In relation to the TSI, the total volatility stress spillover index explains that a slightly higher percentage (20.9%) of the volatility forecast error variance in all countries comes from volatility spillovers.

In Fig 2-8, we present the dynamic behavior of the total volatility spillover index obtained from estimating volatility spillovers, again using 120-month rolling samples. This volatility plot is somewhat similar to the previous total stress spillover plot, as it displays an increasing trend. A burst is evident during the recent global financial crisis of 2008. The directional volatility spillovers from each country to the other countries and the directional volatility spillovers from all countries to each individual countries significantly fluctuate over time. According to these plots, the bidirectional nature of volatility spillovers is further supported.[12] Moreover, the directional volatility spillovers from each country to the other countries are higher than the directional volatility spillovers from all countries to each individual country. Finally, the net volatility spillovers from/to each of the seven countries suggest that the US is consistently a net giver of volatility from 2001 onward. Hence, we conclude that there are asymmetric stress and volatility stress spillover effects among the G7 countries, and we particularly note the major role of the US in the transmission of financial stress.

Table 2-11. Volatility spillover indices.

	USA	UK	CAN	JPN	GER	FRA	ITA	Directional *from* others
USA	66.3	14.5	7.1	6.8	5.0	0.3	0.0	33.7
UK	14.7	58.7	20.1	4.6	0.3	0.3	1.4	41.3
CAN	18.1	4.7	74.9	1.6	0.5	0.2	0.0	25.1
JPN	14.4	10.0	2.8	71.9	0.4	0.2	0.2	28.1
GER	2.5	0.8	0.7	0.6	94.9	0.3	0.2	5.1
FRA	0.6	0.1	4.0	3.2	0.3	91.1	0.7	8.9
ITA	0.4	3.0	0.3	0.6	0.1	0.0	95.6	4.4
Directional *to* others	50.7	33.0	34.8	17.5	6.7	1.3	2.6	146.6
Directional including own	116.9	91.7	109.8	89.4	101.6	92.4	98.2	TSI
Net spillovers	16.9	-8.3	9.8	-10.6	1.6	-7.6	-1.8	20.9%

Notes: Financial volatility spillover indices for seven advanced economies. The VAR lag length of order 2 was selected according to the AIC. The table's indices were calculated from variance decompositions based on 10-step-ahead forecasts.

Fig. 2-8. Total volatility spillover plot of FSI.

Note: Plot estimated using 120-month rolling windows.

[12] The plots are available upon request.

Summary and conclusions

In our empirical analysis, we use the DCC model developed by (Engle, 2002) to examine the dynamic correlations of financial stress and use the generalized VAR model developed by Diebold and Yilmaz (2012) to examine the financial stress spillover effects among the G7 countries. As an indicator of financial instability, we utilize a FSI. Our monthly data span from 1981 to 2009 and cover approximately three decades. For the purpose of this study, we present DCC plots; spillover indices; and total, directional and pairwise stress spillover plots.

We find greater stress co-movement among the G7 countries during financial crisis periods and periods of economic uncertainty, indicating the vulnerability of the G7 countries to external shocks. Return co-movements are significantly and positively associated with financial crises for the Asian and Russian crises, the dot-com bubble and the last global financial crisis. In addition, the results of the analysis of the conditional correlations and conditional volatility reveal that the conditional correlations are positively associated with increased uncertainty, particularly in the US, UK and Canadian economies. The statistically significant effect of volatility on the conditional correlations during episodes of extreme financial stress may be attributed to the increased integration of the international financial markets. Overall, the transmission of stress during financial crises may result from investors' herding behavior in the financial markets. In addition, increased stress co-movements during financial crises may be attributed to trade and financial linkages, which are intensified by second-round effects, i.e., spillovers from receiver countries back to transmitter countries (Balakrishnan et al., 2009).

The spillover analysis shows that a significant level of financial stress is explained by own-country stress spillovers, whereas cross-country stress spillovers explain a much more modest magnitude of the forecast error variance. In addition, our study shows that own-country stress spillovers explain the forecast error variance at a level ranging from approximately 71.2% for the US to 84.8% for Italy. The results indicate that the US, Canada and the UK are the primary transmitters of stress spillovers to other countries. Overall, our results indicate that, on average, 19.9% of the forecast error variance in all examined countries comes from stress spillovers.

Furthermore, the decomposition of the overall FSI into its three subcomponents provides useful insight into the importance of each component in transmitting stress. We find that the securities market subindex explains a greater proportion of the stress spillovers than the banking sector and foreign exchange rate subindices. The examination of volatility stress spillovers yields similar results, supporting our previous findings: approximately 20.9% of the volatility forecast error variance comes from stress spillovers, and the US is the dominant net transmitter of volatility.

Further examination of the stress linkages involved the dynamic examination of the directional stress spillover plots. The directional stress spillovers plots from one country to others and vice versa varies significantly, indicating their bidirectional and asymmetrical nature. Moreover, the plots reveal that the US has consistently been a major transmitter of stress to other countries, particularly after 2001, indicating the significant role of the US as a financial stress transmitter. The net directional and pairwise stress spillover plots verify our previous findings and the dominant role of the US in transmitting stress to other countries.

Our findings are important because they highlight the significance of stress spillovers among the G7 countries. We provide insight into the nature of cross-country stress transmission, highlighting the importance of stress spillovers from one country to another during financial disturbances. Thus, we propose the use of FSIs as a monitoring tool for measuring the fluctuation of stress spillovers from one country to another using our approach. Although the scope of this study is to investigate stress linkages among the G7 countries, the results also reveal new opportunities for research. For example, future research can examine stress spillovers from advanced to emerging economies utilizing the framework developed by Diebold and Yilmaz (2009, 2012). Furthermore, because this study does not include more recent stress events because of data limitations, the European sovereign debt crisis and the potential stress spillovers from peripheral to core Eurozone countries will be an important issue for future research.

Financial Stress Spillovers Across the Banking, Securities and Foreign Exchange Markets

Introduction

This study aims to provide a detailed assessment of financial stability, a concept that has gained in importance over the last two decades in general and after the most recent financial crisis in particular. This study seeks to examine the heightened imbalances in the financial sector that originated with the collapse of Lehman Brothers and that rapidly evolved into global turmoil thereafter. In reaction to these events, many central banks attempted to prevent deeper downturns by stabilizing their respective economies and bolstering their respective banking sectors.

Due to the novelty of the notion of financial stability in the literature, we find several definitions for the concept. Some scholars define financial stability in terms of the desired stability of financial system (Crockett, 1996; Schinasi, 2004; Allen and Wood, 2006b), whereas other scholars define financial stability in terms of instability and describe situations in which financial instability impairs the real economy (Mishkin, 1999; Davis, 2003). For instance, Mishkin (1999) indicates that a state of financial instability is characterized by information problems that undermine the financial system's ability to allocate funds to productive investment opportunities. In this study, we adopt a definition that is closer to the second strand of the literature and understand financial stability as the absence of or low stress in the financial system, which leads to decreased uncertainty.

We first study the underlying dynamic relationships of financial stress in the banking, securities, and foreign exchange markets for the G7 over a period that lasts almost 30 years.

foreign exchange market crisis (Melvin and Taylor, 2009).

The results of our analysis suggest that policy measures should safeguard and strengthen financial stability. Based on an analysis of the stress spillover indices, our findings stress the securities markets as the major net transmitter of stress not only to the domestic banking and exchange markets but also across international financial markets. Our findings are bolstered by the analysis of the plots of the directional stress spillovers. The net directional stress spillovers highlight the significance of the US securities market as a net stress transmitter. Finally and most importantly, almost 43% of the forecast error variance in all the markets examined in the US economy derives from spillovers.

The analysis of generalized impulse responses (GIRs) to aggregate financial stress shocks indicates that financial stress has a significant and negative effect on both output growth and price levels for a short period. An examination of the GIRs to each of the financial stress subcomponent shocks yields similar results. In addition, we utilize a sign restriction approach to verify our findings. Finally, we check the robustness of our results by employing different approaches to calculate the impulse-response functions and alternative indicators of financial stress and economic activity.

The remainder of the study proceeds as follows. In Section 3.2, we briefly review the literature regarding financial stability and financial stress indices. Sections 3.3 and 3.4 describe our methods and data, respectively. Section 3.5 examines the stress tables and spillover plots based on the generalized VAR framework. Section 3.6 presents the impulse responses to financial instability and inflation shocks. Section 3.7 includes our sensitivity analysis, which incorporates alternate measures of financial stress, economic activity, and monetary stability. Finally, we summarize and conclude in Section 3.8.

Literature review

3.2.1 The linkages of financial stress

The recent financial crisis revealed the importance of international financial spillovers. Financial stress co-movements and the risk of contagion increase during periods of extreme turbulence because the financial markets have gradually become more interconnected. The literature indicates that trade and financial linkages are the two main channels of international financial stress transmission (Balakrishnan et al., 2009; Forbes, 2002; Forbes and Chinn, 2004). We examine the linkages of financial stress among the international markets and offer an interpretation of how financial stress spreads, in addition to identifying the spillover channels both within and across countries.

Previous studies have demonstrated that credit plays a key role in the transmission of financial distress to the broader economy. Several studies indicate that the credit channel is the main channel of transmission of financial distress (Jacobson et al., 2005; Gilchrist et al., 2009; Carlson et al., 2011), This transmission channel may be further influenced by the financial accelerator mechanism (Kiyotaki and Moore, 1997; Bernanke et al., 1999). Bernanke et al. (1999) argue that monetary policy, in particular, impacts the real economy through the financial accelerator mechanism. Alternatively, Goodhart et al. (2006) analyze financial fragility by means of a micro-founded general equilibrium model featuring endogenous default and heterogeneous agents that is distinct from, but complementary to, the role of the financial accelerator. Recent theoretical developments move in the direction of incorporating the financial sector into a macroeconomic framework, thus relating financial frictions to economic activity (Cúrdia and Woodford, 2009; Gertler and Karadi, 2011; Gertler and Kiyotaki, 2010). Several scholars focus on the relationship between asset prices and monetary policy and seek to determine whether monetary policy should react to asset price movements (Bernanke and Gertler, 2000, 2001; Mishkin, 2001; Bordo and Jeanne, 2002; Dupor, 2005).

The link between financial development and growth is well established in the literature. For instance, King and Levine (1993) find that financial development is positively correlated with capital accumulation, per capita GDP and future growth. Rajan and Zingales (1998) investigate how financial development facilitates growth and posit that there is a linkage from financial development to growth via the interdependence of those industries that are most reliant on external financing. In contrast to the literature that examines the effects on growth over the long term, there is limited research on the link between financial stability and growth and how short-run effects are established (Cevik et al., 2013; Hakkio and Keeton, 2009; Mallick and Sousa, 2013). Bloom (2009) argues that uncertainty shocks lead to drops in output because higher uncertainty causes firms to temporarily halt investment plans. However, the causal relationship between financial stability and growth might run the other direction. Scholars have found evidence of a reverse relationship in which growth negatively affects financial instability (Beck et al., 2006; Demirgüç-Kunt and Detragiache, 1998; Klomp and De Haan, 2009).

Another strand of the literature investigates linkages between financial stability and monetary stability. Schwartz (1995) finds that achieving price stability over the medium term is sufficient to prevent financial crises. Borio and Lowe (2002) argue that there is the possibility of financial instability even in conditions of low inflation and growth when there is a combination of supply shocks and asset price booms with overoptimistic assessments of risk. De Graeve et al. (2008) find evidence of a tradeoff between monetary stability and financial stability and suggest that an unexpected tightening of monetary policy increases the mean probability of distress. Thus, a key challenge for central banks is to maintain both monetary and financial stability simultaneously.

Another strand of the literature investigates bank lending stability and the transmission of financial shocks by examining the cross-sectional transmission of stress via the banking channel (Van Rijckeghem and Weder, 2001, 2003; Popov and Udell, 2010; Cetorelli and Goldberg, 2010; De Haas and Van Horen, 2012; Haas and Horen, 2013).

3.2.2 Different measures of financial stress

An examination of the literature in search of an appropriate financial stability measure reveals different approaches. One approach uses a single measure, such as the probability of default (PD).[13] Alves (2005) accounts for the likelihood that defaults and macroeconomic variables display common trends. Carlson et al. (2011) develop an index of financial sector health using a distance-to-default (DD) measure that is based on a Merton-style option-pricing model and find that the soundness of the financial sector has an impact on macroeconomic variables. Hoggarth et al. (2005) consider the dynamics between banks' write-off to loan ratios and key macroeconomic variables in estimating the costs of banking crises and find that economic growth has somewhat of an effect on banks' stress ratios but no effect in the opposite direction. Zicchino et al. (2006) find that an increase in the default probability of the banking sector induces a decrease in GDP growth. In addition, they find that GDP growth responds positively to a positive shock to the banking sector equity index.

