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by Jonas Dovern and Björn van Roye

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Keywords: Financial stress, Financial crises, Business cycles, Dynamic Factor Model, Global VAR.

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International transmission of financial stress: evidence from a GVAR

Jonas Dovern* and Björn van Roye†

Kiel Economics and the Kiel Institute for the World Economy

June 19, 2013

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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, also financial markets in the emerging economies were negatively affected. In nearly all countries, stock markets plummeted, bank stocks came under pressure due to systemic risk, and volatilities on stock markets and foreign exchange markets increased significantly.

While there is a vast growing literature of analyzing the role of financial conditions and financial stress during these events, relatively little research has been undertaken to investigate the global perspective of financial stress. This paper tries to contribute of closing this gap, by taking a global perspective of financial stress and its spillover effects between countries. We investigate the international transmission channels of financial stress by analyzing how financial stress events propagate to the economy in various countries. In order to shed light on these international macro-financial linkages, we construct financial stress indexes (FSI) for 20 countries and investigate the relationship to main macroeconomic variables. Using the FSI, we employ a Global VAR model, originally developed by Pesaran et al. (2004), and investigate the propagation of financial stress shocks. We find that financial stress quickly spreads internationally and has a lagged but persistent negative effect on industrial production. Likewise, a shock to financial stress that is solely originated in the United States quickly to financial markets in other countries and also incurs a lagged but persistent economic contraction. These findings are in line with other studies that investigate the impact of international housing shocks and find persistent effects on real economic activity after housing and financial crises (Jannsen (2010), Cesa-Bianchi (2012) and Claessens et al. (2012)).

Measuring financial stress has become more and more prominent in recent years. Central banks and international organizations, private banks and economic research institutes have constructed financial stress indexes to assess the state of financial stability and to identify potential systemic risk at an early stage. Among the first, Illing and Liu (2006) constructed a financial stress index for Canada for providing a "snapshot" of the current degree of stress in the financial system. Hakkio and Keeton (2009) and Kliesen and Smith (2010) constructed financial stress indexes for the United States, which are regularly referred to by the Federal Reserve.[1] The European Central Bank periodically publishes a Composite Indicator for Systemic Stress (CISS) as a tool for its macro-prudential monitoring.[2] The CISS consists of variables from the money, equity, bond, and foreign exchange market and summarizes the market specific sub-indexes in one composite index for the euro area. Also for other countries financial stress indexes were established as a thermometer of the financial system.[3]

In addition to a simple measure of financial stability, also the role of financial stress for economic dynamics has gained center stage in recent years. Several studies find that financial stress reduces economic activity significantly. Most of these studies investigate the effects of financial stress on economic activity in the United States. While Hakkio and Keeton (2009) show that increases in financial stress lead to persistent business cycle downturns when the financial system is under stress, Hubrich and Tetlow (2012) support their results, employing a Markov-Switching Bayesian Vector Autoregressive (MSBVAR) model. They show that financial stress events leads to a strong economic contraction and that conventional monetary policy is only little effective in this regime. Mittnik and Semmler (2013) employ a multi-regime vector autoregression (MRVAR) approach, to capture the regime-dependency and size-dependency of financial stress shock. By employing the financial stress index constructed by the IMF, they find that large negative shocks to financial stress have sizable positive effects on real activity and support the idea of unconventional monetary policy measures in cases of extreme financial stress.

Beyond the studies for the United States, the relationship between financial stress and economic activity has been investigated also for other countries. Aboura and van Roye (2013) develop a financial stress index for France, con-

[1] The indexes can be downloaded on the Federal Reserve's webpages: KCFSI and STLFSI.

[2] The CISS was constructed by Holló et al. (2012) and is published on the website of the European Central Bank as a macroprudential risk indicator of the European Stability and Risk Board: CISS.

[3] Cardarelli et al. (2011) develop FSIs for a variety of countries which were also used for analysis of the IMF World Economic Outlook. van Roye (2013) and Aboura and van Roye (2013) constructed a FSI for Germany and for France using a very broad selection of financial variables over a long time horizon.

sisting of 17 financial variables, and analyze the impact of financial stress on economic activity. They find evidence for a two-regime economy; i.e. a high stress regime when financial stress has a negative effect on economic activity and a low stress regime when financial stress does not incur any significant effect on the business cycle. An alternative approach to model these regime dependencies, is developed by van Roye (2013). Using a threshold VAR model, he estimates a threshold above which financial stress significantly impacts on economic activity in Germany. Cevik et al. (2012) analyze the relationship between financial stress on economic activity in transition countries. They use a linear bivariate VAR to show that financial stress dampens industrial production in these countries.

While there is a there is a vast literature on country-specific analysis, the international transmission of financial stress has been only analyzed scarcely. Balakrishnan et al. (2009) were the first who analyzed the transmission of financial stress between countries. They use a common time-varying component in the FSI for emerging markets and its relationship to the FSI in advanced economies and other global factors. Furthermore, they employ a two stage econometric analysis of monthly financial stress co-movement using a country-by-country approach and an annual panel data analysis of determinants of financial stress. They find that financial stress spreads quickly from advanced economies to emerging markets with a high pass-through.

