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International transmission and business-cycle effects of financial stress[☆]

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ABSTRACT

We analyze the international transmission of financial stress and its effects on global economic activity. Our analysis is based on country-specific monthly financial stress indices (FSIs) over the sample period 1970–2012 for 20 major economies. First, we show that co-movement between the FSIs increases during major financial crises and towards the end of our sample period. Second, we show that the risk of large financial stress spillovers to an economy increases with its level of economic openness. Third, we show – using a global VAR (GVAR) model – that (i) a financial stress shock in the US quickly transmits internationally, (ii) financial stress shocks have lagged but persistent negative effects on economic activity, and (iii) that a negative US demand shock induces only limited financial stress on a global scale. Finally, we show that spillovers of financial stress run mainly from advanced to emerging economies and not in the opposite direction.

1. Introduction

The financial and economic crisis of 2007–2009 had a widespread impact on countries all over the world. While advanced economies were directly exposed to the events in the wake of the default of Lehman Brothers, financial markets in emerging economies were also negatively affected (Baur, 2012). In nearly all countries, stock markets plummeted, bank stocks came under pressure due to systemic risk, and the volatilities in stock markets and foreign exchange markets increased significantly.[1]

These events have led to the view that an understanding of financial markets is much more important for policy-makers – especially during periods of financial stress – than suggested by the dominant belief before the crisis. It is now evident that economic policy needs answers to such questions as follows: How is financial stress, i.e., systemically relevant tensions over a broad range of financial market segments, transmitted internationally? What are the real economic consequences, e.g., in terms of business-cycle effects, of unexpected increases in financial stress? What determines the degree to which a country is exposed to financial stress spillovers from abroad? Addressing these types of questions is not only relevant for short-term policy reactions in response to financial stress shocks but also for financial market regulation.

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[1] For a chronology of the crisis, see Melvin and Taylor (2009) and the references therein.

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Measuring financial stress has become more and more prominent in recent years. As Holló et al. (2012) note, financial stress may be defined as a current state of financial instability, which in turn can be interpreted as the amount of systemic risk that has already materialized.[2] From this definition, it is clear that financial stress is unobservable. However, economic theory suggests that it is reflected in a wide range of financial variables, and many central banks, international organizations, private banks, and economic research institutes have constructed so-called financial stress indices (FSIs) to measure financial stress. In addition to simply measuring the degree of financial stress, there is also a growing literature attempting to link measures of financial stress to the dynamics of the real economy. Several studies find, for instance, that an increase in financial stress significantly reduces economic activity (Hakkio and Keeton, 2009; Hubrich and Tetlow, 2012; Mittnik and Semmler, 2013; Cevik et al., 2012; van Roye, 2014).

Beyond the rapidly growing literature analyzing the role of financial conditions and financial stress on the macroeconomy, few authors have investigated financial stress from a global perspective. Of these few studies, most concentrate on certain aspects of financial stress, i.e., specific market segments. Helbling et al. (2011), for instance, demonstrate the importance of US credit market shocks in global business-cycle dynamics. Eickmeier and Ng (2011) examine the propagation of credit supply shocks in various countries and emphasize the strong international transmission of US credit supply shocks. Cesa-Bianchi (2013) finds that U.S. housing demand shocks are quickly transmitted to other advanced economies, while the transmission to emerging economies is rather subdued. N'Diaye et al. (2010) examine how an increase in banks' and non-financial corporations' default risks is transmitted in the global economy. Focusing on the reverse causal effect, Castrén et al. (2010) investigate how global macro-financial shocks influence default probabilities in the corporate sector. The first paper analyzing the global transmission of financial stress based on a broad measure of financial stress is Balakrishnan et al. (2009). However, these authors focus solely on the transmission of financial stress from advanced to emerging economies and do not take into account business-cycle effects or feedback loops, i.e., second-round effects.

To model the effects on the real economy and endogenous feedback loops on a global scale, GVAR models may be used. Originally established by Pesaran et al. (2004), they were further developed by Dées et al. (2009) and Dées et al. (2010), among others. GVAR models can be used to analyze international interdependencies among countries and transmission channels of international shocks. This type of model has, for instance, been used to analyze the international transmission of oil price shocks (Cashin et al., 2012), house price shocks (Cesa-Bianchi, 2013), credit supply shocks (Eickmeier and Ng, 2011), cost-push shocks (Galesi and Lombardi, 2009), liquidity shocks during the Great Recession of 2007–2009 (Chudik and Fratzscher, 2011), and stress-testing of the financial sector (Castrén et al., 2010). To the best of our knowledge, however, it has not yet been used to analyze the international aspects of systemic financial-stress shocks.

We contribute to the literature on the international transmission of financial shocks along several dimensions. First, we analyze the international transmission and global business-cycle effects of shocks to (broadly measured) systemic financial stress in a GVAR model that endogenizes all relevant variables. Second, we analyze the interaction between financial stress in emerging economies with that in advanced economies, accounting for second-round effects. Third, we demonstrate how the degree of the co-movement of financial stress, i.e., cross-country spillover effects, varies over time and how this dynamic is related to major global financial crises. Finally, we use cross-section and panel-data evidence to show how the degree of financial stress spillovers in each country is related to the degree of economic openness.

The remainder of this paper is organized as follows. Section 2 explains the methodology that we use to construct the country-specific FSIs, describes the data, and presents estimates for the FSIs. Section 3 shows how the degree of co-movement of financial stress across countries varies over time, identifies regional patterns in the spillover effects of financial stress, and presents evidence on the correlation between the degree of financial stress spillovers and economic openness. Section 4 describes the GVAR model and analyzes how financial stress shocks are internationally transmitted and how they affect global economic activity. Section 5 presents brief conclusions for this study.

2. Measuring financial stress

The construction of FSIs to measure financial stress has been tackled in a large number of papers. Among the first, Illing and Liu (2006) construct an FSI for Canada to provide a "snapshot" of the degree of stress in the national financial system. Hakkio and Keeton (2009) and Kliesen and Smith (2010) construct FSIs for the US, which are regularly referred to by the Federal Reserve. The European Central Bank periodically publishes a Composite Indicator of Systemic Stress (CISS) as a tool for its macro-prudential monitoring Holló et al. (2012). FSIs have been established as thermometers for systemic financial risk in other countries as well.[3] In this paper, we are faced with a trade-off between the consistency of FSIs across countries, as data are scarce, especially for emerging economies, and complete coverage of all financial market segments. Given the systemic and broad character attributed to financial stress in the definition by Holló et al. (2012) cited above, we select a set of broadly available financial variables that reflect tensions in different financial market segments.

2.1. Methodology

To extract a common stress component of the financial variables, we apply a dynamic approximate factor model. The methodology is similar to that in Banbura and Modugno (2014) and van Roye (2014). In particular, we set up a model with the following form:

$$y_{i,t} = \Lambda_i f_{i,t} + \varepsilon_{i,t} \quad with\, \varepsilon_{i,t} \sim \mathcal{N}(0, C_i) \tag{1}$$

In this equation, $y_{i,t}$ is a vector of stationary and standardized indicators for financial stress in country i, $f_{i,t}$ is a single country-specific latent factor, and Λ_i is a $n \times 1$ vector of the indicators' factor loadings.[4] The vector $\varepsilon_{i,t}$ represents the idiosyncratic component which is allowed to be slightly correlated both serially at all leads and lags and cross-sectionally.

The dynamics of the latent factor $f_{i,t}$ are described by the transition equation

$$f_{i,t} = A_i f_{i,t-1} + \xi_{i,t} \quad with\, \xi_{i,t} \sim \mathcal{N}(0, D_i), \tag{2}$$

[2] The precise definition of financial stress differs across the literature. For a survey on different definitions of financial stress and different methodologies for its measurement, see, e.g., Hatzius et al. (2010).

[3] Cardarelli et al. (2011), for instance, develop FSIs for a number of countries. van Roye (2014) and Aboura and van Roye (2013) construct FSIs for Germany and France, respectively.

[4] Likelihood ratio tests support our assumption of one factor against the alternative hypothesis of two or more latent factors for all countries in our sample.

where A_i is the autoregressive coefficient, capturing the dynamics of $f_{i,t}$. For each time period, we compute the country-specific FSI as the estimate of the unobserved factor: $FSI_{i,t} = \hat{f}_{i,t}$.

Because we aim to estimate the model over a long time horizon and for many countries for which data availability is limited, we estimate the model using a combined maximum likelihood and expectation maximization (EM) algorithm approach. Compared to non-parametric methods based on principal components, this approach has the advantage of allowing an arbitrary pattern of missing data to be addressed (Banbura and Modugno, 2014).

2.2. Data

To compute the FSIs, we use six indicators for each country (Table 1).[5] These indicators can be individually interpreted as a measure of financial stress in a specific market segment and are well established in the literature (Illing and Liu, 2006; Holló et al., 2012; Cardarelli et al., 2011; Misina and Tkacz, 2009; Lo Duca and Peltonen, 2011). In particular, we focus on financial stress in the banking sector, stock markets, bond markets, money markets, and foreign exchange markets.

To develop a measure for stress in the banking sector, we construct a volatility index of bank equity. We take the equity index of the countries' most important financial institutions provided by Thomson Reuters Professional Datastream. Using the daily bank equity returns, we construct a volatility measure by estimating GARCH(1,1) models and average the daily conditional variances to obtain a monthly measure. For aggregate stock market uncertainty, we use an analogous approach based on the returns of the countries' main stock market indices. In addition, we use negative three-month moving-average stock market returns as an indicator for financial market losses. To measure the financial stress on government bond markets, we construct a volatility measure using GARCH(1,1) models for the daily returns of government bond indices provided by Thomson Reuters Professional Datastream and average them to obtain a monthly measure.[6] Again, the stress measure for money markets is computed analogously based on daily money-market returns. Finally, we calculate a monthly volatility index for the real effective exchange rate to measure financial stress on foreign exchange markets. To this end, we extract the series of conditional variances from GARCH(1,1) models for the monthly real effective exchange rate returns.