Gilchrist et al. (2009) argue that credit market shocks contribute significantly to US

13 PD is another way to express the distance to default and is calculated using modern contingent claims analysis (CCA) and the Merton model.

economic fluctuations during the 1990-2008 period. In particular, they find that unexpected increases in bond spreads cause large and persistent contractions in economic activity. Chen et al. (2010) examine how bank and corporate distress affect the domestic economy and how these types of distress are transmitted abroad. They find that growth in emerging economies is more sensitive to corporate distress than to banking distress, whereas the opposite outcome holds for developed economies. A different approach for measuring the contribution of institutional risk to the financial system has been developed by Adrian and Brunnermeier (2011). Focusing on bank spillovers, these authors develop the mean Corrected Value at Risk (CoVaR) method to measure systemic risk. A similar approach to measure banking risk has been developed by Acharya et al. (2010).

However, Čihák (2007) contends that existing measures of financial stability based on PD are inadequate because they ignore the fact that "size matters". In addition, Schinasi (2006) argues that the analysis of financial stability must include all sources of risks and vulnerabilities, which requires systematic monitoring of the individual parts of the financial system and the relationships among them. Additionally, a suitable measure of financial stability should include a wide range of quantitative variables that allows cross-border contagion risks and financial system vulnerabilities to be captured (Gadanecz and Jayaram, 2009). To achieve the objectives of this study, we use an FSI that incorporates the appropriate attributes to proxy financial stability. Compiling such an index has been recommended by several researchers (Hanschel and Monnin, 2005; Illing and Liu, 2006; Van den End, 2006; Hakkio and Keeton, 2009).

3.2.3 The use of financial stress indices in the literature

There are various stress indices found in the literature that combine different quantities of

innovations stemming from these markets influence economic activity and price levels.

Empirical method

We employ the method developed by Diebold and Yilmaz (2009, 2012) to explore the stress linkages between three key markets – the banking, securities, and foreign exchange markets – across the G7 countries. Next, we utilize a trivariate VAR model to examine the relationship among financial stability, monetary stability, and growth, and we present the associated GIRs.

3.3.1 Financial stress spillovers

Stress spillovers from one market to another are measured using the VAR approach developed by Diebold and Yilmaz (2012). The p^{th} order N-variable VAR is defined as:

$$x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \varepsilon_t,\ \varepsilon_t \sim iid\ (0, \Sigma), \quad (3.1)$$

where $x_t = (x_{1,t}, \dots, x_{N,t})'$, Φ is a N x N parameter matrix, ε_t is a vector of independently and identically distributed errors, and Σ is the covariance matrix. In our model, x is a vector of the three financial stress subindices (i.e., of the banking, securities, and exchange markets) for the G7 countries (US, UK, Canada, Japan, Germany, France and Italy). In the case of a covariance stationary VAR, the moving average representation is given by $x_t = \sum_{i=1}^{\infty} A_i \varepsilon_{t-i}$, where the N × N coefficient matrices, A_i, are estimated recursively by $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \cdots + \Phi_p A_{i-p}$, with A_0 being an N × N identity matrix and where $A_i = 0$ for $i < 0$. According to the generalized VAR framework of Koop et al. (1996) and Pesaran and Shin (1998), the H-step-ahead forecast error variance decomposition is given by:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)}, \tag{3.2}$$

where Σ is the variance matrix for the error vector ε, σ_{jj} is the standard deviation of the error term for the j^{th} equation, and e_i is an N x 1 vector with one as the i^{th} element and zeros elsewhere. We normalize each entry of the decomposition matrix by the row sum to obtain a unit sum of each row of the variance decomposition as follows:

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} \tag{3.3}$$

where the decomposition (including own shocks) sums to 1 in the construction, $\sum_{j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = 1$, and the total decomposition sums to N, $\sum_{i.j}^{N} \tilde{\theta}_{ij}^{g}(H) = N$. Using the normalized elements of the decomposition matrix of Eq. 3.3, we construct the total stress spillover index, which captures the level of cross-market spillovers by measuring the contribution of shock spillovers across all N variables to the total variance in forecast errors. We compute the total stress spillover index based on H-step-ahead forecasts with the following:

$$S^{g}(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \times 100 \tag{3.4}$$

Using the normalized elements of the generalized variance decomposition matrix, the directional stress spillovers received by market i from all other markets j are given by the following:

$$S_{i\leftarrow}^{g}(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100 = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \times 100 \tag{3.5}$$

The directional stress spillovers transmitted by market i to all other markets j are measured similarly:

$$S^{g}_{\to i}(H) = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\theta}^{g}_{j\,i}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}^{g}_{ji}(H)} \times 100 = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\theta}^{g}_{ji}(H)}{N} \times 100. \tag{3.6}$$

We obtain the net stress spillover from market i to all other markets j by offsetting the last two measures as follows:

$$S^{g}_{i}(H) = S^{g}_{\to i}(H) - S^{g}_{i\leftarrow}(H). \tag{3.7}$$

3.3.2 Impulse responses

In the second part of this study, we investigate the relationship between financial stability, monetary stability, and output growth, and we utilize the VAR framework to estimate impulse-response functions. Our benchmark VAR consists of three quarterly endogenous variables measuring aspects of the US economy that are grouped in the vector $x_t = (y_t, \pi_t, s_t)'$, where y_t represents output growth, π_t is inflation growth, and s_t represents financial stress. To demonstrate the robustness of our findings, we use the KCFSI; real private domestic investment, personal consumption expenditures and the private investment index; and the Federal Reserve interest rate as alternative measures of financial stability, economic activity and monetary stability, respectively. The impulse response functions are calculated following the generalized framework of Koop et al. (1996) and Pesaran and Shin (1998), where the impulse responses are invariant to the VAR ordering. Next, we check the robustness of our results by implementing the pure sign restriction and the penalty function approaches developed in Uhlig (2005).

3.3.3 The pure sign restriction approach and the penalty function approach

$$r_a(k) = \sum_{i=1}^{m} q_i r_i(k) \tag{3.10}$$

The entries of the vector impulse response r_a(k) at various horizons k must satisfy our imposed restrictions. The estimation of the impulse responses involves a Bayesian Monte Carlo procedure, which requires draws from the posterior of the Normal-Wishart for (B, Σ), and draws from the unit sphere, assuming a flat prior. At the end of the procedure, we have compatible impulse responses with the sign restrictions to calculate the median impulse response and the error bands.

To check the robustness of the results of the pure sign restriction approach, we estimate impulse responses, minimizing the penalty function (Uhlig, 2005). This function is defined by $f(x) = \begin{cases} x \; if \; x \leq 0 \\ 100 \times \text{x} \; if \; x \geq 0 \end{cases}$, for a horizon K≥0, which strongly penalizes in linear proportion those responses violating the restrictions and somewhat rewards those that are consistent with the restrictions.

Selected variables and data description

For purposes of our analysis, we use the FSI recently developed by the IMF that provides a consistent measure for a wide range of countries (Balakrishnan et al., 2009). The variables are standardized using a variance-equal weighting method, which generates an index in which each variable has equal importance. This FSI offers some important advantages over other measures of financial stress. The equal weighting method of calculating the seven financial variables in a single aggregate index allows us to proceed to the examination of the three subcomponents of the spillovers. Furthermore, because this index has been compiled for several countries, it facilitates a cross-country examination of the results, which contrasts

In the second part of the study, we analyze the effects of financial stress on macroeconomic fundaments such as output and inflation for the US economy. To calculate the impulse responses, we use quarterly data that are transformed into logarithmic first differences of real gross domestic product (GDP) and the Consumer Price Index (CPI). Our data are from the Federal Reserve Economic Data (FRED) database maintained by the Federal Reserve Bank of St. Louis and span from 1981Q1 to 2009Q1.

Stress spillover results

In this section, we present the results of the stress spillover analyses involving the banking, securities, and foreign exchange markets and utilizing the generalized VAR framework of Diebold and Yilmaz (2012). We use the first difference of the time series to avoid any problems of non-stationarity.

3.5.1 Total stress spillover index

The lag specification of the VAR(2) model is selected by minimizing the Akaike Information Criterion. Our aim is to examine both the US cross-market spillovers and cross-border externalities. Table 3-2 presents the F-test of the VAR model for the three markets in the US economy and shows that both lags of the US banking, securities and exchange markets have an important influence on their own markets, according to the joint significance F-tests.

Table 3-2. VAR model of financial stress spillovers: F-tests.

Dependent variable	US Bank	US Securities	US Exchange
F-Statistic			
US BANK	7.834***	0.773	0.404
US SEC	0.206	12.963***	0.246
US EXC	0.476	0.802	3.046**
UK BANK	3.893**	1.013	4.913***
UK SEC	1.521	0.357	2.822*
UK EXC	0.289	0.038	0.529
CAN BANK	3.359**	3.625**	0.349
CAN SEC	2.433*	12.796***	1.052
CAN EXC	0.258	3.352**	1.839
JPN BANK	0.332	1.675	4.550**
JPN SEC	0.960	0.942	0.559
JPN EXC	1.930	0.467	2.631*
GER BANK	0.181	1.108	0.295
GER SEC	0.227	1.364	1.904
GER EXC	0.896	1.056	9.125***
FRA BANK	0.294	0.151	0.087
FRA SEC	1.827	0.185	5.336***
FRA EXC	5.873***	2.176	1.403
ITA BANK	3.351**	0.076	0.671
ITA SEC	0.185	2.065	2.374*
ITA EXC	2.131	0.208	2.065

Notes: F-statistics in the columns estimated from a VAR(2) model.
*** Significance at the 1% level.
** Significance at the 5% level.
* Significance at the 10% level.

Table 3.3 presents the spillover stress indices of the three markets. The ij^{th} entry is the estimated contribution to the forecast error variance of market i coming from innovations to market j. The data in this table are based on the above VAR(2) model and generalized variance decompositions of the 10-month-ahead stress forecast errors. This spillover table provides an "input-output" decomposition of the spillover index and shows that approximately 42.8% of the forecast error variance comes from stress spillovers, which demonstrates the importance of spillovers.

The market stress spillovers – which are shown as the diagonal elements that depict the fraction of the forecast error variance of market i that is caused by its own shock – explain the highest share of forecast error variance and fluctuate between 36.6% for the US securities market to 81.3% for the Japanese banking market. The off-diagonal elements provide additional important information about cross-market spillovers. The results show that cross-sectional spillovers are lower in magnitude than cross-country spillovers. For instance, on the one hand, innovations in the US banking stress index are responsible for 0.5% of the error variance in forecasting the 10-month-ahead US securities stress index and for 0.4% of the error in the variance of the US foreign exchange stress index. On the other hand, the US banking market transmits the highest stress to the UK, Canada and the German banking markets. In addition, the US securities market transmits financial stress mainly to the Canadian, UK, and Japanese securities markets. Finally, the US exchange market transmits stress to the Japanese, Canadian, and French exchange markets.

Furthermore, gross stress spillovers from all other markets to the US banking, exchange and securities stress indices are 35.2%, 63.4% and 55.1%, respectively. The gross stress spillovers from the three US markets to all others account for 19.5%, 88.9%, and 55.6% of the forecast error variance. The row "directional to others" shows that the US securities market is the major transmitter of stress to all the other markets. The last row, which shows net spillovers, demonstrates that the UK and US securities sub-indices have the highest net ratios (27.1% and 25.5%, respectively). Overall, the securities markets are the major net stress transmitters to all the other markets for all countries, as shown in the last row.

Table 3-3. Financial stress spillover indices.