This paper contributes to the literature in several dimensions. First, we construct a comprehensive measure of financial stress for 20 countries that is available in real time. Second, we show that the correlation of financial stress across countries is particularly high during major financial crises (such as global stock market turmoils and currency crises). Third, we show that countries that are financially open exhibit stronger correlation of financial stress to other countries than do countries that have relatively higher restrictions on financial openness. Finally, we show how financial stress propagates internationally and how it impacts the business cycles of the sample countries.

The paper is organized as follows. Section 2 characterizes the conceptual methodology that is used to construct the financial stress indexes, shortly describes the data and the estimation technique, and finally presents the financial stress indexes for all countries. We identify important country-specific and global financial stress events and analyze how financial stress is correlated between countries. Section 3 describes the GVAR model and investigates how financial stress is transmitted internationally and how it dampens economic activity. Section 4 briefly concludes.

2 Measuring financial stress: Constructing financial stress indexes

Financial stress is unobservable but presumably reflected in many financial variables. As Illing and Liu (2006) point out, financial stress may be defined as the force exerted on economic agents by uncertainty and changing expectations of a loss in financial markets and its institutions behind. Given this definition, we primarily focus on measures of uncertainty on financial markets. In particular, we include a measures for aggregate stock market volatility as an indicator for aggregate market uncertainty, the volatility of bank equities as an indicator of uncertainty in the banking sector (a proxy of systemic risk), and foreign exchange rate volatility that indicates pressures on foreign exchange markets. To capture all these features, we construct single composite indexes containing a broad measure of potential misalignments on these markets. In particular, we use a dynamic approximate factor model and interpret the single factor as the measure of financial stress.

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 (2012) and van Roye (2013). In particular, we set up a model that has the following form:

$$y_t = \Lambda f_t + \varepsilon_t, \qquad \text{where} \;\; \varepsilon_t \;\sim\; iid\, \mathcal{N}(0, C) \tag{1}$$

where y_t is a vector of stationary and standardized endogenous financial variables, f_t is a single common latent factor, and Λ is a $n \times 1$ vector of the time series' factor loadings. The values in the factor loading vector represent the extent to which each financial variable time series is affected by the common factor. The financial stress index is then given by $FSI_t = f_t$. The $n \times 1$ vector ε_t represents the idiosyncratic component which is allowed to be slightly correlated both serially at all leads and lags and cross-sectionally.[4] The idiosyncratic errors are assumed

[4]The weak correlation of the idiosyncratic component (all eigenvalues of $\mathbb{E}(\varepsilon_t \varepsilon_t') = \Sigma$ are bounded) makes the factor model "approximate"; see Breitung and Eickmeier (2006).

to be normally distributed with zero mean and the diagonal variance-covariance matrix C. The advantage of the dynamic approximate factor model is that it ensures that the idiosyncratic component is not too restrictive in the case of large cross-sections (Stock and Watson (2002)). The dynamics of the latent factor f_t are described in the transition equation, i.e.:

$$f_t = Af_{t-1} + \xi_t, \qquad \text{where } \xi_t \sim iid\,\mathcal{N}(0, D) \tag{2}$$

where A is the matrix of autoregressive coefficients, capturing the development of the latent factor f_t. Since we aim to estimate the model over a longer time horizon and for many countries the data availability is limited, we choose an estimation methodology that can appropriately deal with missing data. In particular, we estimate the model using a combined maximum likelihood and Expectation Maximization (EM) algorithm approach. Originally proposed by Dempster et al. (1977) this method serves as a general solution for models where the likelihood is hardly tractable because of incomplete or hidden data. Compared to non-parametric methods based on principal components, the methodology we use has the advantage that we can deal with an arbitrary pattern of missing data and it is more efficient for small samples (Banbura and Modugno (2012)).

2.2 Data

In order to compute the FSIs, we use 5 indicators for each country. These indicators can individually be interpreted as a measure for financial stress in a specific sector and are well established in the literature when analyzing financial stress (Illing and Liu (2006), Holló et al. (2012), Cardarelli et al. (2011), Misina and Tkacz (2009), and Duca and Peltonen (2011). In particular, we focus on financial stress in the banking sector, on bond markets, and on foreign exchange markets. We illustrate a brief overview of the employed indicators in table 1.

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 bank equity monthly returns, we construct a historical volatility measure by estimating a GARCH(1,1) model. For aggregate financial market uncertainty, we use a GARCH(1,1) model of the countries' main stock market returns. In addition, we take the inverse of the three month moving-average stock market returns as an indicator for financial market losses. To express financial stress on government bond markets, we construct a volatility measure using a GARCH(1,1) model of a government bond index returns that are provided by Thomson Reuters Professional Datastream.[5] Finally, we calculate a monthly volatility index for the real effective exchange rate to map financial stress on foreign exchange markets. To do this, we use a GARCH(1,1) model of the real effective exchange rate returns.