2.3. Constructing financial stress indices

Fig. 1 plots the FSIs for all countries of our sample. In anticipation of the analysis in Section 4, it also reports external FSIs that are calculated by taking a weighted average of financial stress in all other countries. Although the FSIs differ significantly by country, the important global financial crises are immediately visible. In particular, the FSIs indicate high financial stress during the oil crisis in 1973/1974, during the LDC crisis in 1981/1982, after the stock market crash of 1987, during the Asian and Russian crises in 1997/1998, and during the burst of the dot-com bubble after 2001. For the European countries, the ERM crisis and the recent European sovereign debt crisis are additional events that induced a high degree of financial stress. Finally, the largest increase in the FSIs of most countries occurred during the global financial crisis of 2007–2009.

To check the robustness of our results with respect to the method used to construct the FSIs, we also use two different approaches that have been proposed in the literature. We construct alternative FSIs by aggregating the financial market indicators using an arithmetic average of the raw indicators (equal variance weighting) and a simple average of CDF-standardized sub-indices, as in Holló et al. (2012). The CDF-standardized sub-indices transform the raw variables based on their empirical cumulative distribution function. We test the robustness of all results in this paper using these alternative FSIs. Grosso modo, all are relatively robust with respect to the weighting schemes of the raw indicators.[7]

3. Co-movement of financial stress

3.1. Theory and existing evidence

Both theoretical and empirical studies suggest that financial shocks spill over from one country to another. There are several potential channels through which financial shocks may be transmitted internationally. First, banks that operate globally may reduce their lending in one country when they face financial distress in another country (the "common lender effect"). Kollmann et al. (2011) show that global banks are likely to play a significant role in the international transmission of financial shocks.

Second, financial shocks may be transmitted across borders through equity markets due to the arbitrage activities of international investors Dedola and Lombardo (2012) and Perri and Quadrini (2011).

Third, financial shocks may be transmitted through the direct exposure of domestic banks that are holding foreign debt. For instance, any pressure on the sovereign bond market in a foreign country may have direct repercussions on domestic banks' profitability. In highly integrated financial markets, these effects are likely to also affect markets beyond sovereign bonds. Ehrmann et al. (2011) emphasize that international financial spillovers are not only important within single asset classes but also across different financial market segments.

Fourth, investors that are leverage-constrained may rebalance their internationally diversified portfolio and therefore reduce their investment activity not only in the country that is hit by a financial stress shock but also in the other countries (the "international financial multiplier effect"; see, e.g., Devereux and Yetman (2010) and Devereux and Sutherland (2011)).

Fifth, Ciccarelli et al. (2012) and Bayoumi and Vitek (2011) recently reinforced the evidence that cross-country financial spillovers are an important driver of business cycle fluctuations by using large empirical models. Finally, Balakrishnan et al. (2009) demonstrate that financial stress is transmitted immediately from advanced to emerging economies.

3.2. Time variation of financial stress spillovers

To formally assess how international financial stress spillovers have evolved over time during the last four decades, we perform a correlation analysis based on rolling windows of data. Since Forbes and Rigobon (2002) it has been well known that correlation

[5] Including additional financial market variables in those cases where more data are available would increase the information set of some of the FSIs. However, given the lack of long data histories for most emerging economies, we restrict our data set to variables that are available for all countries.

[6] An alternative measure to express stress on bond markets would be to take government bond spreads vis-á-vis a risk-free benchmark bond. However, because government bond yields are not directly comparable across countries, we choose the volatility index.

[7] The correlation analyses and the results of the GVAR analysis based on the alternative FSIs are available upon request.

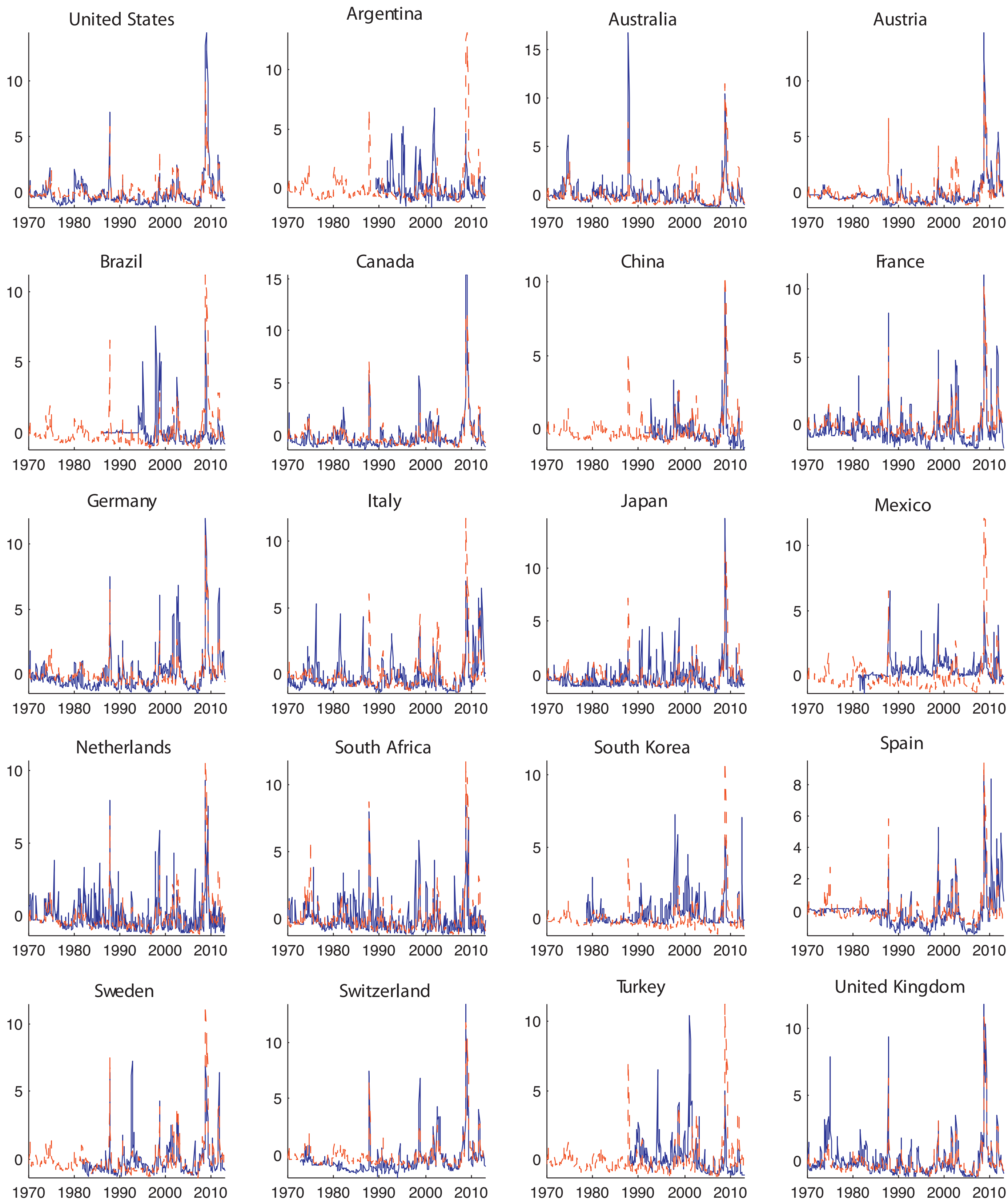

Fig. 1. Financial stress indices. Notes: Domestic financial stress indices (blue) and external financial stress indices (red). The FSIs are constructed using a dynamic approximate factor model (as described in Section 2.1) based on 6 different variables that measure financial stress in different market segments. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Table 1
Indicators, construction method, and market segment.

Indicator	Construction method	Market segment
Stock market volatility	GARCH(1,1) model of day-to-day stock market returns	Stock market
Exchange rate volatility	GARCH(1,1) model of month-to-month real effective exchange rate returns	FX market
Stock market returns	Negative values of the 3-month moving-average stock market returns	Stock market
Government bond volatility	GARCH(1,1) model of day-to-day government bond yields	Bond market
Banking sector volatility	GARCH(1,1) model of day-to-day returns on bank equity	Stock market
Money market volatility	GARCH(1,1) model of day-to-day returns on money markets	Money market

coefficients are conditional on the variance of the two random variables. When they are subject to heteroskedasticity, tests for time variation in the correlation coefficients are biased. This is clearly the case in our analysis, as periods of low and stable levels of financial stress alternate with periods of high and volatile levels. Forbes and Rigobon (2002) suggest a bias correction; however, this correction is not applicable in our multivariate context because it assumes a bivariate setting and because its assumptions (about exogeneity and the identification of regime switches) are too strict. Instead, we base our analysis on correlations between standardized residuals from univariate GARCH models for each FSI.[8] We use t-GARCH(1,1) models (to account for the fat-tailed distribution of residuals) for all variance equations and specify AR models for the mean equations based on the Akaike information criterion.[9]

We base the analysis on centered rolling windows of data with a width of 25 months between 1970 and 2012.[10] We concentrate on the evolution of the average cross-country correlation of financial stress. For each sample period, we compute this measure as

$$\overline{\rho}_t = \frac{1}{N(N-1)/2}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{[t-12;t+12]}(FSI_i^{sd}, FSI_j^{sd}), \tag{3}$$

where $\rho_{[t_0,t_1]}(X, Y)$ denotes the correlation between two random variables X and Y computed over $t = t_0, \ldots, t_1$ and FSI_i^{sd} are the standardized residuals from the t-GARCH model for the FSI of country i.