	US Bank	US Sec	US Exc	UK Bank	UK Sec	UK Exc	CAN Bank	CAN Sec	CAN Exc	JPN Bank	JPN Sec	JPN Exc	GER Bank	GER Sec	GER Exc	FRA Bank	FRA Sec	FRA Exc	ITA Bank	ITA Sec	ITA Exc	Directional from Others
US Bank	64.8	2.4	0.4	4.8	2.5	0.2	2.8	4.0	0.7	0.8	2.2	0.6	2.0	2.1	1.4	0.6	2.8	2.1	1.0	0.8	1.1	35.2
US Sec	0.5	36.6	0.2	0.4	12.6	0.2	1.4	14.2	0.8	0.3	8.1	0.2	0.9	6.7	2.1	1.0	8.3	0.6	0.6	4.2	0.2	63.4
US Exc	0.4	1.6	44.9	1.0	1.8	1.2	0.5	2.4	12.8	2.6	0.4	11.7	0.2	1.0	4.6	0.1	2.5	7.9	1.0	0.4	1.0	55.1
UK Bank	3.1	2.0	0.5	66.3	6.6	0.1	0.3	1.5	0.4	0.3	2.0	1.1	4.3	3.3	0.8	1.0	1.7	0.3	1.6	2.0	0.9	33.7
UK Sec	0.2	13.6	0.2	1.9	39.3	0.5	1.0	9.7	0.5	0.3	5.4	0.2	0.8	7.5	0.5	0.9	7.2	0.2	1.6	8.3	0.4	60.7
UK Exc	1.1	3.6	1.1	1.7	2.1	52.8	5.2	4.3	7.4	0.7	1.9	1.1	1.5	1.8	1.8	0.6	0.9	2.0	0.4	2.7	5.2	47.2
CAN Bank	2.7	3.3	0.3	1.6	3.4	1.0	67.2	4.1	0.4	0.3	2.4	0.1	2.2	1.9	0.4	1.9	0.9	0.6	1.5	3.9	0.1	32.8
CAN Sec	0.3	14.1	0.5	0.7	10.1	0.1	0.9	43.1	1.3	0.6	4.5	0.3	0.5	9.2	0.3	1.6	6.6	0.8	0.4	3.7	0.2	56.9
CAN Exc	1.3	3.2	13.9	1.3	3.2	1.2	2.8	3.5	49.9	0.3	0.8	7.2	2.6	1.2	1.1	0.5	0.6	2.3	1.7	0.2	1.3	50.1
JPN Bank	1.5	0.3	1.1	2.1	0.7	0.4	0.6	0.6	0.2	81.3	0.4	1.3	1.9	1.7	0.4	1.9	0.6	0.9	0.6	0.9	0.6	18.7
JPN Sec	1.1	10.0	0.9	0.4	6.8	1.0	2.0	4.8	0.4	0.1	54.9	0.8	0.7	4.0	1.2	0.4	6.9	0.2	1.4	1.2	0.7	45.1
JPN Exc	0.6	2.1	18.7	1.1	2.7	0.9	0.4	1.8	8.7	1.0	1.7	48.4	1.9	1.0	0.3	0.5	2.5	2.3	0.8	1.4	1.1	51.6
GER Bank	2.5	1.7	2.3	4.1	1.7	0.7	2.1	3.3	2.5	1.3	2.4	1.1	65.9	3.1	0.3	0.9	0.5	0.3	1.5	1.1	0.8	34.1
GER Sec	0.2	7.7	1.2	0.9	7.9	0.2	0.2	10.7	1.2	0.8	3.8	0.7	0.6	43.2	0.8	0.9	10.0	0.3	0.7	7.6	0.3	56.8
GER Exc	0.1	3.5	0.7	1.4	2.1	2.4	0.9	0.5	1.9	0.1	1.7	0.8	0.2	1.2	69.0	0.4	0.8	9.7	0.2	0.7	1.8	31.0
FRA Bank	1.0	1.8	1.3	0.5	0.9	0.2	1.3	2.4	0.8	0.3	0.7	1.0	1.0	2.1	0.6	80.7	0.6	1.3	0.3	0.4	0.9	19.3
FRA Sec	0.9	8.8	0.4	1.0	7.9	0.7	0.1	5.5	0.4	0.6	6.5	1.1	0.6	8.8	0.6	0.3	47.1	1.0	1.9	5.6	0.1	52.9
FRA Exc	0.5	1.8	8.2	0.7	2.2	1.8	0.3	0.5	3.8	2.4	1.4	1.5	0.1	0.9	6.3	4.8	5.3	51.2	2.8	0.3	3.2	48.8
ITA Bank	0.4	1.4	1.7	1.0	3.1	0.3	1.8	0.9	1.6	0.7	3.3	1.1	1.2	1.1	0.3	0.2	0.6	0.1	74.5	3.8	0.9	25.5
ITA Sec	0.7	5.4	0.5	1.2	8.5	0.5	2.3	3.7	0.4	0.4	2.0	0.5	0.4	7.9	0.4	0.8	6.3	0.1	2.7	54.6	0.5	45.4
ITA Exc	0.4	0.4	1.6	2.1	1.2	5.2	2.3	0.5	1.9	1.7	3.2	2.1	1.5	1.4	1.7	0.4	1.6	2.5	0.7	1.2	66.3	33.7
Directional to others	19.5	88.9	55.6	30.1	87.8	18.6	29.3	78.8	48.2	15.4	54.9	34.5	25.2	67.7	26.0	19.7	67.1	35.5	23.3	50.6	21.4	898.2
Directional including own	84.3	125.5	100.4	96.4	127.1	71.4	96.5	121.9	98.1	96.7	109.8	82.9	91.1	110.9	95.0	100.4	114.2	86.6	97.8	105.2	87.7	2100.0
Net spillovers	-15.7	25.5	0.4	-3.6	27.1	-28.6	-3.5	21.9	-1.9	-3.3	9.8	-17.1	-8.9	10.9	-5.0	0.4	14.2	-13.4	-2.2	5.2	-12.3	42.8%

Notes: Spillover indices are calculated using variance decompositions based on 10-step-ahead forecasts. The VAR(2) model is estimated according to the AIC criterion.

3.5.2 Stress spillover plots

We estimate our VAR model using a rolling windows analysis to obtain time-varying estimates of stress spillover indices that depict the evolution of stress spillovers over time. In Fig. 3-2, Panel A, we present the total stress spillover plot of the US economy, using 120-month rolling samples. The financial turmoil following the collapse of Lehman Brothers in mid-2008 is the most evident event in the picture. Other less evident events in this plot include the stress periods encompassing the 1992 ERM crisis, the Mexican peso crisis of 1994-1995, the 1997 Asian and the 1998 Russian financial crises, the bursting of the tech-stock bubble and following the 9/11 terrorist attacks in 2000-2001, the WorldCom and Enron scandals and collapses in 2002, and the beginning of the second Gulf war in 2003. The spillover plot peaks at the 78.5 percent level in 2008, i.e., during the most recent global financial crisis.

Fig. 3-2. Total stress spillover plot of the US economy.
Note: The plots of the moving total spillover index are estimated using 120-month rolling windows.

Fig. 3.3 presents the estimated 120-month rolling windows directional spillovers from each market to all other markets in the US economy (which correspond to the values in the "directional to others" row in Table 3.3), and Fig. 3.4 presents the estimated 120-month rolling windows directional spillovers from all other markets to each market in the US (which correspond to the values in the "directional from others" column in Table 3.3). Fig. 3.3 shows that the stress spillovers vary greatly over time. The directional stress spillovers from each

Fig. 3-3. Directional stress spillovers from market i of the US economy to all other markets.
Note: Plots of moving directional spillovers are estimated using 120-month rolling windows.

measure of stress in the interbank lending market. Nonetheless, both indices identify major stressful events in US economic history, although the measurement of the significance and intensity of stressful episodes occasionally differs between the two indices. However, the KCFSI cannot be decomposed into its constituent elements due to its construction method. Because the series are available for a shorter period, we estimate our model from 1993Q1 to 2009Q2. As with the FSI, the KCFSI shows increased variability during turbulent periods (Fig 3-10).

Fig. 3-10. KCFSI and aggregate FSI.

The GIRs to shocks to our alternative measure of stress follow a pattern similar to our previous findings and thus verify our results (Fig. 3-11). Specifically, the GIRs of GDP and CPI to a KCFSI shock are negative and significant in the short run, as they are with respect to an FSI shock, although they are somewhat greater in magnitude. The impulse responses using the pure sign and the penalty function approaches follow a pattern similar to that of the aggregate FSI.[17] Our results remain robust with respect to previous findings using the FSI constructed by the IMF, which thus suggests that positive financial stress shocks affect not

[17] Available upon request.

only economic activity but also inflation.

Fig. 3-11. Generalized impulse responses using KCFSI.
Notes: Based on Monte Carlo 2000 repetitions. Median responses with error bands are based upon the 16% and 84% percentiles of each. VAR is estimated with three lags, as indicated by the AIC criterion.

To further ensure the robustness of our results, we utilize less aggregated measures of output, such as real private domestic investment, personal consumption expenditures, and the annual industrial production index. We include private domestic investment to examine whether the effect of uncertainty caused by increased distress is more pronounced on real investment than on broader measures of real output, as Bernanke (1983) posits. Finally, we utilize the US federal funds (FF) rate as an alternative measure of monetary stability in place of the CPI in the trivariate VAR model.

The GIRs exhibit similar patterns of responses when the effects are significant; thus, our findings are robust to these specifications. The responses of the alternate measures of

Fig. 3-12. Impulse response functions to a positive interest rate shock using a pure sign restriction and a penalty function approach (GDP<0, FF > 0, k=2).
Notes: Median responses with error bands are based upon the 16th and 84th percentiles of each. VAR is estimated with two lags, as indicated by the AIC criterion.

Summary and conclusions

In our empirical analysis, we use the VAR model and methodology proposed by Diebold and Yilmaz (2012) to examine financial stress spillovers among the banking, securities and foreign exchange markets. We proxy financial stability with the FSI developed by Balakrishnan et al. (2009). This index is capable of reflecting increased stress volatility during turbulent periods, which allows us to investigate the effects of financial instability on the US economy by simulating conditions of financial stress shocks. Furthermore, its compilation method facilitates an examination of its constitutional subcomponents. Our analysis employs spillover indices and includes total and directional spillover plots. Our main objective was to find evidence of domestic and international stress spillovers across the banking, securities and exchange markets. Our findings, which are based on an analysis of stress spillover indices, point to the securities markets as the major net transmitter of financial stress not only to the domestic banking and exchange markets but also across international financial markets. We also find that domestic cross-market spillovers are lower in magnitude than international cross-country spillovers. The US securities market is the major stress transmitter not only to the US banking and exchange markets but also to all other markets. These findings show that the international linkages among the financial markets – and particularly when involving the securities markets – are more important to the transmission of financial shock than domestic cross-market linkages. This outcome may be attributed to the increased international integration and liberalization of the financial markets during recent decades. Thus, while there is evidence that financial deregulation is related to economic growth and financial stability in the long run, it may also lead to booms and busts in the short-run (Kaminsky and Schmukler, 2008). Overall, our results imply that total spillover stress accounts for 42.8% of the forecast error variance across all markets.

Next, we shed light on the relationship between financial stability, monetary stability and output growth. For that purpose, we utilized a VAR model to examine the influence of financial stress on macroeconomic fundamentals. We used generalized impulse responses, a pure sign restriction approach and a penalty function approach to examine the response of macroeconomic fundamentals to financial stress and inflation shocks. Our results indicate that financial instability has a negative and significant short-run effect on real output and monetary stability. Furthermore, the results of the penalty function approach imply that financial instability is positively related to monetary contraction and inflation shocks.

Our study has two important limitations that must be discussed. First, the method used

Appendix A: VAR model.

Table 3-4. VAR model of financial stress spillovers.