Table 1: *Indicators, construction method and market segment*

Indicator	Construction method	Market segment
Stock market volatility	GARCH(1,1) model of month-to-month stock market returns	Stock market
Exchange rate volatility	GARCH(1,1) model of month-to-month real effective exchange rate returns	Foreign exchange 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 month-to-month government bond yields	Bond market
Banking sector volatility	GARCH(1,1) model of month-to-month returns on bank equity	Stock market

[5] An alternative measure to express stress on government bond markets would be to take government bond spreads vis-à-vis a risk-free benchmark bond. However, since government bond yields are not directly comparable between countries and it is difficult to identify a risk-free government bond currently, we rather chose this volatility index.

2.3 The financial stress indexes

In figure 1 the financial stress indexes for all considered countries are illustrated. In addition, we report an external financial stress index that is calculated by taking a trade-weighted average of financial stress in all other countries. Some major episodes, during which the financial system was under strain, become immediately evident when considering the FSI for each country.

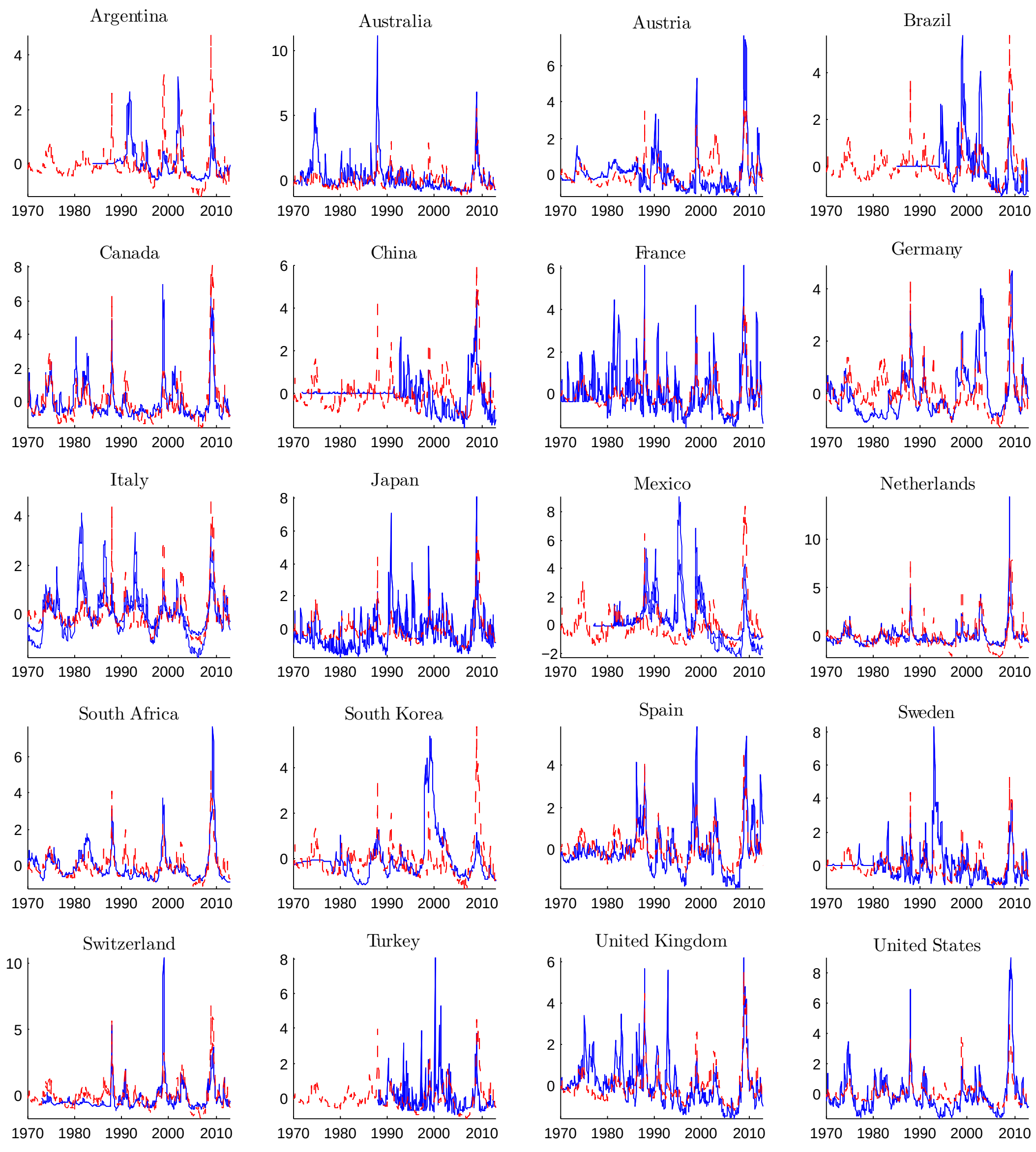
Depending on the country, the amplitude during these events significantly differ. The first episode of high financial stress in our data sample occurs during the oil crisis in 1973/1974. During this crisis financial stress increased especially in the advanced economies, which were primarily dependent on oil.