The left-hand plot in Fig. 2 shows the time series of these average correlation coefficients. The results of the cross-country correlation analysis are twofold. First, the increasing trend in the cross-country correlation during the last two decades mirrors the integration of financial markets around the globe. Second, the degree of financial stress spillovers between countries varies significantly over time. There tends to be a strong co-movement during episodes of major global financial stress, while cross-country spillovers are more moderate during tranquil times. This phenomenon can easily be observed by comparing the time-varying correlation to the right-hand plot of Fig. 2, which shows the "common component" of financial stress in advanced and emerging economies computed using the regression-based approach applied by Balakrishnan et al. (2009). Essentially, the two lines reflect those fractions of financial stress that are common to all advanced (emerging) economies at each point in time. The huge and rapid increase in co-movement in 1987 coincides with the spike in financial stress in advanced economies following the Black Monday events in stock markets. The other episodes of sharply increasing correlations can be attributed to the Asian crisis of the late 1990s, the burst of the dot-com bubble after 2001, and the recent global financial crisis starting in 2007.

3.3. Regional clustering of financial stress spillovers

The magnitude of financial stress spillovers varies by country and region. On average, emerging economies seem to be less exposed to global financial stress events than advanced economies. The degree of correlation of financial stress in Mexico, Brazil, and Korea with all other countries, for instance, is lower on average than the corresponding correlations of Germany, Spain, the UK, and the US (Table 2). The average financial stress correlation of the advanced economies is significantly higher for advanced economies than emerging economies, indicating stronger financial linkages among one another. This especially holds true for Germany (0.51 vs 0.24), Spain (0.53 vs 0.32), the UK (0.45 vs 0.21), and the US (0.46 vs 0.22). In contrast, the correlation of financial stress to advanced economies is relatively low in emerging economies, e.g., Mexico (0.13), Brazil (0.12), and South Korea (0.15). These results imply that cycles of financial stress in the emerging economies exhibit a different pattern than those in advanced economies.

There also seems to be a regional clustering of financial stress correlation. For instance, the correlations of financial stress between Germany and France (0.62), Canada and the US (0.69), and Spain and France (0.78) are relatively high. This result reflects the strong financial linkages and high financial integration among countries that are geographically close to each other. This is also true in general, as the average correlation of financial stress to countries in the same region is higher than that to countries in other regions for almost all countries.

Finally, the correlation of financial stress in the US with other countries' stress levels is high in general (Mexico and Brazil are two notable exceptions). This confirms the notion that the US is a very important propagator of financial shocks in the world economy.

3.4. Financial stress spillovers and economic openness

As mentioned in Section 3.1 we expect a certain degree of financial spillover when two or more economies are interlinked. In addition, a plausible hypothesis is that these spillovers are higher the closer the economies are interlinked, i.e., the more economically open the economies are. To test this hypothesis empirically, we first make use of the cross-country variation. To this end, we relate the average full-sample correlation of each country's financial stress with the stress levels in all other countries to measures of openness for each country. To strengthen the case, second, we also use the time-variation in both the spillover level and the openness measures in a panel setup.

To ensure the robustness of our results, we use three different measures of openness: two for financial openness and one proxy for trade openness. First, we use the Chinn-Ito index, a de-jure measure of financial openness that measures a country's degree of capital account openness. The index was originally introduced by Chinn and Ito (2006) and is available for all countries in our

[8] The use of Spearman rank correlations (which are robust against non-linearities and outliers) instead of simple correlation coefficients does not change the results.

[9] An alternative approach is the identification of time-varying correlations based on multivariate GARCH models, such as the DCC-GARCH proposed by Engle (2002). This approach, however, yielded no stable estimates in our case because the innovations to financial stress exhibit such fat tails, i.e., numerous large outliers, that even a DCC-t-GARCH model cannot be estimated properly.

[10] The broad result remains unchanged when we use a narrower window of 13 months.

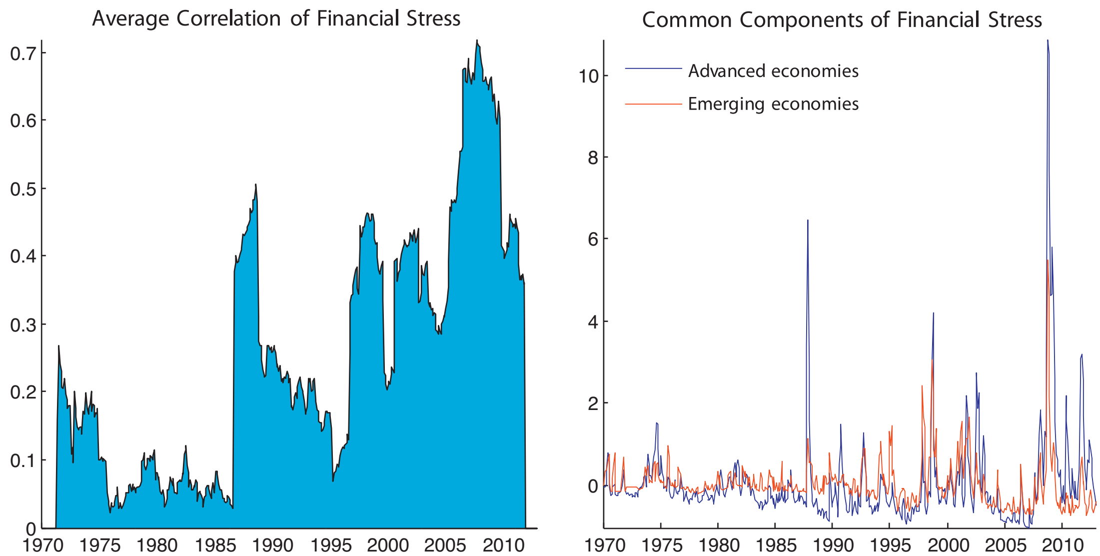

Fig. 2. Co-movement of financial stress. Notes: The left plot shows the average correlation between any two pairs of standardized residuals from t-GARCH models for the financial stress indices computed for centered 25-months rolling windows according to Eq. (3). The right plot shows the "common component" of FSIs for advanced and emerging economies, which are computed using the method used in Balakrishnan et al. (2009, p.15).

sample between 1970 and 2011. Second, we use the ratio of total portfolio investment abroad to domestic GDP. These data are from the Coordinated Portfolio Investment Survey (CPIS) of the International Monetary Fund and are available for the period between 2001 and 2011 and for all countries in our sample except Mexico (sample covers only 2003–2011) and China (no information). Third, we compute the ratio of the sum of imports and exports to the GDP as a proxy for trade openness.

Using sample averages, we find a positive albeit weak relationship between the degree of economic openness and the average

Table 2
Bilateral correlations of financial stress.
Notes: The upper panel shows the full-sample correlations between any pair of two countries computed based on the standardized residuals from country-specific t-GARCH model as explained in Section 3.2. The lower panel shows averages of these correlations computed for each country against different sets of other countries. We treat as emerging economies: Argentina, Brazil, China, Mexico, South Africa, South Korea, and Turkey. Country codes are as follows: ARG: Argentina; AUS: Australia; AUT: Austria; BRA: Brazil; CAN: Canada; CHE: China; FRA: France; DEU: Germany; ITA: Italy; JPN: Japan; MEX: Mexico; NLD: Netherlands; SAF: South Africa; KOR: South Korea; ESP: Spain; SWE: Sweden; CHE: Switzerland; TUR: Turkey; GBR: United Kingdom; USA: United States.

Country	DEU	FRA	ITA	ESP	NLD	AUT	GBR	SWE	CHE	USA	CAN	MEX	BRA	ARG	JPN	CHN	KOR	TUR	AUS	SAF
Europe																				
DEU	–	0.62	0.44	0.67	0.32	0.55	0.57	0.48	0.56	0.56	0.55	0.07	0.03	0.22	0.32	0.49	0.19	0.39	0.49	0.32
FRA	–	–	0.55	0.78	0.29	0.45	0.60	0.24	0.51	0.55	0.45	0.08	0.11	0.21	0.24	0.45	0.17	0.33	0.50	0.29
ITA	–	–	–	0.63	0.19	0.42	0.35	0.19	0.33	0.31	0.22	0.13	0.08	0.27	0.21	0.28	0.10	0.24	0.24	0.19
ESP	–	–	–	–	0.31	0.53	0.62	0.68	0.55	0.45	0.47	0.38	0.29	0.28	0.23	0.45	0.25	0.29	0.44	0.31
NLD	–	–	–	–	–	0.24	0.28	0.08	0.27	0.30	0.29	0.41	0.52	0.18	0.18	0.29	0.08	0.21	0.30	1.00
AUT	–	–	–	–	–	–	0.35	0.23	0.31	0.34	0.31	0.09	0.08	0.23	0.26	0.37	0.13	0.37	0.23	0.24
GBR	–	–	–	–	–	–	–	0.22	0.52	0.60	0.51	0.06	0.07	0.26	0.24	0.42	0.16	0.23	0.58	0.28
SWE	–	–	–	–	–	–	–	–	0.27	0.22	0.21	0.09	0.05	0.16	0.11	0.55	0.15	0.30	0.12	0.08
CHE	–	–	–	–	–	–	–	–	–	0.58	0.55	0.10	0.06	0.14	0.20	0.44	0.10	0.34	0.53	0.27
Americas																				
USA	–	–	–	–	–	–	–	–	–	–	0.69	0.07	0.09	0.22	0.27	0.36	0.27	0.23	0.65	0.30
CAN	–	–	–	–	–	–	–	–	–	–	–	0.08	0.07	0.23	0.27	0.41	0.17	0.30	0.51	0.29
MEX	–	–	–	–	–	–	–	–	–	–	–	–	0.74	0.13	0.03	0.24	0.07	0.27	0.04	0.41
BRA	–	–	–	–	–	–	–	–	–	–	–	–	–	0.09	0.03	0.07	0.05	0.16	0.05	0.52
ARG	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.15	0.21	0.29	0.17	0.16	0.18
Asia																				
JPN	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.23	0.12	0.14	0.24	0.18
CHN	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.20	0.19	0.36	0.29
KOR	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.13	0.10	0.08
TUR	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.21	0.21
Other																				
AUS	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.30
SAF	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Avg. corr. to																				
All countries	0.41	0.39	0.28	0.45	0.30	0.30	0.36	0.23	0.35	0.37	0.35	0.18	0.17	0.20	0.19	0.33	0.15	0.25	0.32	0.30
Advanced economies	0.51	0.48	0.34	0.53	0.25	0.35	0.45	0.25	0.43	0.46	0.42	0.13	0.12	0.21	0.23	0.39	0.15	0.28	0.40	0.31
Emerging economies	0.24	0.23	0.18	0.32	0.38	0.21	0.21	0.20	0.21	0.22	0.22	0.31	0.27	0.18	0.12	0.20	0.14	0.19	0.18	0.28
Countries in own region	0.53	0.50	0.39	0.60	0.25	0.38	0.44	0.30	0.41	0.27	0.27	0.25	0.25	0.17	0.16	0.21	0.15	0.15	0.30	0.30