Dependent variable	US Bank		US Securities		US Exchange	
Variables						
US BANK {1}	-0.170***	(-2.886)	-0.097	(-1.208)	-0.041	(-0.880)
US BANK {2}	-0.166***	(-2.932)	-0.030	(-0.388)	0.005	(0.115)
US SEC {1}	0.016	(0.274)	-0.388***	(-4.769)	0.028	(0.580)
US SEC {2}	-0.026	(-0.455)	-0.254***	(-3.275)	0.026	(0.567)
US EXC {1}	-0.095	(-0.974)	0.119	(0.895)	-0.129*	(-1.666)
US EXC {2}	-0.013	(-0.132)	-0.106	(-0.812)	-0.151*	(-1.964)
UK BANK {1}	-0.067	(-1.343)	-0.026	(-0.376)	0.103**	(2.600)
UK BANK {2}	0.105**	(1.994)	0.088	(1.221)	0.100**	(2.385)
UK SEC {1}	0.035	(0.682)	-0.041	(-0.583)	0.097**	(2.351)
UK SEC {2}	0.090*	(1.744)	0.023	(0.331)	0.051	(1.2410
UK EXC {1}	0.032	(0.483)	0.021	(0.228)	0.022	(0.415)
UK EXC {2}	-0.030	(-0.525)	0.014	(0.182)	0.045	(0.984)
CAN BANK {1}	0.091**	(2.271)	-0.146**	(-2.665)	-0.018	(-0.570)
CAN BANK {2}	0.082*	(1.946)	-0.073	(-1.269)	0.013	(0.3810
CAN SEC {1}	0.099**	(2.200)	0.276***	(4.493)	0.031	(0.850)
CAN SEC {2}	0.047	(0.975)	0.019	(0.286)	0.056	(1.444)
CAN EXC {1}	-0.067	(-0.422)	-0.352*	(-1.622)	-0.243*	(-1.914)
CAN EXC {2}	-0.100	(-0.605)	0.430	(1.918)	0.002	(0.012)
JPN BANK {1}	0.038	(0.812)	0.088	(1.376)	-0.113***	(-3.013)
JPN BANK {2}	0.016	(0.334)	0.101	(1.601)	-0.043	(-1.165)
JPN SEC {1}	0.012	(0.294)	-0.074	(-1.345)	-0.008	(-0.243)
JPN SEC {2}	-0.051	(-1.248)	-0.032	(-0.580)	-0.034	(-1.057)
JPN EXC {1}	0.086*	(1.965)	-0.056	(-0.946)	0.058	(1.666)
JPN EXC {2}	0.039	(0.982)	-0.016	(-0.298)	0.070**	(2.197)
GER BANK {1}	0.001	(0.031)	-0.001	(-0.013)	0.012	(0.310)
GER BANK {2}	-0.027	(-0.585)	-0.094	(-1.465)	-0.024	(-0.633)
GER SEC {1}	0.030	(0.674)	0.082	(1.340)	0.008	(0.229)
GER SEC {2}	0.014	(0.308)	0.091	(1.481)	-0.058	(-1.604)
GER EXC {1}	0.040	(0.983)	0.076	(1.370)	0.015	(0.470)
GER EXC {2}	0.049	(1.254)	0.010	(0.188)	0.125***	(4.000)
FRA BANK {1}	0.011	(0.261)	0.009	(0.151)	-0.014	(-0.417)
FRA BANK {2}	-0.028	(-0.632)	0.033	(0.549)	-0.003	(-0.083)
FRA SEC {1}	0.073*	(1.659)	-0.036	(-0.601)	0.065*	(1.853)
FRA SEC {2}	0.071	(1.616)	-0.022	(-0.367)	0.114***	(3.245)
FRA EXC {1}	-0.017	(-0.174)	-0.078	(-0.579)	-0.040	(-0.507)
FRA EXC {2}	0.308**	(3.425)	-0.245**	(-1.996)	0.115	(1.604)
ITA BANK {1}	0.099**	(2.354)	-0.021	(-0.374)	0.036	(1.085)
ITA BANK {2}	0.060	(1.385)	-0.009	(-0.156)	-0.009	(-0.256)
ITA SEC {1}	-0.023	(-0.550)	-0.117**	(-2.030)	-0.066*	(-1.949)
ITA SEC {2}	0.003	(0.076)	-0.031	(-0.545)	-0.051	(-1.528)
ITA EXC {1}	-0.092*	(-1.844)	-0.034	(-0.493)	0.080**	(1.992)
ITA EXC {2}	-0.002	(-0.031)	0.010	(0.141)	0.023	(0.565)
Constant	0.012	(0.303)	0.033	(0.589)	0.000	(-0.012)

Notes: VAR(2) model, St. Errors in parentheses, model estimated with 334 monthly observations. Lag determined by AIC.
*** Significance at the 1% level.
** Significance at the 5% level.
* Significance at the 10% level.

Fig. 3-14. GIRs using the Securities markets FSI sub-index.
Notes: Based on Monte Carlo 2000 repetitions. Median responses with error bands are based upon the 2.5 and 97.5 percentiles of each. The VAR estimated with two lags, as indicated by the AIC criterion.

Fig. 3-15. GIRs using the Exchange markets sub-index.

Notes: Based on Monte Carlo 2000 repetitions. Median responses with error bands are based upon the 2.5% and 97.5% percentiles of each. The VAR estimated with one lag, as indicated by the AIC criterion.

Spreading Crisis: Evidence of Financial Stress Spillovers in the Asian Financial Markets

Abstract

Employing a generalized vector autoregression (VAR) framework, this study examines financial stress spillovers in five Asian countries, namely, China, South Korea, Malaysia, Thailand, and the Philippines, during turmoil periods. Our data span the period from the end of 1997 to early 2009, encompassing the impact of the 2007-2009 global financial crisis on several Asian economies. We use a financial stress index specifically designed for emerging economies as a proxy for financial stress, and our findings reveal significant cross-country stress spillover effects, where China is the dominant stress transmitter among the five countries during stressful periods. Further, the generalized impulse responses (GIRs) on stress innovations show a positive short-run effect up to one standard deviation before it fades away. Overall, our findings shed light on the dynamics of financial stress spillovers in the Asian financial markets.

Keywords: Stress spillovers; GIRs; Granger causality; Financial stress index.

JEL classification: F3; G1.

Spreading Crisis: Evidence of Financial Stress Spillovers in the Asian Financial Markets

Introduction

The Asian crisis has been extensively examined from the perspective of financial market co-movements and contagion effects. However, little attention has been devoted to contagion effects in the most recent financial crisis. We study the underlying dynamic relationship between financial stress episodes during the period from 1997 to 2009 in five Asian countries, namely, China, South Korea, Malaysia, Thailand, and the Philippines. While the literature on the transmission of financial stress spillovers between countries remains nascent, financial stress episodes are frequently connected with economic downturns, as they destabilize the financial system and its capability to operate smoothly. Moreover, by employing a financial stress index (FSI), recent research has focused on the transmission of financial stress and examined the likelihood that such stressful episodes engender economic downturns (Cardarelli et al., 2009; Balakrishnan et al., 2009). Compared with the use of single market indices, the use of an aggregate FSI contributes to a better understanding of financial stability. High levels of financial stress signal the inability of the financial system to effectively perform its tasks, and extreme levels of financial instability are related to financial crises and recessions. Cardarelli et al. (2009, 2011) use an FSI to examine why certain financial stress episodes lead to economic downturns. In a similar line of research, Balakrishnan et al. (2009) use an FSI to study how financial stress, defined as periods of impaired financial intermediation, is transmitted from advanced to emerging economies. Davig and Hakkio (2010) explore the linkages between financial stress and economic activity. Specifically, they use an FSI and employ impulse response functions to find evidence of a link between the index and economic activity. Baxa et al. (2013) use Cardarelli et al. (2011) FSI to examine the relationship between financial instability and monetary policy. Melvin and Taylor (2009) use an FSI to examine the effect of the most recent global financial crisis on foreign exchange markets. In Chapter 2, we use an FSI to examine the transmission of financial stress in the G7 advanced economies. In Chapter 3, we examine the relationships among financial stability, monetary stability and growth and provide insights into the spillover effects in major financial markets, such as the banking, securities and foreign exchange markets.

The Asian currency crisis of 1997 spread quickly from Thailand to other Asian countries, affecting primarily Indonesia, South Korea, Thailand, Malaysia and the Philippines and, to a lesser extent, China. Much of the literature has focused on investigating contagion and the interdependence of the Asian stock markets in the aftermath of 1997 Asian currency turmoil. In this regard, Forbes and Rigobon (2002) provide a clear distinction between interdependence and contagion effects: a contagion effect is characterized by bursts and by a significant increase in cross-market co-movements during turmoil periods, whereas interdependence is characterized by a continued high level of correlation and, thus, stronger linkages among countries. The recent global financial crisis had an adverse effect on most Asian markets, such as those in China, where the Shanghai market experienced a sharp drop.

Previous scholars have examined financial market co-movements or contagion effects by using generalized autoregressive conditional heteroscedasticity (GARCH) (Chiang et al., 2007; Yang, 2005) or vector autoregression (VAR) models (Cheung et al., 2010; Dekker et al., 2001; Goh et al., 2005; Khalid and Kawai, 2003).[18] To investigate the long-run

[18] Other studies include Guo et al. (2011), Morales and Andreosso-O'Callaghan (2014), and Syllignakis and Kouretas (2011).

relationships among equity markets, co-integration techniques are used (Fernández-Serrano and Sosvilla-Rivero, 2001; Jang and Sul, 2002; Roca et al., 1998). Several studies find evidence of financial co-movements (Baig and Goldfajn, 1999; Corsetti et al., 2005; Sachs et al., 1996), whereas others find evidence supporting a contagion effect in the aftermath of crisis events (Basu, 2002; Bordo and Murshid, 2001; Chiang et al., 2007; Forbes and Rigobon, 2002; Froot et al., 2001). Using a VARMA model that allows for spillovers, Allen et al. (2013) examine spillovers from the Chinese equity market to those of its major trading partners.

Our research differs from the existing literature because it uses an FSI to examine stress spillover effects. Specifically, in this study, we examine stress spillover indices by utilizing the framework of Diebold and Yilmaz (2012). The newly developed version of the spillover index involves generalized variance decompositions, and it has recently been applied to investigate the interconnectedness of volatility in financial markets (Yilmaz, 2010; Antonakakis and Vergos, 2013). For instance, Yilmaz (2010) examines the interdependence among equity markets in East Asian countries and finds that the volatility spillover index experiences significant jumps during major financial crises. Furthermore, we examine the cross-country Granger causation of financial stress and the dynamics of the VAR model by using generalized impulse response functions. The present study contributes to the rapidly growing literature on financial stability by utilizing an aggregate FSI and by examining financial stress spillovers across Asian countries during the 2008 global financial crisis.

Our results reveal important stress spillover effects among the five Asian countries examined, where China is the dominant stress transmitter among the five countries. Analysis of the spillover plots shows that the transmission of financial stress is amplified during stressful periods, and the generalized impulse responses (GIRs) on stress innovations show a positive short-run effect up to one standard deviation before it fades away. Overall, our findings highlight the interconnectedness of the Asian markets, revealing the increased integration among these markets.

The rest of this study is organized as follows: Section 4.2 describes the methods used to identify the stress spillovers among the five examined Asian countries. Section 4.3 briefly discusses the data utilized in this study. The results of the empirical analyses are then presented in Section 4.4. We conclude in Section 4.5.

Empirical method

This study is based on the generalized VAR framework developed by Diebold and Yilmaz (2012) to explore stress spillovers between the five examined Asian countries. We employ an N-variable, p[th] order VAR, $y_t = \sum_{i=1}^{p} \Phi_i y_{t-i} + \varepsilon_t$, where $y_t=(y_1,\ldots,y_{N,t})'$ is an N × 1 vector, with y denoting a vector of the financial stress indices for the five countries; Φ is an N × N matrix of the parameters; ε_t is a vector of independently and identically distributed errors; and Σ is the covariance matrix. The moving average representation is given by $y_t = \sum_{i=1}^{\infty} A_i \varepsilon_{t-i}$, where the N × N coefficient matrices A_i are estimated by the recursion $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \cdots + \Phi_p A_{i-p}$, with A_0 denoting an N × N identity matrix and with A_i equaling 0 for i < 0. In the case of the generalized VAR framework of Koop et al. (1996) and Pesaran and Shin (1998) (KPPS), the H-step-ahead forecast error variance decomposition is given by

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)}, \tag{4.1}$$

where σ_{jj} is the standard deviation of the error term for the j[th] equation, Σ is the variance matrix for the error vector ε, and e_i is a N x 1 vector, with the i[th] element taking a value of one and the elements taking zero otherwise. The sum of each row of the variance decomposition matrix does not sum to unity because the shocks to each variable are not orthogonalized; therefore, we normalize each element of the decomposition matrix by dividing by the row sum:

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)}, \tag{4.2}$$

with $\sum_{j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = 1$ and $\sum_{i.j}^{N} \tilde{\theta}_{ij}^{g}(H) = N$ by construction. The KPPS variance decomposition matrix is used to calculate the total spillover index (TSI) and the directional stress indices. This index captures the level of cross-country spillovers by measuring the contribution of shock spillovers across all countries to the total forecast-error variance. The TSI based on H-step-ahead forecasts is

$$S^{g}(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \times 100. \tag{4.3}$$

The directional spillovers transmitted by variable i to all other variables j are given by:

$$S_{i\cdot}^{g}(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100 = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \times 100. \tag{4.4}$$

Similarly, the directional spillovers received by variable i from all other variables j are given by:

$$S_{\cdot i}^{g}(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ji}^{g}(H)} \times 100 = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ji}^{g}(H)}{N} \times 100. \tag{4.5}$$