The second period of high financial stress occurred during the increasingly restrictive monetary policy of the Federal Reserve during the years 1980-1982. This financial stress event was primarily triggered by a restrictive monetary stance in the United States, accompanied by steep cuts in government spending under the Reagan administration. Although many countries dropped into a recession, the magnitude of financial stress remained rather limited, especially in the United States.

The next remarkable peak of financial stress was due to the stock market crash in 1987. On Monday, 19 October 1987 stock markets all over the world plummeted. The Dow Jones dropped by about 23 percent in one day. Until the end of October, the stock market index of Canada decreased by more than 20 percent, of Australia by more than 40 percent, and of Hong Kong by even more than 45 percent.

Compared to these large amplitudes during the 1987 stock market crash, the collapse of the Soviet Union had a very tiny impact on financial stress. Similarly, the crisis of the European exchange rate mechanism (ERM) in 1992-1993 had only a very regional effect. In particular, only European countries, such as the United Kingdom, Italy, France and Spain were directly exposed to the sharp corrections of their currencies with respect to the Deutschmark. On a global scale, the ERM crisis had almost no effect on financial markets. This becomes

Figure 1: *Financial stress indexes*



Notes: Blue solid line: Domestic financial stress index; red dashed-dotted line: external (trade-weighted) financial stress index; the FSI consist of respectively 5 different variables that represent financial stress. The FSI are constructed using a dynamic approximate factor model.

evident when considering the FSI for the United States, Canada, Australia or China. The Tequila crisis in Mexico 1995 and the Argentinean crisis in 2002 are a good examples for a domestic crises, which had a large impact on the Mexico and Argentina but had no major repercussions on other countries.

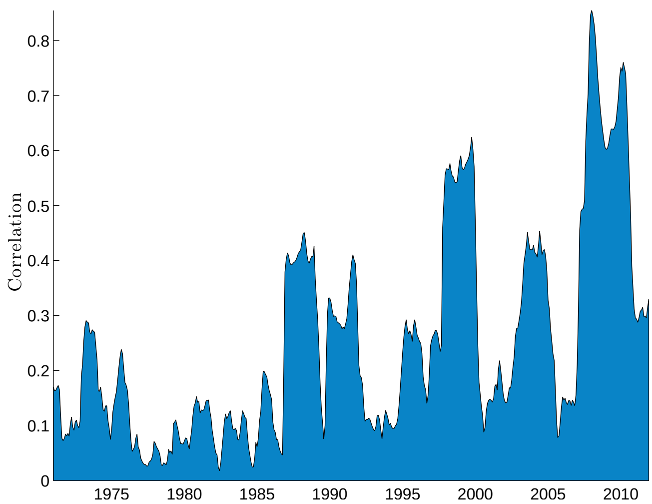
The next global financial stress event was the outbreak of the Asian and Russian crisis and the associated default of the large hedge fund Long Term Capital Management (LTCM)in 1997-1998. For the Asian economies, the Asian crisis is the largest peak of financial stress in our analysis. Especially in South Korea financial stress rose to very high levels. The Brazilian crisis, which immediately connected to the events in Russia and Asia, led to widespread strains in the financial system in Latin American countries. In particular, it was the beginning of the persistent turmoil in Argentina, which culminated in a sharp financial crisis in 2002.

The legacy with the burst of the dotcom bubble was another event when financial stress was present in many countries all over the world. Most notably financial markets in Germany and in Italy were affected significantly by sharp corrections in stock markets. The most significant peak over the sample period was clearly the recent financial crisis. Nearly all indicators from all market segments point to a sharp increase in financial stress in almost all countries. While the amplitude in several emerging market economies is not exceptionally high, mainly the advanced economies were exposed to extraordinary high levels of financial stress. The European sovereign debt crisis led mainly to financial stress increases in European countries, such as Spain and Italy, while it remained subdued in the rest of the world. This emphasizes that the crisis in the euro area still remains a crisis within the euro area and, up to now, has not substantially affected the currency area as a whole.

2.4 Correlation of financial stress

To get insights of how financial stress co-moves across countries, we carry out a correlation analysis. First, we compute an average cross-correlation among all countries over the sample period. Second, we examine how financial openness is a factor that contributes to an exposure of financial stress. Third, we report country-specific bivariate correlation statistics to analyze between which countries the financial cycle is mostly synchronized. For the average cross-country correlation we compute pair-wise contemporaneous cross-correlations of the FSI over the sample period. Particularly, we compute a 24-month moving average of the contemporaneous correlations between 1970 and 2012. The correlations are calculated as follows: $\rho_t = \frac{1}{N-1}\sum_{i=i}^{N} Corr(FSI_{i,[t-12,t+12]}, FSI_{j,[t-12,t+12]})$, where $N = 20$ represents the number of countries. The correlation analysis is graphically illustrated in Figure 2.