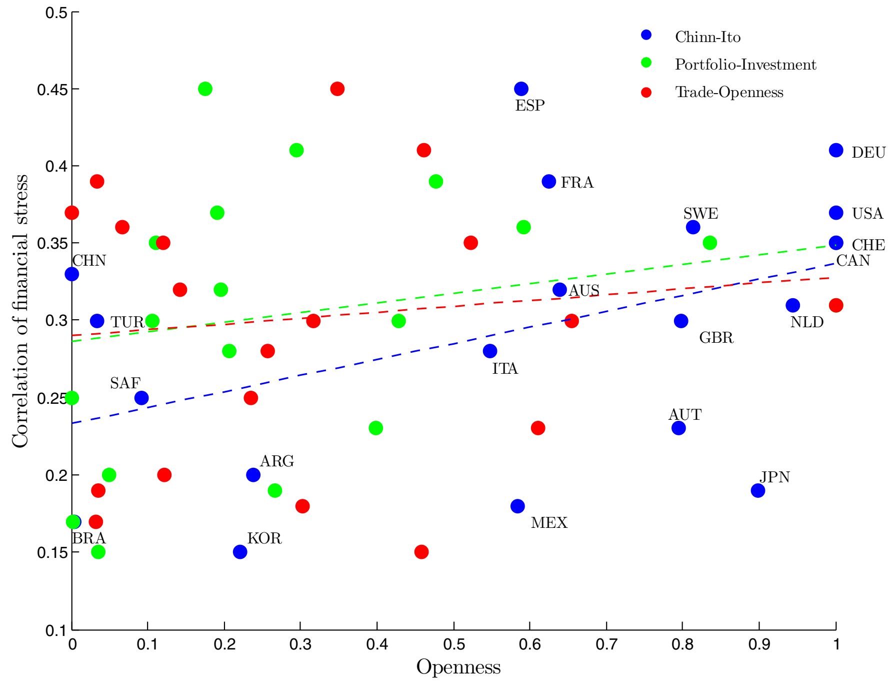

Fig. 3. Avg. correlation of financial stress and economic openness. Notes: The degree of financial stress spillovers for a country i is expressed as the average correlation of domestic financial stress with the other countries stress levels based on the standardized residuals from t-GARCH models as explained in Section 3.2, i.e. $(1/N-1)\sum_{j\neq i}\rho_{[1970M4;2012M12]}(FSI_i^{ad}, FSI_j^{ad})$. The three measures of economic openness have been standardized to values between 0 and 1 to facilitate the readability of the graph. Country codes are as follows: ARG: Argentina; AUS: Australia; AUT: Austria; BRA: Brazil; CAN: Canada; CHN: China; FRA: France; DEU: Germany; ITA: Italy; JPN: Japan; MEX: Mexico; NLD: Netherlands; SAF: South Africa; KOR: South Korea; ESP: Spain; SWD: Sweden; CHE: Switzerland; TUR: Turkey; GBR: United Kingdom; USA: United States.

correlation of financial stress with that of other countries (Fig. 3). While there is only a weak correlation for financial stress in countries that have a low degree of financial openness, the financially highly integrated countries exhibit a strong correlation.

Using the time variation as well helps identify the positive relationship between the degree of financial stress spillover and economic openness more clearly. To this end, we compute the averages of our variables for non-overlapping 3-year windows. We then estimate fixed-effects panel models by regressing the average financial stress correlation on the averages for the different measures of economic open-ness. The results confirm our findings that financial openness is an important determinant for the degree of spillovers of financial stress (Table 3). In particular, we find that there is a strongly significant positive relation between openness and the correlation of financial stress. Overall, the results are very robust. They do not depend on which of the methods we use to construct the FSIs. Likewise, they are quite robust across different measures of openness; the specifications with the contemporaneous portfolio investment measure are the only ones that do not yield strongly significant results. In general, the estimated effects are considerably stronger when we relate the correlation measures to the openness measures for the previous 3-year period.[11]

4. International transmission: evidence from a GVAR model

4.1. Estimation of GVAR models

To investigate the international transmission channels of financial stress, we use a GVAR model framework. In the following, we present a very brief sketch of the GVAR model and the appropriate estimation strategy. For a detailed description of the methodology, we refer to Smith and Galesi (2011). The GVAR model consists of VAR models for each individual country. These country-specific models are linked to one another via a weighting matrix, which can be based on any measure of bi-lateral interconnectedness (such as trade linkages or financial linkages).

For each country $i = 1, \ldots, N$ the VAR(p_i, q_i) model links a $k_i \times 1$ vector of domestic variables $x_{i,t}$ to a $k_i^* \times 1$ vector of foreign variables $x_{i,t}^*$; these foreign variables are assumed to be weakly exogenous in the country VAR model. In addition, we allow for a constant and deterministic trend in the VAR models:

$$x_{i,t} = a_{0i} + a_{1i}t + \Psi_{1i}x_{i,t-1} + \ldots + \Psi_{p_i i}x_{i,t-p_i} + \Lambda_{0i}x_{i,t}^* + \ldots + \Lambda_{q_i i}x_{i,t-q_i}^* + u_{i,t}, \quad (4)$$

where the $\Psi_{i,n}$ and $\Lambda_{i,n}$ are $k_i \times k_i$ and $k_i \times k_i^*$ coefficient matrices connected to the domestic and foreign variables respectively, a_{0i} is a $k_i \times 1$ vector of constant terms, a_{1i} is a $k_i \times 1$ vector of slope coefficients, and u_i, t is a $k_i \times 1$ vector of country-specific shocks that are assumed to be serially uncorrelated with mean zero and a constant covariance matrix Σ_i. The country-specific foreign variables are constructed as weighted averages across the domestic variables of all countries, i. e. $x_{i,t}^* = \sum_{i=1}^{N} w_{ij}x_{j,t}$, with $w_{ii} = 0$ and $\sum_{i=1}^{N} w_{ij} = 1$ for all $j = 1, \ldots, N$.

In a first step, these country-specific VAR models are transformed into an error correction form and separately estimated on a case-by-case basis, taking potential cointegration between $x_{i,t}$ and $x_{i,t}^*$ into account.

In a second step, all individual VAR models are grouped into the single GVAR model. This is solved globally, since – from a global perspective – all variables are endogenous. To this end, all

[11] We show the specifications with lagged openness measures to address potential concerns with respect to the endogeneity of the openness measures.

Table 3
Financial stress spillovers and openness – panel results.
Notes: Panel regressions are based on 3-years averages of all variables. Panel A, B and C of the table show results for different measures of economic openness (details in text) as explanatory variables in the panel models. Column headers refer to the version of the FSI that is used as dependent variable in the panel models (FAC: Factor model; EQV: Equal variance weighting; CDF: CDF weighting). All panel models include country fixed-effects. The size of coefficients is not comparable across panels as the measures of economic openness have not been standardized before the regressions.

	FAC	EQV	CDF	FAC	EQV	CDF
A: Chinn-Ito index						
Contemporaneous	0.132***	0.094***	0.071***	–	–	–
	8.2	5.7	4.9	–	–	–
Lagged	–	–	–	0.121***	0.091***	0.068***
	–	–	–	7.8	5.8	5.0
N	223	214	211	222	213	210
R^2	0.25	0.14	0.11	0.23	0.15	0.12
B: Portfolio investment						
Contemporaneous	0.430	0.142	0.790*	–	–	–
	0.7	0.8	1.9	–	–	–
Lagged	–	–	–	1.412***	2.029***	1.046***
	–	–	–	3.2	4.5	2.6
N	54	54	54	54	54	54
R^2	0.02	0.00	0.07	0.22	0.36	0.16
C: Trade openness						
Contemporaneous	1.115***	1.228***	1.020***	–	–	–
	6.8	6.5	7.3	–	–	–
Lagged	–	–	–	1.343***	1.436***	1.225***
	–	–	–	5.9	6.2	7.3
N	179	178	177	168	167	167
R^2	0.26	0.32	0.30	0.28	0.33	0.32

* denotes significance at a 10% level.
*** denotes significance at a 1% level.

country-specific vectors with endogenous variables are stacked into $x_t = [x_{1,t}', x_{2,t}', \ldots, x_{N,t}']'$. It can be shown that by stacking all equations of the country-specific VAR models the reduced-form GVAR model is obtained as

$$x_t = b_0 + b_1 t + F_1 x_{t-1} + \ldots + F_r x_{t-r} + \epsilon_t, \tag{5}$$

where b_0, $b1$ and $F_1, \ldots, F_r$ are vectors and matrices that depend on the coefficient estimates for the country-specific VAR models and the weights of the link matrix. There are no a-priory restrictions placed on the covariance matrix of the shocks, $\mathbb{E}_t(\epsilon_t \epsilon_{t'})$, and the GVAR model can basically be treated like an ordinary VAR model for most purposes.