We obtain the net stress spillover from variable i to all other variables j subtracting Eq. 4.5 from Eq. 4.4. The net directional stress spillover is then given by

$$S_i^g(H) = S_{\cdot i}^g(H) - S_{i\cdot}^g(H). \tag{4.6}$$

Moreover, the net pairwise stress spillovers are given by

$$\begin{aligned} S_{ij}^g(H) &= \left(\frac{\tilde{\theta}_{ji}^g(H)}{\sum_{i,k=1}^N \tilde{\theta}_{ik}^g(H)} - \frac{\tilde{\theta}_{ij}^g(H)}{\sum_{j,k=1}^N \tilde{\theta}_{jk}^g(H)}\right) \times 100 \\ &= \left(\frac{\tilde{\theta}_{ji}^g(H) - \tilde{\theta}_{ij}^g(H))}{N}\right) \times 100. \end{aligned} \tag{4.7}$$

Data and descriptive statistics

We examine financial stress spillovers measured by the FSI between five emerging Asian countries (China, South Korea, Malaysia, the Philippines and Thailand). For the purpose of our analysis, we use the IMF-FSI measure of Balakrishnan et al. (2009). The FSI is constructed by the equal variance-weighted average of seven variables, which are grouped into three subindices: the banking sector, the securities market and the foreign exchange market. Details regarding these subindices are as follows.

i. The banking sector subindex comprise a single variables the banking beta (the 12-month rolling beta).

ii. The securities market subindex comprises three variables: stock market returns, measured as the inverted month over month change in the stock index; stock market volatility, estimated by a GARCH(1,1) model; and the sovereign debt spreads, measured as the difference between the bond and the 10-year US treasury yield.

iii. The foreign exchange market subindex is constructed by calculating the EMPI pressure index:

$$EMPI_{i,t} = \frac{(\Delta e_{i,t} - \mu_{i,\Delta e)}}{\sigma_{i,\Delta e}} - \frac{(\Delta RES_{i,t} - \mu_{i,\Delta \text{RES})}}{\sigma_{i,\Delta RES}}, \tag{4.8}$$

where $\Delta e_{i,t}$ and $\Delta RES_{i,t}$ denote the percentage changes in the exchange rate over the month and total reserves minus gold, respectively. The EMPI pressure index captures exchange rate deprecations and declines in international reserves. The FSI is given by:

$$FSI_{i,t} = beta + stock\ market\ returns + \tag{4.9}$$
$$stock\ market\ volatility + sovereign\ debt\ spreads + EMPI_{i,t}.$$

The summary statistics of the input data, spanning the period from the end of 1997 (12/1997) to early 2009 (3/2009) and covering the Asian currency crisis and the most recent global financial crisis, are presented in Table 4-1. On average, Malaysia and South Korea have the greatest financial stress levels. The highest level of financial stress is observed for South Korea at 15.6 points, followed by Thailand at 12.6 points. Moreover, Malaysia and Thailand have the highest volatility of financial stress. Serial correlation and ARCH effects are evident for most series, according to the Ljung-Box Q and ARCH-LM tests. Simply correlation analysis reveals the co-movements of financial stress among the Asian countries, which is highest between South Korea and Thailand at 0.76. The Augmented Dickey-Fuller (ADF) unit root test indicates the stationary of the series.

Fig. 4-1 reflects the temporal evolution of financial stress. From the plot, we can distinguish two periods of increased financial stress, one in 1998, during the Asian financial crisis, and a second in 2008, during the global financial crisis. The FSI thus captures the major episodes of financial distress during the last two decades, with higher values indicating more stressful periods. The fall of Lehman Brothers and the subsequent global financial turbulence is highly reflected by the FSI, as shown by the spike in the plot in mid-2008.

Table 4-1. Descriptive statistics.

Country	CHN	KOR	MYS	PHL	THA
Summary statistics					
Mean	0.072819	0.200616	0.288027	0.102745	-0.012415
Maximum	7.793332	15.55711	11.65528	8.100572	12.55762
Minimum	-3.728248	-4.144983	-4.901752	-5.367270	-4.507173
St. Dev.	2.565114	2.925385	3.079501	2.589584	3.080291
Q (20)	459.374**	284.043**	296.530**	302.906**	551.264**
Q^2 (20)	82.6655**	16.7788	164.565**	58.0731**	78.2913**
ARCH (1-5)	7.1749**	2.7363*	41.660**	7.6735**	12.166**
Skewness	0.619329**	1.720655**	1.356787**	0.312367	1.536826**
Kurtosis (excess)	-0.29118	5.5592**	2.4606**	-0.010025	2.9036**
Jarque-Bera	9.174688*	242.2374**	76.03573**	2.212233	101.3095**
ADF	2.503454*	-2.68811**	-4.002075**	-4.407083**	-4.254276**
Correlations					
CHN	1	0.5781**	0.6330**	0.5241**	0.6220**
KOR		1	0.6434**	0.6762**	0.7636**
MYS			1	0.6613**	0.7295**
PHL				1	0.7074**

Note: The sample size is 136; 1997:12-2009:03, ADF is calculated without a trend or intercept.
** Significance at the 1% level.
* Significance at the 5% level.

Fig. 4-1. FSI.

Empirical results

In Table 4-2, we present the results of the spillover analysis.[19] The ij^{th} entry is the estimated

19 The results are derived from a VAR (2) model and 10-month-ahead stress forecast errors based on generalized variance decompositions. The lag order was selected according to the Akaike Information Criterion (AIC).

contribution to the forecast error variance of country i stemming from innovations to country j. The own-country stress spillovers, indicated by the diagonal elements, range from a minimum of 37.3% of the forecast error variance for the Philippines to a maximum of 69.2% for China. On one hand, the off-diagonal elements in Table 4-2 show that stress innovations stemming from China are responsible for 20.9%, 18%, and 16.5% of the error variance in 10-month-ahead forecasts of financial stress for Malaysia, South Korea, and the Philippines, respectively. On the other hand, Thailand and South Korea are responsible for 9.7% and 8.6% of the error variance in forecasts of Chinese financial stress, respectively. The directional to others row indicates that China is the primary transmitter of stress to all other countries, while the directional from others column shows that the Philippines and South Korea are the primary receivers of financial stress. In the last row of Table 4-2, we present the net stress spillovers, where China has the largest magnitude of net spillovers. Finally, the total stress spillover index indicates that approximately 53% of forecast error variance stems from spillovers.

Next, because of the construction method for the FSI, we can decompose the FSI into its three less-aggregate subcomponents, i.e., banking, securities and foreign exchange subindices. The results presented in Table 4-3 show that compared to the banking and foreign exchange markets, the securities market is associated with the highest-magnitude stress spillovers. On average, approximately 9.3% of the volatility in the forecast error variance stems from banking stress spillovers, 61.4% stems from securities stress spillovers, and 33.4% stems from foreign exchange stress spillovers. Moreover, regarding the banking market, South Korea has the greatest net contribution of stress spillovers, at 21.1%. Moreover, for the securities and foreign exchange markets, China has the highest net stress spillovers.

Table 4-2. Total stress index.

Country	CHN	KOR	MYS	PHL	THA	Directional from others
CHN	69.2	8.6	6.3	6.1	9.7	31
KOR	18	39.4	13	12.1	17.5	61
MYS	20.9	10.1	45.1	10.3	13.5	55
PHL	16.5	14	13.2	37.3	19	63
THA	14	16.8	12.1	13.4	43.8	56
Directional to others	69	50	45	42	60	265
Directional including own	139	89	90	79	104	
Net spillovers	38.0	-11.0	-10.0	-21.0	4.0	53%

Notes: A VAR(2) model estimated according to the AIC and the underlying variance decompositions is based on generalized variance decompositions. The (i,j)th value is the estimated contribution to the error variance in the 10-month-ahead forecasts of financial stress for country i stemming from the financial stress innovations of country j.

Table 4-3. Total stress subindices.

	CHN	KOR	MYS	PHL	THA	From others
Panel A: Banking FSI						
CHN	94.2	0.9	2.4	0.2	2.2	5.8
KOR	0.7	96.0	2.0	0.0	1.2	4.0
MYS	0.3	3.7	94.4	0.5	1.1	5.6
PHL	0.4	6.3	5.3	88.0	0.1	12.0
THA	2.2	14.1	0.6	2.0	81.0	19.0
Contribution to others	3.6	25.0	10.3	2.8	4.7	46.4
Contribution including own	97.8	121.1	104.7	90.8	85.7	
Net spillover	-2.2	21.1	4.7	-9.2	-14.3	9.3%
Panel B: Securities FSI						
CHN	56.9	11.4	9.7	6.2	15.7	43.1
KOR	23.1	34.4	8.6	11.4	22.4	65.6
MYS	20.5	13.2	31.3	8.3	26.8	68.7
PHL	18.2	17.6	10.1	30.7	23.3	69.3
THA	16.4	17.5	13.8	12.6	39.7	60.3
Contribution to others	78.2	59.7	42.2	38.6	88.3	307.0
Contribution including own	135.1	94.2	73.5	69.3	127.9	
Net spillover	35.1	-5.8	-26.5	-30.7	27.9	61.4%
Panel C: Exchange FSI						
CHN	96.4	0.7	0.1	2.6	0.1	3.6
KOR	20.5	58.4	3.5	6.9	10.7	41.6
MYS	11.3	7.1	64.3	6.3	11.1	35.7
PHL	3.9	18.7	10.3	56.2	10.8	43.8
THA	2.6	21.5	11.0	7.0	57.9	42.1
Contribution to others	38.2	48.0	25.0	22.8	32.7	166.7
Contribution including own	134.6	106.4	89.3	79.0	90.7	
Net spillover	34.6	6.4	-10.7	-21.0	-9.3	33.3%

Notes: The VAR model estimated with 1, 3, and 2 lags for banking, securities, and exchange markets, respectively, according to AIC and the underlying variance decompositions is based on generalized variance decompositions. The (i,j)th value is the estimated contribution to the error variance in the 10-month-ahead forecasts of financial stress for country i stemming from the financial stress innovations of country j.

Fig. 4-2. Plot of total financial stress spillovers.
Note: 60-month rolling windows.

Next, we calculate spillover indices over rolling 60-month subsample windows. Fig. 4-2 shows the dynamic behavior of the total stress spillover index. From 2003 to 2007, the total stress spillover plot follows a downward trend, reaching its lowest point immediately before the global financial crisis, at 25%. After that point, we observe a sharp increase that peaks at 61%, concurring with the global financial meltdown.

In Fig. 4-3, we present the estimated directional spillovers with 60-month rolling windows from each country to all the other countries (Eq. 4.4), and in Fig. 4-4, we present the estimated directional spillovers with 60-month rolling windows from all the other countries to each country (Eq. 4.5). These two figures indicate the bidirectional nature of stress spillovers among the five Asian countries. For instance, according to Fig. 4-3, the spillover from China to all four Asian countries exceeds 60% during the 2008 global financial crisis. Among the five countries, the gross stress spillovers stemming from South Korea are generally greater in magnitude. Furthermore, Fig. 4-4 shows that the directional stress spillovers from all the countries to South Korea, the Philippines and Thailand peak during the global financial turmoil of 2008. In general, we can infer that the directional stress spillovers from each country to all other countries are higher in magnitude than the directional stress spillovers from all other countries to each of the five Asian countries.

Fig. 4-3. Directional financial stress spillovers to all other countries from each country.
Note: 60-month rolling windows.

Fig. 4-4. Directional financial stress spillovers from all countries to each country.
Note: 60-month rolling windows.

Fig. 4-5. Net directional financial stress spillovers.
Note: 60-month rolling windows.

Fig. 4-6. Net pairwise financial stress spillovers.
Note: 60-month rolling windows.

Fig. 4-5, which plots the time-varying net directional spillovers, shows that China is a net transmitter of stress shocks during the most recent global financial meltdown of 2008. Moreover, South Korea to a greater degree and Thailand to a lesser degree are major net transmitters of stress from 2003 to 2005. The plots further indicate that the Philippines is a net receiver of stress, as it has little impact on stress in the other countries.

In Fig. 4-6, we plot the net pairwise spillovers between pairs of countries to check the robustness of our findings. Depicting the bilateral spillovers among the Asian countries, the plots of the dynamic representations support our previous findings presented in Figures 5 and 6. Specifically, China is a net transmitter of stress from 2007 to the end of analysis period. The effect of the most recent financial crisis is depicted as positive stress spillovers from China to the other countries, with the most prominent spillover flowing from China to the Philippines, at 70%. Furthermore, the most prominent directional stress spillovers during the most recent global crisis flow from Malaysia to Thailand (60%) and the Philippines (50%) and from South Korea to Thailand (45%).

Next, we examine the cross-country Granger causation of financial stress. In Table 4-4, we report the Chi-square Wald statistics for the null hypothesis that the financial stress of country i does not Granger-cause the financial stress of country j. The final row reports the joint probability of all lagged variables in the equation, in which we test the null hypothesis that all lags of all variables can be excluded from each equation in the VAR system. We find that China Granger-causes Malaysia and the Philippines and that South Korea Granger-causes Malaysia, suggesting lagged financial stress for Malaysia and the Philippines.