Figure 2: *Average cross-correlations of financial stress*



Notes: The cross-correlation is computed by taking a 24-month moving average of the contemporaneous bivariate pairwise FSIs. In particular, the computation is: $\rho_t = \frac{1}{N-1}\sum_{N}^{i=1} Corr(FSI_{i,[t-12,t+12]}, FSI_{j,[t-12,t+12]})$

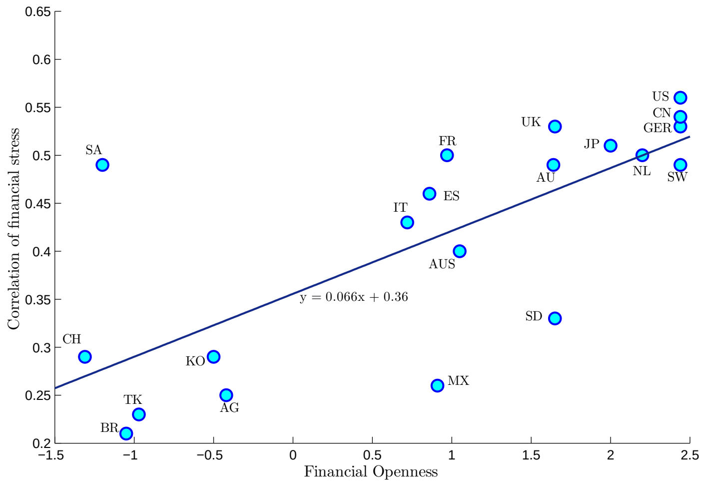
The results of the cross-country correlation analysis are twofold. First, the increasing trend in the cross-country correlation financial stress emphasizes the vigorous growth in international financial integration. In general, financial cycles tend to co-move more among countries over time. Second, the synchronization of financial stress among countries varies significantly over time. There tends to be a strong co-movement in financial stress in selected stress episodes that reflect global financial stress events, such as the 1973-1974 oil crisis, the 1987 stock market crash, the Asian and Russian crisis 1997-1998, the legacy of the dotcom bubble burst and most prominently the recent financial crisis.

When considering the relationship between financial openness and the correlation of financial stress to other countries, the results indicate that financial openness is an important factor to explain differences in the co-movement of financial stress across countries (Figure 3).[6] We find a significant positive relationship (p-value of the slope: 0.0001) between the degree of financial openness and the correlation of financial stress among countries. While there is only little correlation of financial stress in countries that have a low degree of financial openness, the financially high integrated countries exhibit strong correlation of financial stress. It stands out that correlation of financial stress in emerging markets is relatively low and over the sample period these countries were financially closed. In particular, Brazil, Turkey, Argentina, China and Korea stand out with a low correlation of financial stress and low values in financial openness. In contrast, countries with high financial openness, such as the United States, Canada, Switzerland, Germany, and the Netherlands exhibit a strong correlation with the financial stress indexes of the other countries. A single outlier in the sample is South Africa, which has a low degree of financial openness over the sample period, but exhibits a strong correlation of financial stress with the other countries.

The lower exposure of emerging markets to global financial stress events also becomes evident when analyzing the country-specific cross-correlations of financial stress (Table 2). The financial cycle in emerging markets exhibits a different pattern than the financial cycle in the advanced economies. For instance, the degree of correlation of financial stress in Argentina, Mexico and Korea with other countries is on average by far lower than the correlation of Germany, the United

[6] As an indicator for financial openness we use the Chinn-Ito index, a de jure measure of financial openness, which measures a country's degree of capital account openness. The index was originally introduced in Chinn and Ito (2006). Given that the degree of financial openness does not change very often over time, we use an average degree of financial integration from 1970 until 2011. For emerging markets, where financial markets developed substantially over the past decade, this measure might leave out the recent change in financial integration of these countries.

Figure 3: *Correlation of financial stress and financial openness*



Notes: The correlation of financial stress is expressed as country-specific correlations of the domestic FSI with all other FSIs ($\frac{1}{N-1}\sum_{j=1}^{N} Corr(FSI_{i,[t-12,t+12]}, FSI_{j,[t-12,t+12]})$); AG: Argentina; AUS: Australia; AU: Austria; BR: Brazil; CN: Canada; CH: China; FR: France; GER: Germany; IT: Italy; JP: Japan; MX: Mexico; NL: Netherlands; SA: South Africa; KO: South Korea; ES: Spain; SD: Sweden; SW: Switzerland; TK: Turkey; UK: United Kingdom; US: United States.