4.2. *Empirical GVAR specification*

We implement the GVAR model, which we use to analyze the international transmission of financial stress, based on monthly data for the (log) industrial production, the (log) price level (CPI), the short-term policy rate[12], and the measures of financial stress that are presented above. In what follows, we present results obtained using the factor-model-based stress indicators.[13] We use a balanced sample covering the period between April 1991 and December 2012. We select the lag orders of the country-specific VAR models based on the Akaike information criterion but restrict the maximum lag order to $p_i = q_i = 2$ for all countries to ensure the stability of the GVAR.[14] We select the number of cointegrating relations based on Johansen's trace statistic as proposed in Pesaran et al. (2000). To link the country-specific VAR models to one another, we use fixed weights based on the Consolidated Banking Statistic provided by the Bank for International Settlements.[15] We base these weights on the time averages of foreign claims of the domestic banking system.[16]

4.3. *Identifying meaningful shocks*

Identifying meaningful shocks in a model as large as our GVAR model ($20 \times 4 = 80$ endogenous variables) is a formidable undertaking due to the large number of additional restrictions that would be necessary to fully identify a structural GVAR model behind the estimated reduced-form version. Fortunately, we are not interested in identifying all structural shocks of the model, preferring to analyze the response of the model's variables to a small number of selected, meaningful shocks. We chose these shocks to shed light on i) the international transmission of financial stress, ii) the business-cycle effects of an exogenous increase in financial stress, and iii) the sensitivity of financial stress to business-cycle shocks. In particular, we will analyze the response of the modeled variables to

- a financial stress shock in the US;
- a (negative) demand shock in the US;
- and a global financial stress shock.

We make use of two different approaches to analyze the effects of these shocks, which differ in the degree of structure they are able to impose on the model.

12 The policy rate is transformed as $0.25 \times \ln(1 + R_t/100)$ to deal with the very high interest rate levels in some of the emerging economies in our sample during the early part of the period studied.
13 The majority of results are qualitatively unchanged when working with the alternative stress indicators. The results are available upon request.
14 For a cointegrated GVAR, the roots of the determinantal equation of the companion matrix of the model should lie inside or on the unit circle. Apparently, it is a common feature that GVAR models with a richer lag structure exhibit explosive behavior and are not well suited for dynamical analysis.
15 The results are broadly robust with respect to switching to fixed or time-varying trade weights. The results are available upon request.
16 More formally, w_{ij} is a function of the claims of the banking sector in country i against debtors from country j. We use data on an ultimate risk basis whenever available and data on an immediate borrower basis for Brazil, Mexico, and South Korea. Due to a lack of data in our primary source, we use data on international total portfolio investment from the Coordinated Portfolio Investment Survey published by the IMF for Argentina and South Africa and conventional trade weights for China.

First, Smith and Galesi (2011) suggest looking at so-called structural generalized impulse response functions (SGIRFs) when the shock of interest is a country-specific shock. The idea is to identify k_i structural shocks for one particular country i by imposing identification conditions based on Sims (1980) triangular approach on the matrix, which relates the k_i innovations of the reduced-form VAR model to the k_i structural (orthogonal) shocks.[17] We use this approach to identify the financial stress shock and the demand shock in the US. To this end, we place the US as the first country in our GVAR and order the four domestic variables in such a way that i) a US financial stress shock contemporaneously affects only financial stress and no other US variable and ii) the US demand shock can affect all four variables on impact.[18] The SGIRFs yield the response of all variables of the GVAR model to the set of structurally identified shocks.

Second, it is less clear which additional restrictions we could impose to identify (global) shocks in a GVAR model that involve restrictions on equations from more than one country.[19] Therefore, we use generalized impulse response functions (GIRFs; Pesaran and Shin, 1998) to analyze the model dynamics following the manifestation of a (not properly identified) global financial stress shock. Although not intellectually satisfying, this conservative approach is preferable, in our view, to a "shaky" or controversial structural identification scheme.[20] To define the shock, we follow Smith and Galesi (2011) and construct an impulse vector with non-zero entries only at positions that correspond to the positions of the financial stress indices in our GVAR model. These entries are based on the sum of claims that all banking systems (of those countries in our sample for which we have data from the Bank for International Settlements) hold against each particular country and have been normalized to sum to one.[21]

4.4. Results

4.4.1. A shock to financial stress in the US

To investigate how financial stress is internationally transmitted when the original shock is limited to a single country, we plot the SGIRFs of financial stress and industrial production corresponding to a financial stress shock in the US in Fig. 4.[22]

The transmission of financial stress from the US to financial systems in other countries is unambiguous in all cases: an exogenous increase of financial stress in the US leads to a persistent increase of financial stress in all other countries, albeit not significantly so in South Korea. The increase in financial stress outside the US is (with the exception of Australia, Canada, and the Netherlands) much smaller than the increase of the FSI in the US. On average, the maximum increase is less than half the size of the initial shock to financial stress in the US. The GIRFs for financial stress show a hump-shaped response, indicating that the transmission takes some time. On average, the largest impact on financial stress in other countries is reached after approximately 6 months. The median responses are quite persistent, although they become insignificantly different from zero after approximately one year (judged by the 90-percent confidence bands). The fact that the financial stress in virtually all countries of our sample is significantly affected by a financial stress shock in the US shows the dominant position of the US financial sector in the global financial system.[23]

In addition to these financial spillovers, we also find significant and persistent global business-cycle effects of a financial stress shock in the US. Industrial production persistently declines in all countries. This finding is similar to the results of Bloom (2009), who finds for the US that uncertainty shocks have significant effects on industrial production. Surprisingly, the output losses are as high as those in the US in many cases despite the more limited effect on financial stress in other countries (as we have shown).[24] This indicates that a considerable part of the adverse effect on economic activity is not directly transmitted via financial markets and is instead indirectly transmitted via a fall in foreign demand.[25] Industrial production reacts sluggishly in many countries; the maximum effect is often reached after approximately 6 months.

4.4.2. A (negative) demand shock in the US

Fig. 5 shows how industrial production and financial stress respond to a negative demand shock in the US. In the US, a fair amount of financial stress is triggered by a slowdown in economic activity, which only fades slowly. The rise of financial stress in other countries is much smaller on average. The level of financial stress is significantly elevated only temporarily in most countries. This indicates that a demand shock of modest size triggers financial instability only in the short-run. Surprisingly, the stress levels in Mexico and China – two major trading partners of the US – are not significantly affected following the shock to economic activity in the US. This indicates that in the aftermath of real economic shocks, financial linkages seem to be more important than trade linkages for the transmission of financial stress.

4.4.3. A global shock to financial stress

Fig. 6 shows the dynamic responses of the level of financial stress and industrial production to a standardized global shock to financial stress. By definition, financial stress increases upon impact in all countries. In most countries, the stress level decreases only slowly after the initial shock. This persistent response of FSIs suggests that financial markets need time to calm down after the occurrence of global financial turmoil.[26]

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[17] If this particular country is ordered first in the GVAR and there are no short-run over-identifying restrictions imposed on the GVAR coefficients, then the ordering of the remaining variables in the GVAR does not affect the dynamics of the SGIRFs. For technical details of this identification approach, we refer the reader to Smith and Galesi (2011, p. 101).

[18] The other two structural shocks could be labeled as a monetary policy shock and a cost-push shock.

[19] Cashin et al. (2012) use the method of sign-restrictions (Uhlig, 2005) to identify global oil demand and supply shocks by making use of the distinction between oil-exporting countries and oil-importing countries. It is not clear, however, which global sign-restrictions we could impose to distinguish a structural shock to global financial stress from other structural shocks.

[20] In addition, comparing the SGIRFs and GIRFs following a financial stress shock in the US did not reveal major differences for the reaction of both the US variables and variables for other countries. Thus, we believe that the GIRFs for a global financial stress shock are a reasonable approximation of the model's response to a truly structural global financial stress shock.

[21] Thus, contrary to our approach for the construction of bilateral weights for the GVAR model, we now measure the relative size of total financial exposure that any country of our sample generates on a global scale. Again, the results do not change qualitatively if we use an impact vector based on PPP-weighted GDP data.