Evidence of a lead-lag interaction of financial stress between the examined countries is scant. China and South Korea drive the movement of financial stress during the sampling period, and Granger causalities from China and South Korea to Malaysia and the Philippines are characterized as unidirectional. Therefore, we argue that the causality runs one way only—from China and South Korea to Malaysia and from China to the Philippines. The joint significance Chi-square statistics in the last row indicate that China, South Korea and Thailand are not Granger-caused by any lags but that Malaysia and the Philippines are

Granger-caused by all the lagged variables at a 0.05 percent significance level. The above findings confirm that both China and South Korea have a predominant influence on the Asian financial system.

Table 4-4. Granger causality tests among the Asian countries.

	CHN	KOR	MYS	PHL	THA
CHN		3.980729	14.6497***	6.252206**	1.977750
KOR	5.20626*		11.85784***	5.935523*	2.470697
MYS	0.834881	4.028696		1.341764	2.511208
PHL	2.463433	0.049191	0.750193		3.62672
THA	1.904416	0.370652	2.591622	0.620896	
All	12.71634	15.12955*	35.47107***	27.7181***	12.52253

Notes: The tests are based on the VAR(2) model. Entries in the table are chi-square statistics for the null hypothesis that financial stress of the row country does not Granger-cause returns of the column country.
*** Significance at the 1% level.
** Significance at the 5% level.
* Significance at the 10% level.

In the final part of the analysis, we examine the stress spillovers among the five countries by calculating the generalized impulse response functions to financial stress innovations. In Fig. 4-7, we illustrate the impulse responses estimated by the generalized KPPS framework, which are thus invariant to the ordering of the variables in the VAR. In general, the GIRs among the Asian countries behave in a homogeneous manner. Although stress innovations stemming from China have important effects on all the other countries, China is less affected by stress shocks from the other Asian countries.

In Fig. 4-7, we observe that the immediate response of a shock in each country is positive and of higher magnitude in all the countries, regarding their own shocks as represented along the diagonal. Shocks stemming from China are more persistent than shocks coming from the other countries, as they fade out at a lower pace. A one-standard-deviation shock from China leads to a longer-lasting response of approximately 1.0 point in the other countries than a one-standard-deviation shock from South Korea, Malaysia, the Philippines or Thailand. In contrast, shocks from the other countries lead to a shorter-run response to China of up to 0.7 and die out relatively quickly. In addition, comparing China and South

Korea, shocks stemming from South Korea lead to higher-magnitude responses in Thailand than shocks stemming from China, but shocks from South Korea, while similar in magnitude, generally have shorter-run effects and fade away at a higher pace than shocks from China.

As an additional robustness analysis, we examine the effects of common stress shocks. The intuition for this analysis is that the five countries may be simultaneously hit by a stress shock. We estimate the impact of a 1-unit common shock emanating from all five countries. Followed by Malaysia (0.68 points), the Philippines has the highest-impact response among the five countries in period two (0.90 points), whereas China has the lowest-impact response (0.33 points).[20] All the responses fade away after the initial common shock except China's response, which increases in period three (0.42) before beginning to move downward to equilibrium.

[20] Results available upon request.

Fig. 4-7. GIRs of financial stress across the five Asian countries.
Note: VAR(2), error bands were drawn from 2000 repetitions.

Conclusions

In this study, we examine financial stress spillovers among five Asian countries, namely, China, South Korea, Malaysia, Thailand, and the Philippines. We employ an FSI compiled specifically for developing countries for the period from the end of 1997 to early 2009. Our empirical analysis involves a spillover analysis of the contamination of financial stress across these five countries based on spillover indices. We further analyze the dynamics of stress transmission by using spillover plots and estimate impulse response functions to examine the countries' responses to stress shocks.

We find that own-country stress spillovers are responsible for 69% of the forecast error variance for China. The results of the estimation of the directional spillovers from each country to all other countries show that China is the primary transmitter of financial stress spillovers. Furthermore, South Korea and the Philippines are the primary receivers of financial stress from the other countries. Most importantly, the total stress spillover index indicates that approximately 53% of the forecast error variance stems from stress spillovers. The dynamic examination of stress spillovers reveals that China had a major influence in the transmission of stress during the most recent global financial crisis, and the examination of the net directional and net pairwise spillover plots provides similar results.

The strong linkages among the Asian countries with respect to financial stress were enhanced during the most recent financial crisis. Our findings highlight the increasing importance of China in transmitting stress spillovers, which peaked after the outbreak of the crisis. Although China's importance in transmitting stress has gradually evolved, China is more isolated than the other countries from receiving stress spillovers. Moreover, South Korea and Thailand were the most important transmitters of financial stress before the most recent turmoil. Our findings are in line with those of Yilmaz (2010), who argues that the Chinese equity market has become more important during the last decade. The increased interdependence and integration among the Asian markets facilitate the transmission of stress during periods of extreme instability. Therefore, financial imbalances from one country could easily spread throughout the region, destabilizing the financial system of each country. Our findings offer important insights to inform policies aimed at monitoring, securing and guarding financial stability.

Financial Stability, Monetary Stability and Growth: A PVAR Analysis

Introduction

The impact of macroeconomic factors on finance as well as the channels that lead to financial imbalances have been well researched in the past. However, since the global financial crisis of 2007, the interest of scholars has concentrated on the impact of financial cycles on the real economy, sparking a debate over whether there is such an influence. Previous studies have demonstrated that credit plays a key role in the transmission of financial distress to the broader economy. Several studies indicate that the credit channel is the main channel for the transmission of financial distress (Jacobson et al., 2005; Gilchrist et al., 2009; Carlson et al., 2011). Empirical findings highlight credit growth as a predictor of financial stress in economies.

From a theoretical perspective, scholars argue that monetary policy impacts the real economy through the financial accelerator mechanism (Kiyotaki and Moore, 1997; Bernanke et al., 1999). Recent theoretical developments have moved in the direction of incorporating the financial sector into a macroeconomic framework, thus relating financial frictions to economic activity (Cúrdia and Woodford, 2009; Gertler and Karadi, 2011; Gertler and Kiyotaki, 2010). There is limited research on the relationship between financial stability and growth (Cevik et al., 2013; Hakkio and Keeton, 2009; Hatzius et al., 2010; Mallick and Sousa, 2013). Controlling for growth and inflation and using a financial soundness indicator, Hatzius et al. (2010) examine the predictive power of financial conditions with regard to future economic activity. Mittnik and Semmler (2013) argue that in times of severe financial stress, large negative shocks to financial stress have sizeable positive effects on real activity.

effects of financial stress on financial stability and growth, as well as the reverse effects. Following Love and Zicchino (2006), we exploit a PVAR generalized method of moments (GMM) estimator to explore the stress dynamics and macroeconomic variables of 19 OECD advanced countries. Our panel VAR model can be written as follows:

$$Y_{it} = \Gamma_0 + \Gamma(L)Y_{it-1} + f_i + d_t + e_{it}, \qquad i = 1,\ldots,N \quad t = 1,\ldots,T \tag{5.3}$$

where Y_{it} is a vector of three variables: GDP (real GDP growth), CPI (change in the CPI) and the FSI; Γ_0 is a vector of constants; $\Gamma(L)$ is a matrix polynomial in the lag operator; f_i denotes fixed effects; d_t denotes the forward mean-differencing; and e_{it} is a vector of independently and identically distributed errors. The data were time demeaned and forward mean-differenced using the Helmert procedure and following Arellano and Bover (1995) as fixed effects are usually correlated with the regressors.

Model 5.3 was estimated using GMM-style instruments, as proposed by Holtz-Eakin et al. (1988). First, we present the results of the PVAR model, and then, we proceed to Granger causality Wald tests for each equation of the underlying PVAR model.

Finally, we present the impulse response functions (IRFs) using Monte Carlo (MC) simulations for the confidence intervals and following Cholesky identification and forecast-error variance decompositions (FEVDs).

Empirical results

First, we test for the stability of our PVAR model by checking whether all eigenvalues lie within the inner circle. Usually, variables that are introduced first in VAR models are assumed to be the most exogenous and affect subsequent variables both contemporaneously and with a lag, whereas variables that are ordered later are less exogenous and affect previous variables only with a lag. Following these general directions, we introduce macroeconomic

lagged variables in the equation, in which we test the null hypothesis that all lags of all variables can be excluded from each equation in the VAR system. We can characterize Granger causalities from the FSI to GDP growth and from the CPI to GDP growth as bidirectional. However, Granger causation from the FSI to the CPI is found to be unidirectional. In that case, we argue that the causality runs one way only – from financial stress to inflation. The joint significance chi-square statistics in the last row indicate all variables are Granger caused by all lagged variables.

Table 5-3. Granger causality tests among the advanced countries.

	GDP	CPI	FSI
GDP		25.019***	9.047**
CPI	17.863***		44.769***
FSI	40.620***	0.155	
All	81.777***	25.669***	47.056***

Notes: The tests are based on the PVAR(2) model. The entries in the table are the chi-square statistics for the null hypothesis that the excluded variable does not Granger cause the equation variable vs. the alternative hypothesis that the excluded variable Granger causes the equation variable. *** denotes significance at the 1% level. ** denotes significance at the 5% level. * denotes significance at the 10% level.

5.4.3 Panel impulse response functions

The same ordering used in the PVAR was used in the estimation of the IRFs and FEVDs. Fig. 5-2 plots the responses to a one-standard deviation shock for a 10-quarter period. GDP growth responds negatively and significantly to a shock to the FSI. Our findings are in line with those of other scholars who examine the relationship of financial stress and growth (Bloom, 2009; Cevik et al., 2013; Creel et al., 2015; Hakkio and Keeton, 2009; Mallick and Sousa, 2013). In the first lags, the FSI responds negatively but not significantly to a shock to GDP growth and responds positively to an inflation shock. This result means that a positive shock to the general level of prices increases financial stress in the short term. Turning now to inflationary responses to a GDP growth shock or an FSI shock, we observe a positive and significant impact from a GDP growth shock; however, inflation responds negatively but not significantly to a shock to the FSI. Finally, GDP growth responds negatively to an inflation shock, which is in line with the findings in Chapter 3.

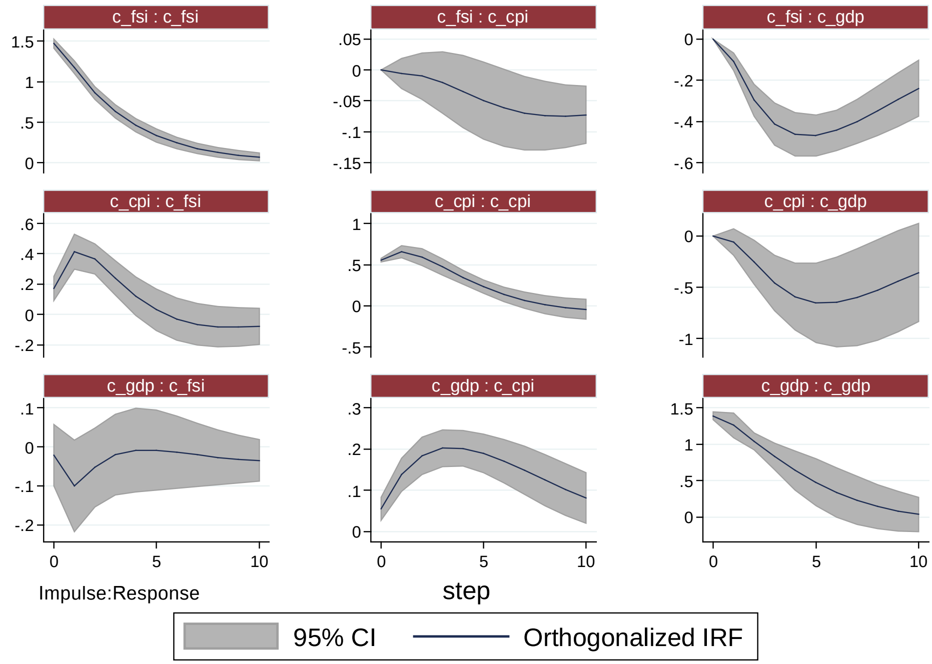

Fig. 5-2. IRFs of shocks, baseline model.
Note: Impulse: Response, PVAR(2), error bands were drawn from 500 MC repetitions**.**

5.4.4 Panel variance decompositions

Table 5-4 reports the FEVDs of the baseline PVAR model after 10 and 20 periods. We observe that the CPI explains approximately 14% of the total variance in GDP and that GDP growth and FSI explain approximately 25% and approximately 28% of the total variance in the CPI, respectively. GDP growth has the largest explanatory power for financial stress, explaining approximately 14%, which indicates a somewhat large influence. The CPI explains only a small portion of the variance in the FSI (2.5%).