Kingdom or the United States. While there is also a clear regional dependency of financial stress correlation, such as high correlation of financial stress between Argentina and Brazil, Korea and China, Spain and France, the correlation of financial stress in the United States with all other countries is in general very high. This supports the presumption that the United States are the most important propagator of financial shocks in the world economy.

Table 2: *Cross-country correlations of financial stress*

	AG	AUS	AU	BR	CN	CH	FR	GER	IT	JP	MX	NL	SA	KO	ES	SD	SW	TK	UK	US
AG	1	0.13	0.29	0.32	0.23	0.14	0.27	0.26	0.47	0.34	0.24	0.25	0.23	0.14	0.16	0.25	0.14	0.17	0.29	0.31
AUS		1	0.28	0.12	0.47	0.34	0.61	0.31	0.40	0.34	0.31	0.52	0.48	0.07	0.38	0.21	0.39	0.20	0.63	0.60
AU			1	0.31	0.71	0.37	0.48	0.42	0.52	0.43	0.26	0.59	0.67	0.15	0.53	0.40	0.55	0.18	0.61	0.71
BR				1	0.20	0.13	0.40	0.50	0.38	0.35	0.42	0.46	0.36	0.60	0.39	0.26	0.56	0.23	0.33	0.28
CN					1	0.29	0.66	0.59	0.49	0.52	0.33	0.72	0.62	0.44	0.59	0.31	0.75	0.34	0.62	0.79
CH						1	0.32	0.01	0.32	0.26	0.31	0.39	0.30	0.65	0.04	0.30	0.51	0.12	0.39	0.34
FR							1	0.35	0.55	0.39	0.31	0.63	0.50	0.15	0.47	0.24	0.55	0.29	0.58	0.63
GER								1	0.25	0.36	0.41	0.56	0.52	0.41	0.63	0.18	0.51	0.18	0.54	0.58
IT									1	0.27	0.24	0.43	0.42	0.19	0.46	0.48	0.27	0.28	0.57	0.52
JP										1	0.33	0.49	0.26	0.25	0.32	0.22	0.42	0.33	0.25	0.45
MX											1	0.12	0.31	0.30	0.16	0.21	0.27	0.15	0.26	0.22
NL												1	0.52	0.19	0.46	0.21	0.52	0.30	0.54	0.77
SA													1	0.33	0.54	0.31	0.62	0.15	0.61	0.76
KO														1	0.36	0.11	0.50	0.16	0.09	0.16
ES															1	0.37	0.66	0.14	0.52	0.54
SD																1	0.26	0.14	0.50	0.67
SW																	1	0.11	0.39	0.53
TK																		1	0.56	0.51
UK																			1	0.67
US																				1

Notes: AG: Argentina; AUS: Australia; AU: Austria; BR: Brazil; CN: Canada; CH: China; FR: France; GER: Germany; IT: Italy; JP: Japan; MX: Mexico; NL: Netherlands; SA: South Africa; KO: South Korea; ES: Spain; SD: Sweden; SW: Switzerland; TK: Turkey; UK: United Kingdom; US: United States.

3 Financial stress and economic activity: Evidence from a GVAR model

In order to investigate the international transmission channels of financial stress, we use a GVAR model framework. Originally established by Pesaran et al. (2004), it was, amongst others, further developed by Dées et al. (2009) and Dées et al. (2010). GVAR models can be used to analyze international interdependencies among countries and the transmission channels of international shocks. This type of model has been used to analyze for example the international transmission of oil price shocks

This type of model has been used to analyze for example the international transmission of oil price shocks (Cashin et al. (2012)), housing price shocks (Cesa-Bianchi (2012)), credit supply shocks (Eickmeier and Ng (2011)), cost-push shocks (Galesi and Lombardi (2009)), and liquidity shocks during the Great Recession of 2007-2009 (Chudik and Fratzscher (2011)).

3.1 The GVAR framework

In what follows, we present a very brief sketch of the GVAR model. For a detailed description of the methodology we refer to Smith and Galesi (2011). The GVAR model basically consists of a number of VAR models for each individual country that are linked to each other via a weighting matrix, which is based on trade weights in our model. 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_{it} to a $k_i^* \times 1$ vector of foreign variables x_{it}^*; these foreign variables are assumed to be weakly exogenous in the country VAR model. In addition, we allow for a constant and a deterministic trend in the VAR models:

$$x_{it} = a_{0i} + a_{1i}t + \Psi_{1i}x_{i,t-1} + \ldots + \Psi_{p_i i}x_{i,t-p_i} + \Lambda_{1i}x^*_{i,t-1} + \ldots + \Lambda_{q_i i}x^*_{i,t-q_i} + u_{i,t}, \quad (3)$$