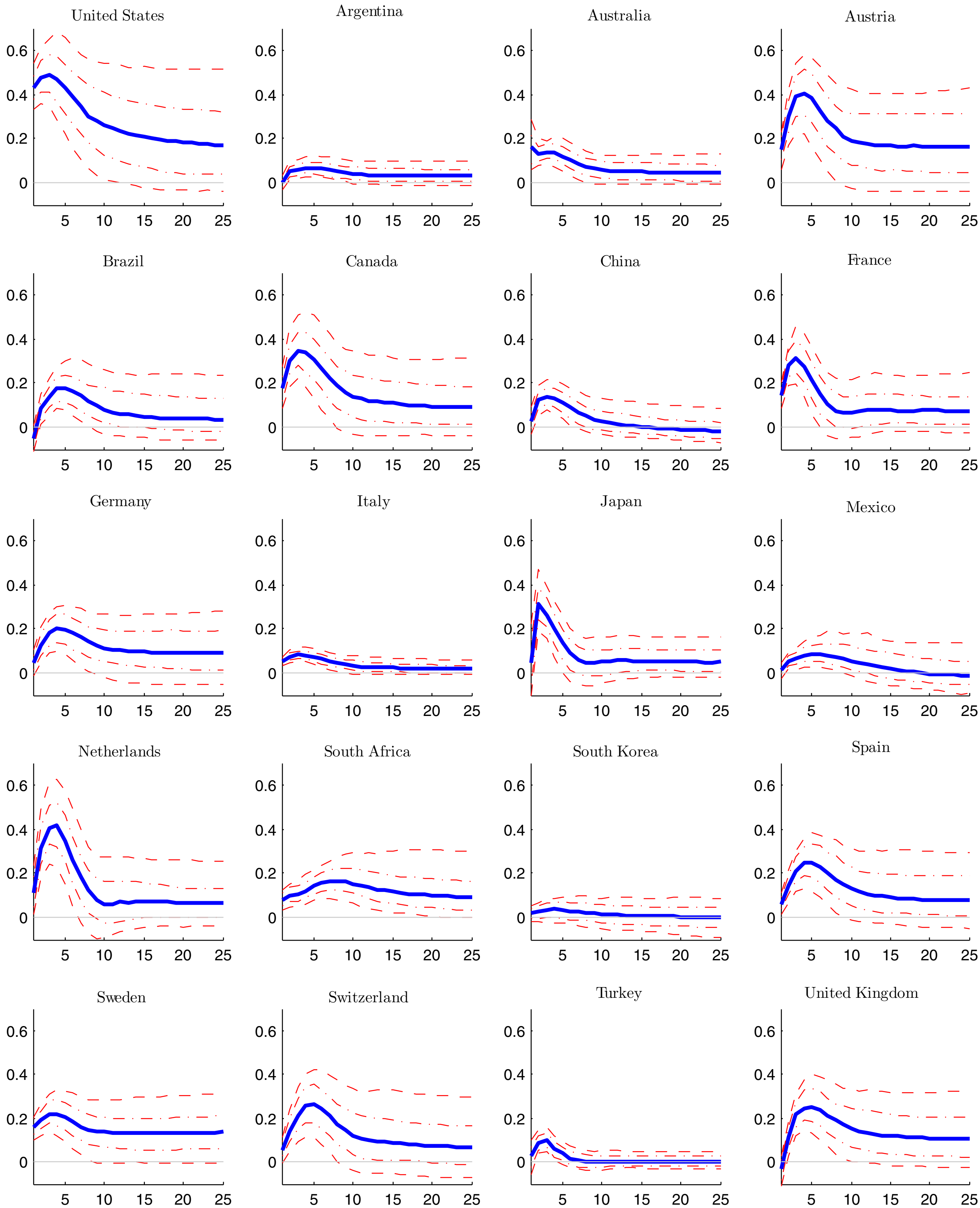
[22] This has arguably been the plot of the financial crisis of 2007–2009 which had its origins in the turmoils on the financial markets in the US (following the burst of the US housing bubble) and spread to all major economies. Results for an estimation of the model prior to the crisis yield significantly small effects of financial stress shocks. Results are available upon request.

[23] The importance of the US for a propagator of shocks for almost all other countries has been shown by Georgiadis (2014). In particular, he shows that there are very strong spillover effects from US monetary policy shocks on economic activity in other countries.

[24] In fact, this finding is consistent with the analyses of Eickmeier and Ng (2011) and Helbling et al. (2011). They find that credit supply shocks in the US exhibit effects that are approximately as large as those on the US itself.

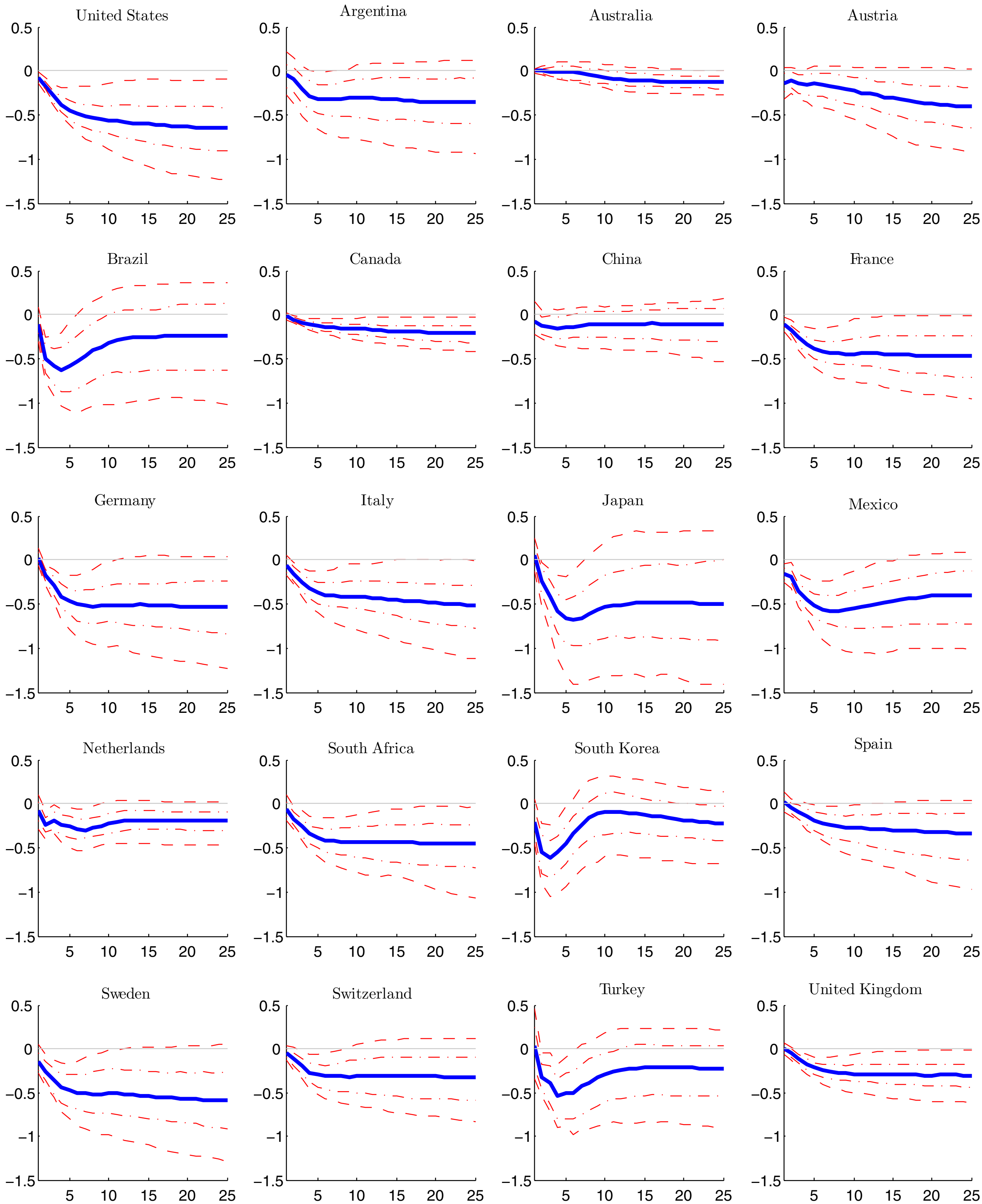
[25] Another potential explanation is that a large share of financial services in many countries is imported from the US, such that we observe the adverse effects of financial stress without actually seeing signs of domestic financial stress.

[26] This result supports the findings in Borio (2012) and Drehmann et al. (2012) who show that financial cycles are very persistent.



(a) Financial Stress

Fig. 4. SGIRFs for a financial stress shock in the US. Notes: The blue lines represent the median impulse responses, the dashed-dotted red lines represent 66-percent bias-corrected bootstrap error bands and the dashed red lines represent analogous 90-percent bands. All statistics are based on 200 bootstrap iterations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)