Table 5-4. Forecast-error variance decomposition (FEVD).

Response variable & Forecast horizon	Impulse variable		
	GDP	CPI	FSI
GDP			
10	0.6323	0.2373	0.1304
20	0.6063	0.2549	0.1387
CPI			
10	0.1403	0.8463	0.0134
20	0.1443	0.8302	0.0255
FSI			
10	0.0029	0.0767	0.9204
20	0.0043	0.0790	0.9167

Notes: *** denotes significance at the 1% level. ** denotes significance at the 5% level. * denotes significance at the 10% level.

5.4.5 Augmented PVAR model including house prices and government deficit

Tables 5-5, 5-6 and 5-7 show the results of the PVAR analysis with 5 variables. Table 5-6 shows that there is a bidirectional relationship between the FSI and housing prices. Table 5-7 indicates that housing prices can explain approximately 10% of the variance in the FSI while the deficit can explain only 1%. Approximately 10% of the variation of GDP growth is explained by the macroeconomic variables. Financial stress and GDP growth explain a large portion of the variation in inflation. The variation in housing prices is explained by the deficit (33%) and GDP growth (18%). Fig. 5-3 illustrates the impulse responses of the augmented model: GDP→DEF→HP→CPI→FSI. The response of GDP growth to FSI shocks remains negative and significant, as in our three-variable model. Afonso et al. (2017) find that a financial stress shock has a negative effect on output and worsens the fiscal situation. Additionally, we observe no significant response by financial stress to a positive growth shock. A positive shock to the FSI has a negative but small effect on housing prices. A shock to housing prices significantly increases financial stress for the first periods. A larger negative

*denotes significance at the 5% level. * denotes significance at the 10% level.*

Table 5-6. Forecast-error variance decomposition (FEVD).

Response variable & Forecast horizon	GDP	DEF	HP	CPI	FSI
GDP					
10	0.4979	0.0158	0.1793	0.1289	0.1781
20	0.4852	0.0173	0.1779	0.1274	0.1922
DEF					
10	0.0282	0.6082	0.3313	0.0216	0.0106
20	0.0286	0.6005	0.3352	0.0250	0.0108
HP					
10	0.0298	0.0071	0.8610	0.0113	0.0908
20	0.0315	0.0073	0.8521	0.0115	0.0977
CPI					
10	0.0390	0.0347	0.0283	0.8976	0.0005
20	0.0389	0.0348	0.0311	0.8948	0.0005
FSI					
10	0.0061	0.0082	0.0177	0.0828	0.8853
20	0.0060	0.0090	0.0177	0.0876	0.8797

Notes: *** denotes significance at the 1% level. ** denotes significance at the 5% level. * denotes significance at the 10% level.

Table 5-7. Granger causality tests among the advanced countries.

Lags (1)	GDP	DEF	HP	CPI	FSI
GDP		16.254***	3.663*	3.115*	0.457
DEF	3.384*		4.604**	17.876***	0.414
HP	138.393***	0		39.751***	25.684***
CPI	28.768***	3.151*	1.829		1.633
FSI	28.926***	2.808*	28.73***	1.321	
All	271.364***	28.825***	38.871***	70.823***	30.367***

Notes: The tests are based on the PVAR(1) model. The entries in the table are chi-square statistics for the null hypothesis that the excluded variable does not Granger-cause the equation variable vs the alternative hypothesis that the excluded variable Granger-causes the equation variable. *** denotes significance at the 1% level. ** denotes significance at the 5% level. * denotes significance at the 10% level.

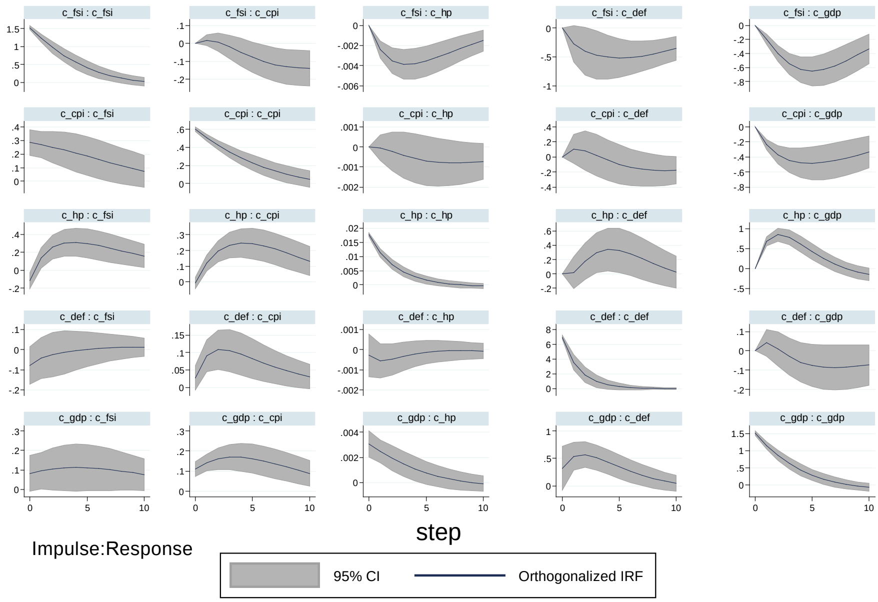

Fig. 5-3. IRFs of shocks, 5-variable model.
Note: VAR(1), error bands were drawn from 500 repetitions.

5.5 Robustness tests

As a robustness test, first, we use an alternative PVAR model and the least squares dummy variable estimator, as described by Cagala and Glogowsky (2015). In Fig 5-4 we provide the IRFs using this approach. The results are similar, except for the response of the FSI to a growth shock (bottom left), which is now positive and significant after a lag.

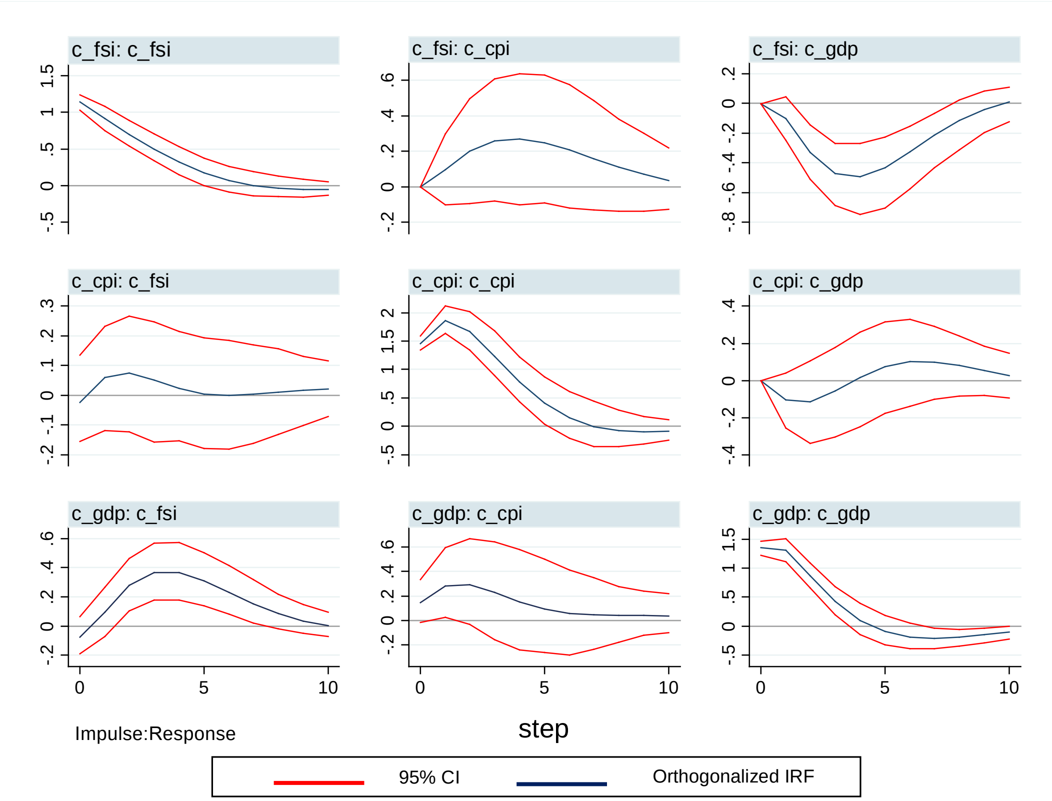

Fig. 5-4. Orthogonalized IRFs of shocks, using the least squares dummy variable estimator.

Note: VAR(2), error bands were drawn from 500 repetitions. 95% confidence intervals.

Furthermore, the responses of the FSI and the CPI to CPI and GDP growth shocks, respectively, have become nonsignificant. Second, we conduct sensitivity analyses with respect to different Cholesky orderings; additionally, we construct and examine cumulative IRFs. More volatile variables are usually placed at the end of the model, as they are expected to affect all other variables contemporaneously but themselves are affected by all other variables with a lag. As GDP and the deficit are expected to affect all other variables contemporaneously but are themselves affected by all others with a lag, they can be found at the beginning of the system; however, the FSI can be always found at the end of the Cholesky ordering, as it is expected to react contemporaneously to all other variables in the system but to affect the other variables with a lag. The following models were estimated:

i. GDP→DEF→CPI→HP→FSI,
ii. DEF→GDP→HP→CPI→FSI,
iii. DEF→GDP→CPI→HP→FSI.

Appendix D provides the IRFs of the different orderings of the five variable PVAR model. The IRFs are similar to the initial ordering, and we can argue that our findings are resistant to the different variable orderings. Finally, Fig 5-5 presents the cumulative IRFs for the baseline model, and Fig. 5-6 presents them for our augmented model. The results verify our previous findings: GDP growth leads to a higher level of inflation. The CPI leads to higher financial stress but lower GDP growth, while the FSI leads to lower inflation and GDP growth. In addition, we observe no significant response by the FSI to a GDP growth shock. In Fig. 5-6, we observe that a shock to housing prices has a positive and significant impact on financial stress but that a financial shock has a negative impact on the deficit and housing prices.

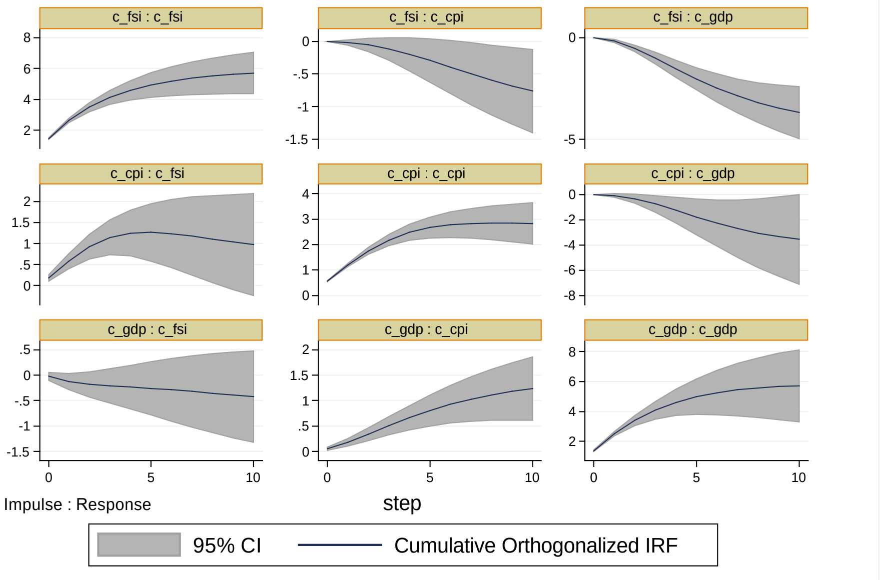

Fig. 5-5. Accumulated IRFs of shocks.
Note: VAR(2), error bands were drawn from 500 repetitions.