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_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 variables are constructed as trade weighted averages across the domestic variables of all countries, i. e. $x^*_{it} = \sum_{i=1}^{N} w_{ij}x_{jt}$, with $w_{ii} = 0$ and sum over all $w = 1$. In our empirical implementation we use fixed trade weights that are computed as an average of the weights over the sample period. These country-specific VAR models can be transformed into error correction form and separately estimated on a case-by-case basis taking potential cointegration between x_{it} and x^*_{it} into account.[7]

In a second step, they are grouped together and the GVAR is solved globally, i. e. jointly for all countries, since from a global perspective all variables are endogenous to the GVAR as a whole. To this end, all country-specific vectors with endogenous variables are stacked into $x_t = [x'_{1t}, x'_{2t}, \ldots, x'_{Nt}]'$, which is of dimension $k^* = \sum_{i=1}^{N} k_i$. It can be shown that using the appropriate weight matrices and stacking the equations of all country-specific VAR models yields

$$G_0 x_t = a_0 + a_1 t + G_1 x_{t-1} + \ldots + G_r x_{t-r} + u_t, \quad (4)$$

where $r = max\{\{p_i\}, \{q_i\}\}$ and the parameters of the G_n are functions of the weight matrices and the parameters estimated for each of the country-specific VAR models.[8] Since G_0 is known, one can premultiply equation (4) by G_0^{-1} to obtain the GVAR model as

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

with $b_0 = G_0^{-1} a_0, b_1 = G_0^{-1} a_1, F_1 = G_0^{-1} G_1, \ldots, F_r = G_0^{-1} G_r$, and $\epsilon = G_0^{-1} u_t$. There are no a-priory restrictions placed on the covariance matrix of the vector of shocks $\mathbb{E}_t(\epsilon_t \epsilon'_t)$ and the GVAR can basically be treated like an ordinary VAR model for most purposes.

3.2 Computing GIRFs for the GVAR model

In this paper, we use generalized impulse response functions (GIRF; Pesaran and Shin (1998)) to analyze the dynamics of the international transmission of financial

[7] See Smith and Galesi (2011) for a detailed description of the estimation procedure and a battery of diagnostic tests for the VAR models.

[8] For details, see Smith and Galesi (2011), p.98.

stress. Though intellectually not satisfying we constrain our analysis to the use of GIRFs as opposed to the identification of true structural shocks, because for a GVAR with usually dozens of endogenous variables there is no good way to place enough meaningful restrictions to identify what could be called a structural GVAR.[9] If u_t is assumed to have a multivariate normal distribution the GIRFs for a standardized shock of one standard deviation at time t_0 to the l^{th} equation of the GVAR corresponding to the j^{th} variable of the GVAR at time t_{0+n} is given by the j^{th} element of

$$GIRF(x_t; u_{lt}, n) = \frac{e' A_n G_0^{-1} \sum_u e_l}{\sqrt{e_l' \sum_u e_l}}, \; n = 0, 1, 2, \ldots, l; \; j = 1, 2, \ldots, k, \qquad (6)$$

where e_l is a vector of dimension k^* with a 1 as the l^{th} element and zeros otherwise if one wants to simulate the responses to a country-specific shock. In case of a global shock to a specific type of variable (e. g. financial stress as analyzed below) e_l has PPP GDP weights that sum to one at the positions of the specific variables in the GVAR and zero elements otherwise. A_n can be computed recursively by using

$$\begin{aligned} A_s &= F_1 A_{s-1} + F_2 A_{s-2} + \cdots + F_p A_{s-r}, s = 1, 2, \ldots \qquad (7)\\ \text{with} \;\; A_0 &= I_m, \;\; A_s = 0, \;\; \text{for} \;\; s < 0. \end{aligned}$$

These GIRFs are invariant to the ordering of the variables (and countries) in the GVAR but they are not interpretable in a structural sense, since the error terms are not orthogonalized.

3.3 Empirical GVAR specification

We implement the GVAR that we use to analyze the international transmission of financial stress on the basis of monthly data about (log) industrial production, the (log) price level (CPI), the short-term policy rate[10], and the measure of financial stress that was presented in section 2. We use a balanced sample covering the time between February 1991 and December 2012. The lag orders of the country-

[9] In some settings it has been argued that sign-restrictions (Uhlig (2005)) can be an appropriate method to identify structural shocks in GVAR models (see e. g. Cashin et al. (2012)).

[10] 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 of our sample during the early period of our sample.

specific VAR models are restricted to a maximum of $p_i = 2$ and $q_i = 2$ for all countries to ensure stability of the GVAR.[11] The number of cointegration vectors for each country model is determined using the maximum eigenvalue statistic with an upper limit of 2. The model was estimated using *RATS 8.2*.

To shed light on the international transmission of financial stress, and on the dynamics of financial stress that is caused in the different countries by major shocks to the world economy, we simulate GIRFs for the following shocks:

- a global shock to financial stress (using PPP GDP weights as discussed in the previous section);
- a US shock to financial stress
- a (negative) shock to industrial production in the US.

The GIRFs are computed for 36 months and median responses as well as confidence bands are based on bootstrap simulations with 250 replications.