(b) Industrial Production

Fig. 4. *Continued.*

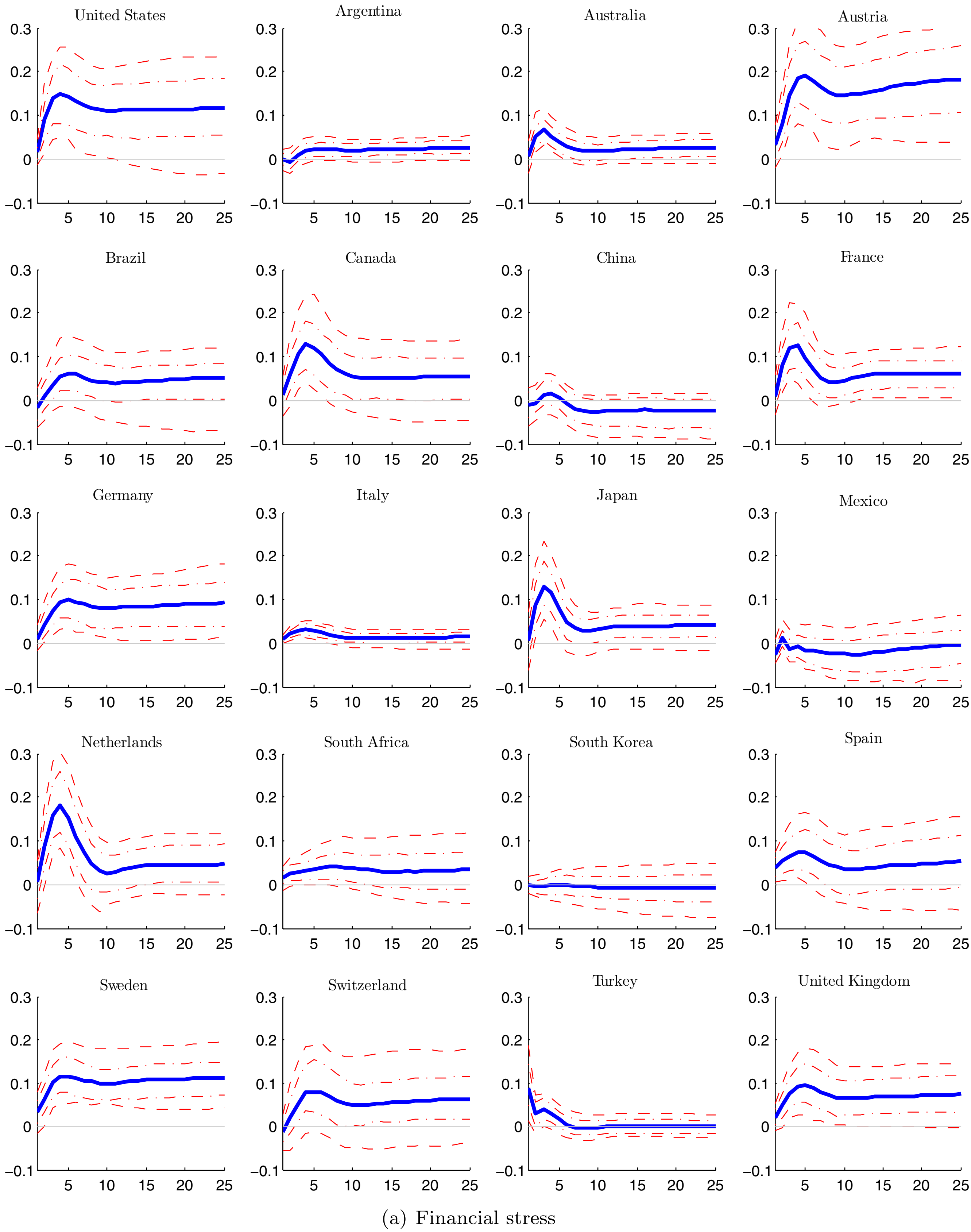
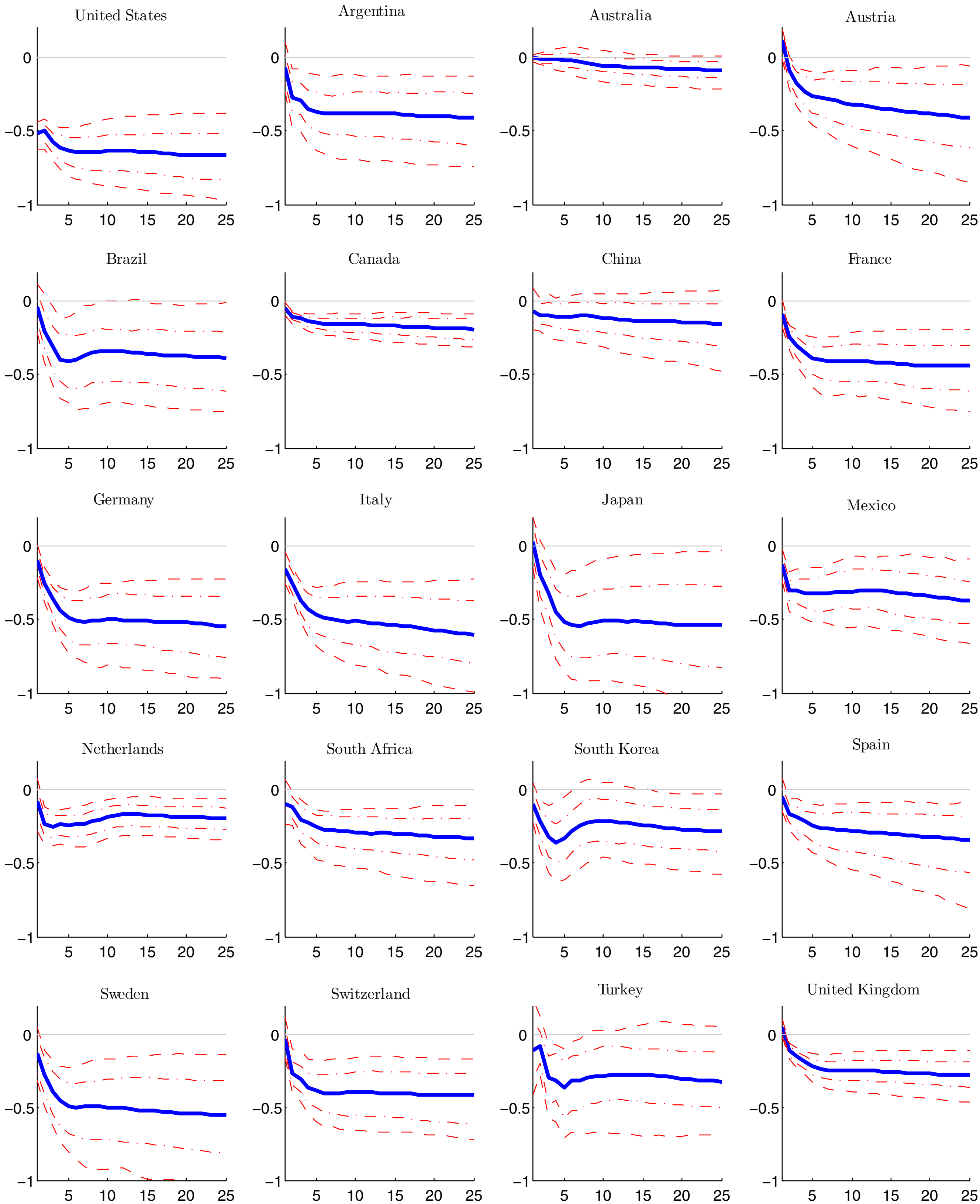
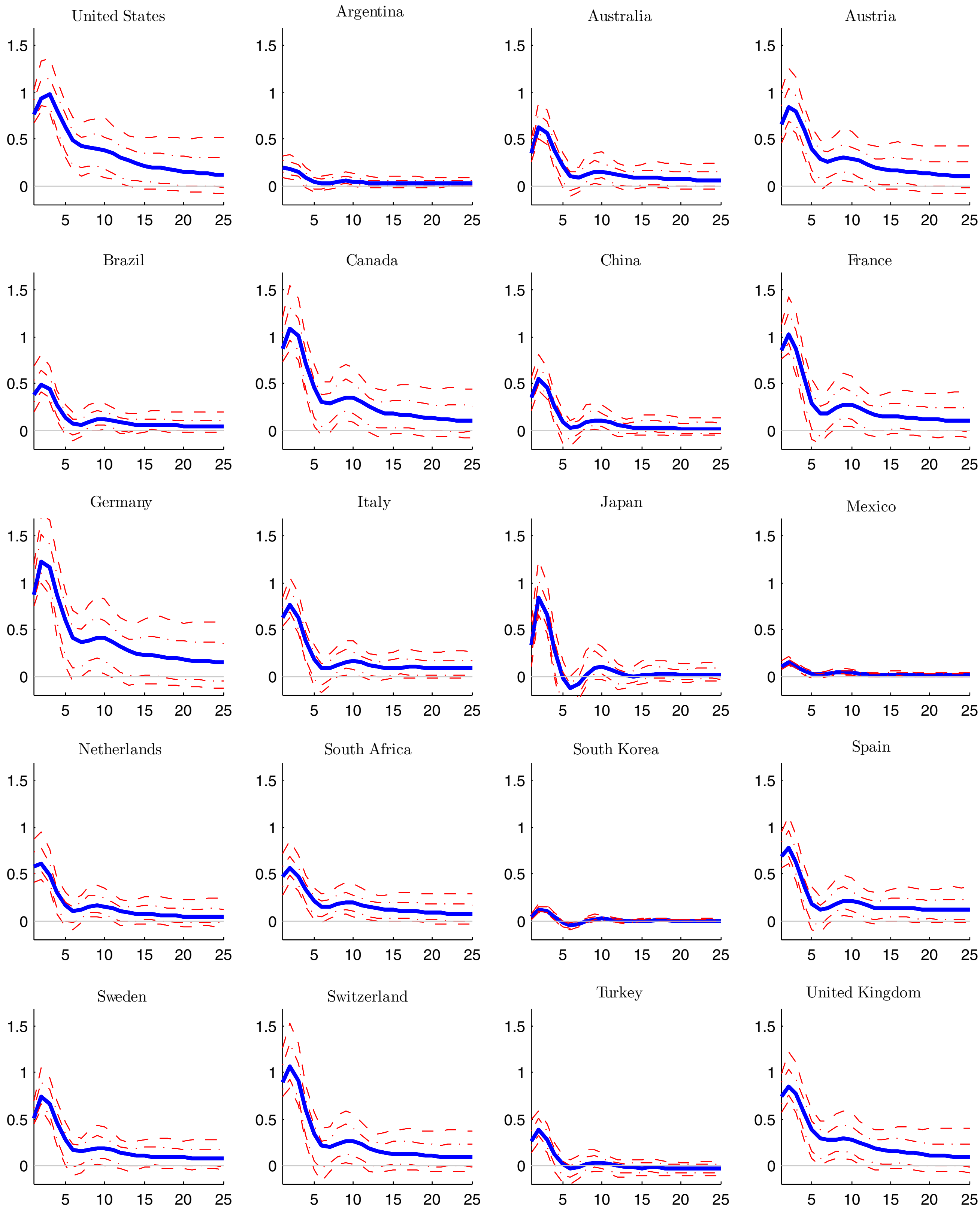


Fig. 5. SGIRFs for a (negative) demand shock in the US. Notes: The blue lines represent the median impulse responses, the dashed-dotted red lines represent 66-percent bias-corrected bootstrap error bands and the dashed red lines represent analogous 90-percent bands. All statistics are based on 200 bootstrap iterations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)