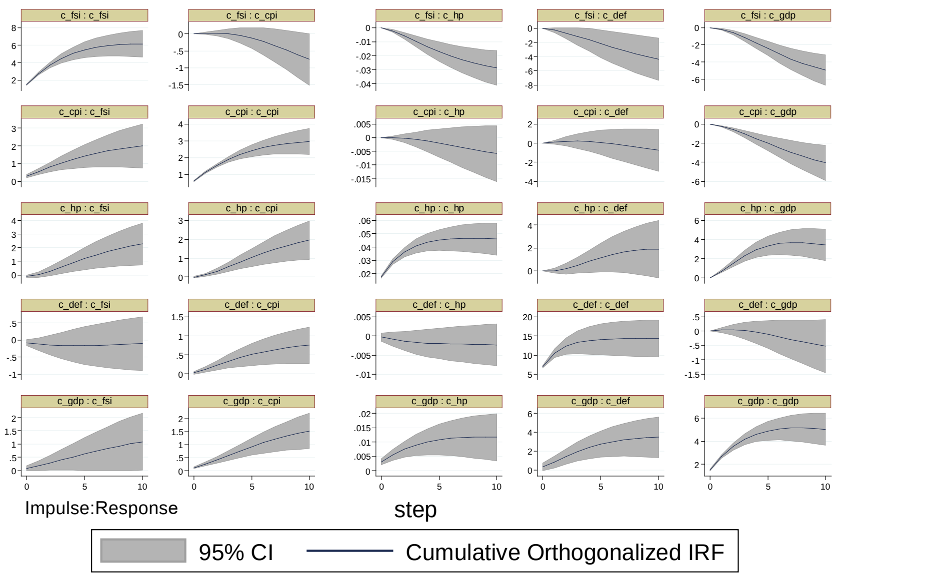

Fig. 5-6. Accumulated IRFs of shocks, 5-variable model.
Note: VAR(1), error bands were drawn from 500 repetitions.

5.6 Conclusions

This study examines the macroeconomic-financial stress relationship by applying a PVAR approach for 19 advanced economies and constructing IRFs over the 1999-2016 period. To the best of our knowledge, this study is the first to adopt a PVAR framework to study the relationship among financial stability, monetary stability and growth.

The results reveal that a positive shock to financial stress results in a negative impact on all macroeconomic variables; first, it has a negative impact on growth and a negative impact on inflation. The response by housing prices and the deficit are also negative. Financial stress is positively influenced by shocks to inflation and increases in housing prices. In contrast, neither a positive economic shock nor an increase in the deficit influence financial stress. Analyses of variance decomposition and Granger causality further support our findings of the relationship between financial stress and macroeconomic variables. We find that growth, the deficit, housing prices and inflation explain approximately 30% of the variation in financial stress. Monitoring the risk stemming from potential housing bubbles is important for the resiliency of the financial system.

Overall, our findings provide new insights about the importance of financial stability in the context of macroprudential policy and regulation. In this light, it is important for policymakers and central bankers to develop a macroprudential monitoring framework and tools for examining financial stability and soundness. Future research should study the relationship between financial stress and macroeconomic variables, focusing on the potential differences between developed and developing countries.

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Appendix D: Robustness tests.

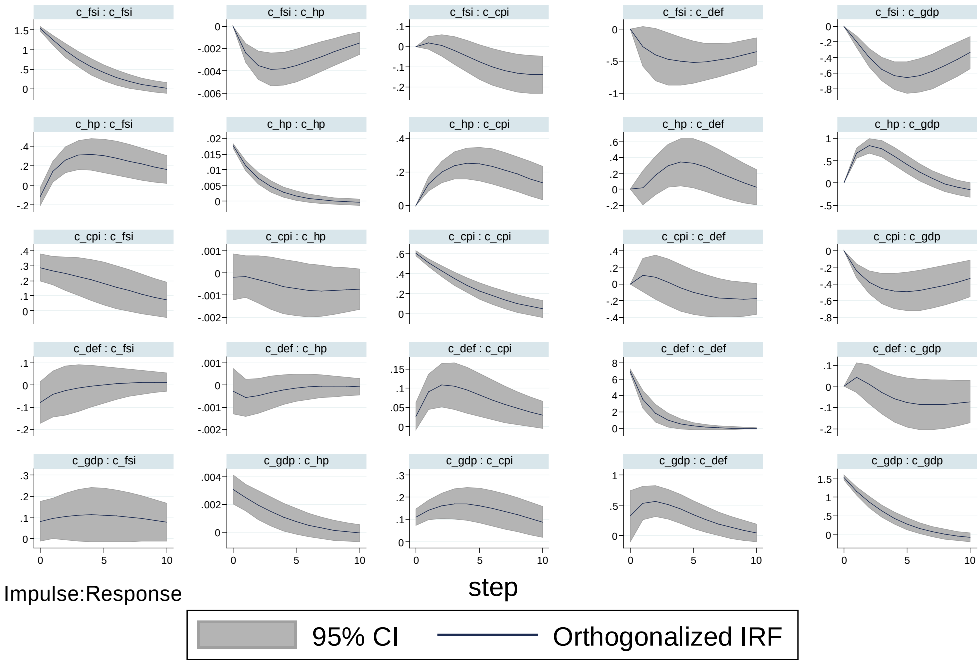

Fig. 5-7. Different Cholesky ordering: GDP→DEF→CPI→HP→FSI.
Note: VAR(1), error bands were drawn from 500 repetitions.

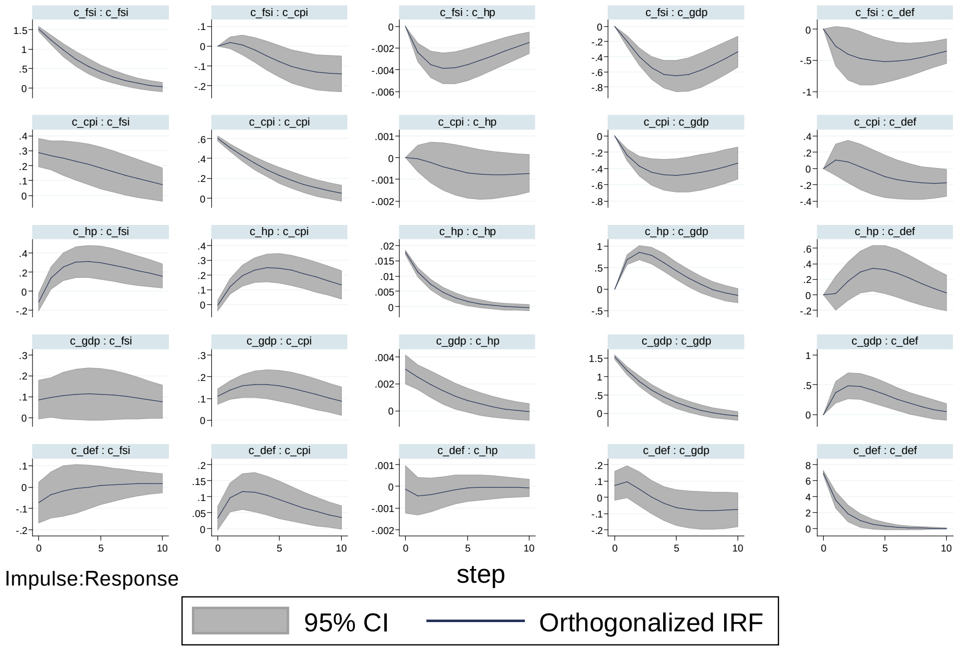

Fig. 5-8. Different Cholesky ordering: DEF→GDP→HP→CPI→FSI.
Note: VAR(1), error bands were drawn from 500 repetitions.

Appendix E: Data description.

A) FSI components.

Component	Calculation	Source
Banking beta (CAPM)	$B_{it} = cov(r_{it}^M, r_{it}^B) / \sigma_{i,M}^2$	DataStream
Inverted term spread	The government short-term rate minus the government long-term rate	DataStream and OECD
Sovereign risk	The long-term interest rate – the US long-term interest rate (0 for the US)	DataStream and OECD
Stock market returns	The inverted month-over-month change in the stock index	DataStream
Stock market volatility	GARCH (1,1)	DataStream
Exchange market volatility	GARCH (1,1)	BIS

Note: Monthly series. The aggregate FSI is compiled by standardizing and summing the six components: FSI_t = Banking beta + Inverted term spread + Sovereign risk+ Stock market returns + Stock market volatility + Exchange market volatility.

B) Description of the time series used in the second part of the Chapter.

Series	Frequency	Source	Description
GDP	Q	DataStream	Real gross domestic product, % YoY, Standardized
CPI	M	DataStream	Consumer price index, % YoY, Standardized
House prices	Q	BIS, DataStream	Residential Property Prices; Long Series, NSA &OE Residential Property Prices: All Dwellings, % MoM
Govt. debt	M	DataStream	Central Government Deficit/Surplus, CHG YoY, Standardized, CURN

6. Conclusion

In the empirical analysis of this dissertation, we employ several different methods and samples to examine co-movements and spillovers along financial markets and countries and the interrelationships between financial stability and macroeconomic fundamentals. In Chapters 2, 3, and 4, we examine financial stress spillovers using the generalized VAR model developed by Diebold and Yilmaz (2012). As a proxy measure of financial stability, we utilize an FSI by IMF scholars. This index can reflect increased stress volatility during turbulent periods, and its compilation method facilitates an examination of its constitutional subcomponents. The outcome of this analysis is presented by showing financial stress spillover index tables and total, directional and pairwise stress spillover plots.

In Chapter 2, the spillover analysis of financial stress among advanced economies of the G7 indicates that the US is the dominant transmitter of financial stress spillovers. The total stress spillover index explains 19.9% of the forecast-error variance, and on average, 20.9% of the volatility forecast-error variance comes from spillovers. In Chapter 3, the spillover analysis across the banking, securities and exchange markets shows that securities markets are the major net transmitter of financial stress to all other markets. The total stress spillover index explains up to 42.8% of the forecast-error variance. In Chapter 4, the spillover analysis shows that China is the dominant transmitter of stress to Asian countries. The total stress spillover index explains up to 53% of the forecast-error variance in that model.

Furthermore, in Chapter 2, we examine the dynamic correlations and co-movements of financial stress by employing the DCC model developed by Engle (2002). The correlation analysis shows that financial stress co-movements are positively associated with crisis periods and that DCCs increase during periods of high uncertainty.

Additionally, in Chapter 3, we examine the interrelationship among financial stability, monetary stability and output growth using a VAR model and analyzing generalized impulse responses. Our results indicate that financial stress has a negative and significant short-run effect on real output and monetary stability. Furthermore, the results of the penalty function approach imply that financial stress is positively related to monetary contraction and inflation shocks.

Furthermore, in Chapter 4, we estimate generalized IRFs to examine the responses to stress shocks of Asian countries (China, South Korea, Malaysia, Thailand, and the Philippines). We find that financial stress innovations result in positive and homogenous responses. Additionally, the Granger causal analysis indicates unidirectional effects from China and South Korea to Malaysia.

Finally, in Chapter 5, we examine the relationship between macroeconomic fundamentals (GDP growth, inflation, government deficit, and housing prices) and financial stress for 19 advanced economies using a PVAR method. We provide PVAR impulse responses, variance decompositions and Granger causality analysis. The impulse response analysis shows negative responses of the macroeconomic variables to financial stress shocks. Variance decomposition analysis indicates that housing prices can explain approximately 10% of the variance in the FSI and that the deficit can explain only 1%. We find that growth, the deficit, housing prices and inflation explain approximately 30% of the variation in financial stress.

This dissertation highlights the significance of stress spillovers among countries and across markets. We provide insights into the nature of cross-country stress transmission, highlighting the importance of stress spillovers among countries and across financial markets in periods of financial turmoil. Financial imbalances from one country or market can easily spread throughout the region and to other markets, destabilizing financial systems. Our findings have significant implications for the policymakers, regulators, and supervisors who are responsible for shaping monetary policy, implementing macroprudential policy, guarding financial stability and promoting growth.

The empirical analysis and the findings in this dissertation also reveal new avenues for research. For example, future research could delve into the sources and determinants of the financial stress interaction among countries and markets. Future research can examine the impact of financial stress episodes and stress spillovers from advanced to emerging economies. Furthermore, as emerging market economies are increasingly gaining importance and influence in the global economic and financial scene, future research can examine the reverse stress transmission to financial markets from a shock stemming from emerging economies. A thorough study should be conducted on the potential stress spillovers from peripheral to core Eurozone countries, incorporating the European sovereign debt crisis. Furthermore, future research should study the relationship between financial stress and macroeconomic fundamentals, focusing on the potential differences between developed and developing countries and between different levels of financial development.

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Chapter 3: Apostolakis, G., Papadopoulos, A.P., 2015. Financial stress spillovers across the banking, securities and foreign exchange markets. Journal of Financial Stability. 19, 1-21. doi:10.1016/j.jfs.2015.05.003.

Chapter 4: Apostolakis, G., 2016. Spreading crisis: Evidence of financial stress spillovers in the Asian financial markets. Journal of International Review of Economics & Finance. 43, 542-551. doi.org/10.1016/j.iref.2016.02.002.

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