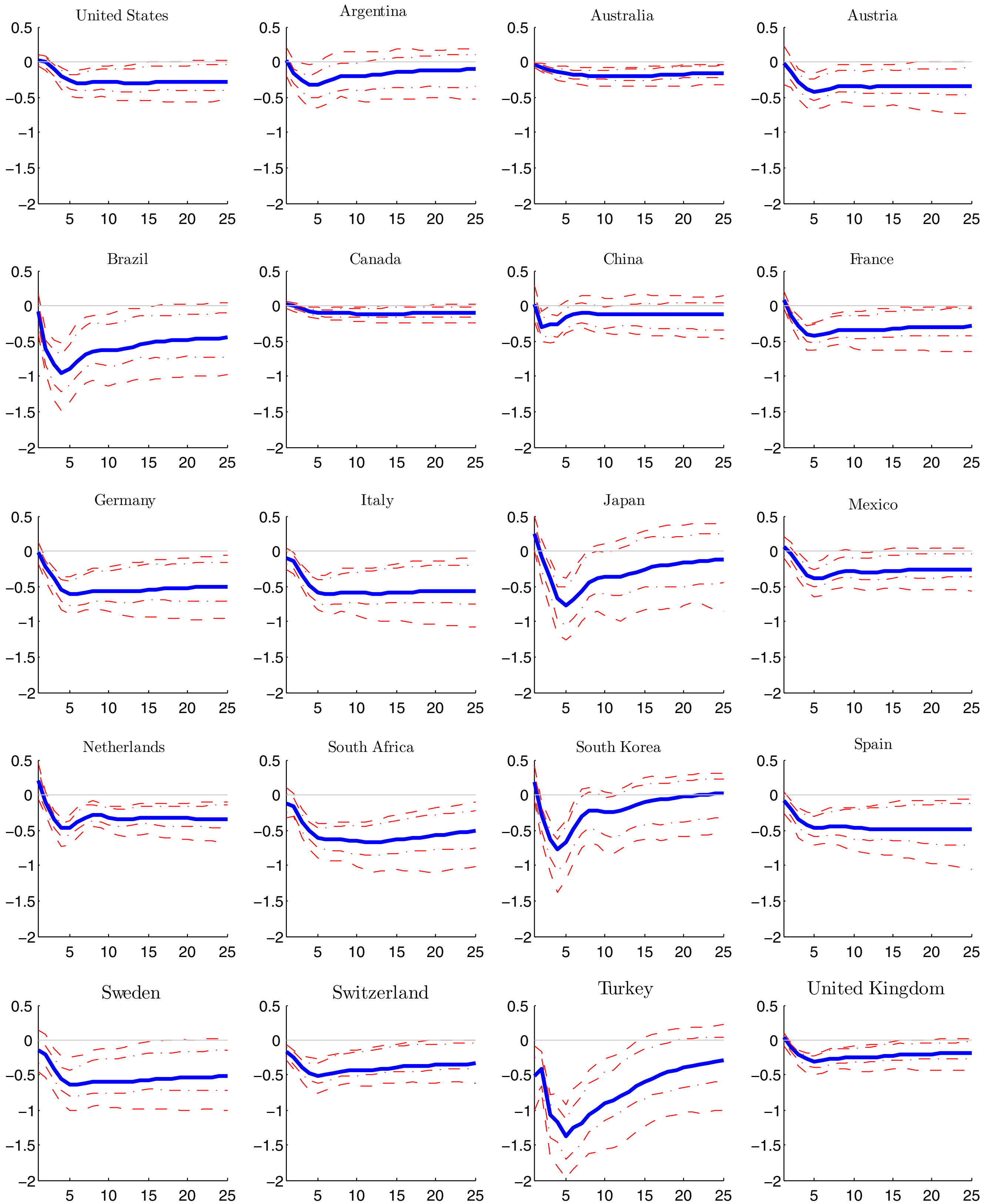
(b) Industrial production

Fig. 5. *Continued.*



(a) Financial stress

Fig. 6. GIRFs for a global shock to financial stress. Notes: The blue lines represent the median impulse responses, the dashed-dotted red lines represent 66-percent bias-corrected bootstrap error bands and the dashed red lines represent analogous 90-percent bands. All statistics are based on 200 bootstrap iterations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)



(b) Industrial production

Fig. 6. *Continued.*

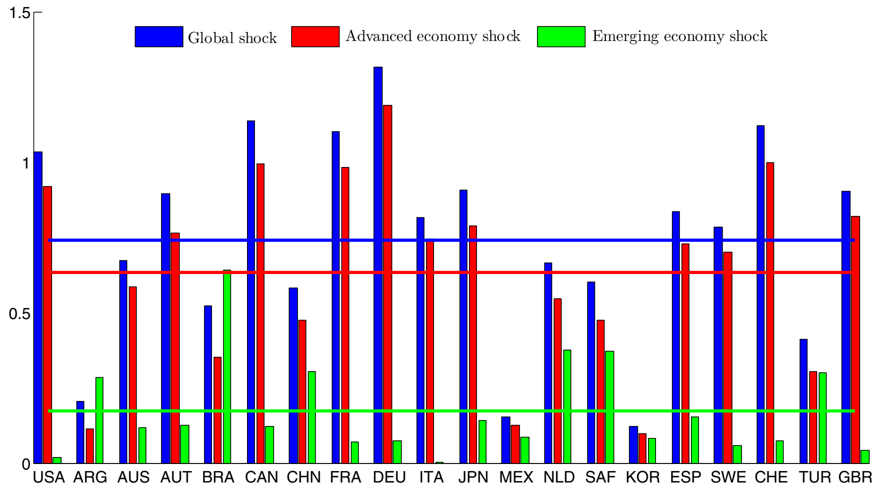


Fig. 7. Maximum impact of different financial stress shocks. Notes: The different bars show the maximum increase of each country's FSI following the three different shocks. Country codes are as follows: ARG: Argentina; AUS: Australia; AUT: Austria; BRA: Brazil; CAN: Canada; CHN: China; FRA: France; DEU: Germany; ITA: Italy; JPN: Japan; MEX: Mexico; NLD: Netherlands; SAF: South Africa; KOR: South Korea; ESP: Spain; SWD: Sweden; CHE: Switzerland; TUR: Turkey; GBR: United Kingdom; USA: United States.

Industrial production is negatively affected in all countries. In most cases, the maximum impact is reached with a lag of approximately 6 months. This indicates that the pass-through of financial stress on real economic activity takes some time.[27] The countries that are least affected in terms of production losses are Argentina, Australia, Canada, and China. The strongest effects are found for a number of emerging economies, notably Brazil, South Korea, and Turkey. This is surprising, given that these countries are not very strongly affected in terms of the size of the increases of their FSIs. Thus, these economies seem to suffer from indirect demand effects that spill over through second- and third-round effects from other economies.

Balakrishnan et al. (2009) present evidence based on a simple Granger causality test that financial stress in advanced economies has an impact on financial stress in emerging economies but not vice versa. Our framework is suited to re-assessing this question while taking macro-financial transmission channels and feedback loops into account. To address the issue, we simulate analogous shocks to the global financial stress shock by restricting the shock impulse to either only advanced economies or only emerging economies. Fig. 7 summarizes the results. It can be observed that even for most emerging economies, the maximum increase in financial stress is higher following a shock to the financial stress originating in the group of advanced economies compared to the reaction following a shock to FSIs in emerging economies. On average, the maximum impact of the shock to financial markets in advanced economies is nearly as large as the corresponding increase following the global financial stress shock.

5. Conclusion

This paper analyzes the international transmission of financial stress and its effects on economic activity for 20 major economies. We construct country-specific financial stress indicators (FSIs) which are based on a set of variables from different financial market segments to approximate the unobservable degree of systemic financial instability.

In the first part of the paper we show that the average co-movement of financial stress across countries displays an upward trend over the past two decades. Furthermore, we show that cross-country spillovers of financial stress tend to be particularly high during times of major financial turmoils. Finally, we show that the risk of large financial stress spillovers to a country is higher when this particular country exhibits a high degree of economic (financial and/or trade) openness.

In the second part of the paper we use a GVAR model to analyze the dynamics of the international transmission of financial stress and the propagation of financial stress to real economic activity. We show that shocks to financial stress in the US as well as to the global level of financial stress significantly reduce economic activity on a global scale. The negative effects are persistent and the maximum impact is reached after about 6 months in most countries. Furthermore, we show that an unexpected increase of financial stress in the US rapidly transmits to other countries. A slowdown in economic activity leads to a temporary but moderate increase of financial stress in most countries.

All in all, our results indicate that financial stress should be a major concern when analyzing international business cycles. Since the global transmission of financial stress is non-negligible and rapid, it is crucial to consider the global dimension of financial stress even from the perspective of a national policy maker. For financial investors our results indicate that diversification is especially hard to achieve during times of global financial stress when investors likely value it most (e.g., Bartram and Bodnar, 2009).

A number of caveats call for an careful interpretation of our results. First, the identification of meaningful shocks in GVAR models is a formidable exercise and hard to achieve with certainty.[28] Second, we base our FSIs on only 6 indicators because we want to estimate FSIs that are comparable across countries.[29] Finally, we have to mention the possibility that our measure of financial stress reacts in a forward-looking manner to future real economic shocks. Therefore, what we measure as an exogenous shift of the stress

[27] This is in line with single-country studies on the effects of financial stress on economic activity, such as Hubrich and Tetlow (2012), Holló et al. (2012), and van Roye (2014).

[28] The results presented for the global shock to financial stress, for instance, should be interpreted as the model's dynamics following a set of structural shocks that lead to an increase of all FSIs on impact.

[29] Given how well these FSIs track historic episodes of crisis, however, we are confident that they constitute a good approximation for financial stress.

level could potentially be just a reflection of some other future shocks.[30]

Against this background, we can imagine the following issues for future research. First, one could use a GVAR that includes more variables for each country. As Balakrishnan et al. (2009) and Georgiadis (2014) show, several country characteristics influence the degree of vulnerability to foreign shocks. Estimating richer GVAR models could help to capture these facts. Second, Markov-switching GVAR models (e.g., Binder and Gross, 2013) could be used to model the observed state-dependencies of the transmission effects.

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[30] If one believes in this view, the measured "effect" from financial stress on real economic activity should merely be interpreted in terms of predictive power rather than in a causal way.