[11] 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 show an explosive behavior and are not well suited for dynamical analysis.

3.4 Results

3.4.1 A global financial stress shock

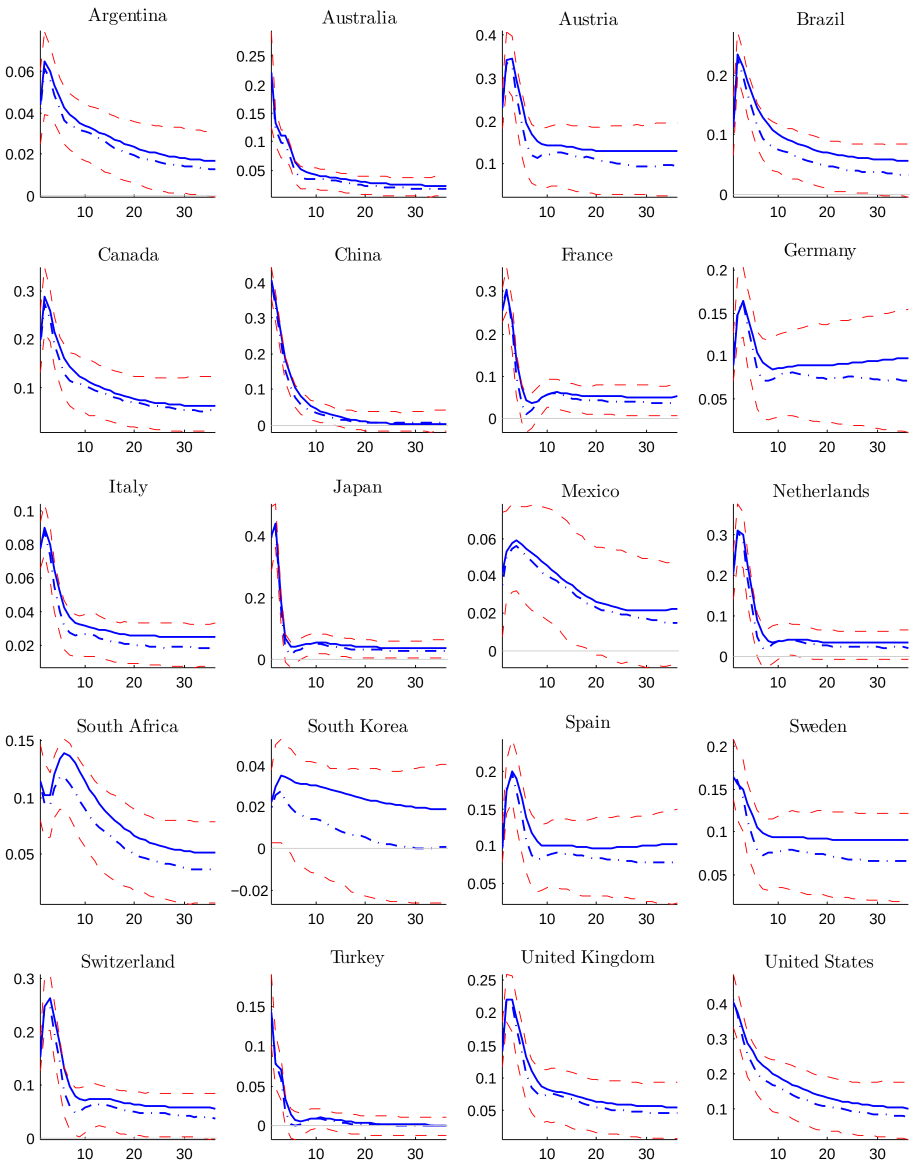
Figures 4.a and 4.b show the dynamic responses of the level of financial stress and industrial production respectively to a standardized global shock to financial stress. Financial stress significantly increases on impact in all countries and – with the exception of a few countries such as China, France, Japan, or the Netherlands – remains high quite persistently.

Industrial production is negatively affected in all countries – though not significantly in all of them. In most cases the maximum impact is reached with a lag of approximately one year. The countries that are least affected in terms of production losses are Australia, China, and surprisingly the United Kingdom. The strongest effects can be expected in Germany, Turkey, and the United States. In these cases, the economic contraction is very persistent and the production level remains significantly below its initial level after 3 years. In South Korea, global financial stress seems to have only a transitory effect. After a sharp contraction on impact (almost 0.7 percent), the economy recovers quickly after the shock and industrial production reaches its initial level after 10 months.

To demonstrate how devastating financial stress can be for economic activity, we re-scale the size of the shock to financial stress in such a way that it matches the experience of the most recent financial crises. To this end, we pick the US as the reference country. During the crisis our measure of financial stress increased by about 8 points in the US which is about 20 times larger than the initial reaction in response to the standardized global shock. Based on our simulation results this would translate to a fall in industrial production of about 8 percent.[12]

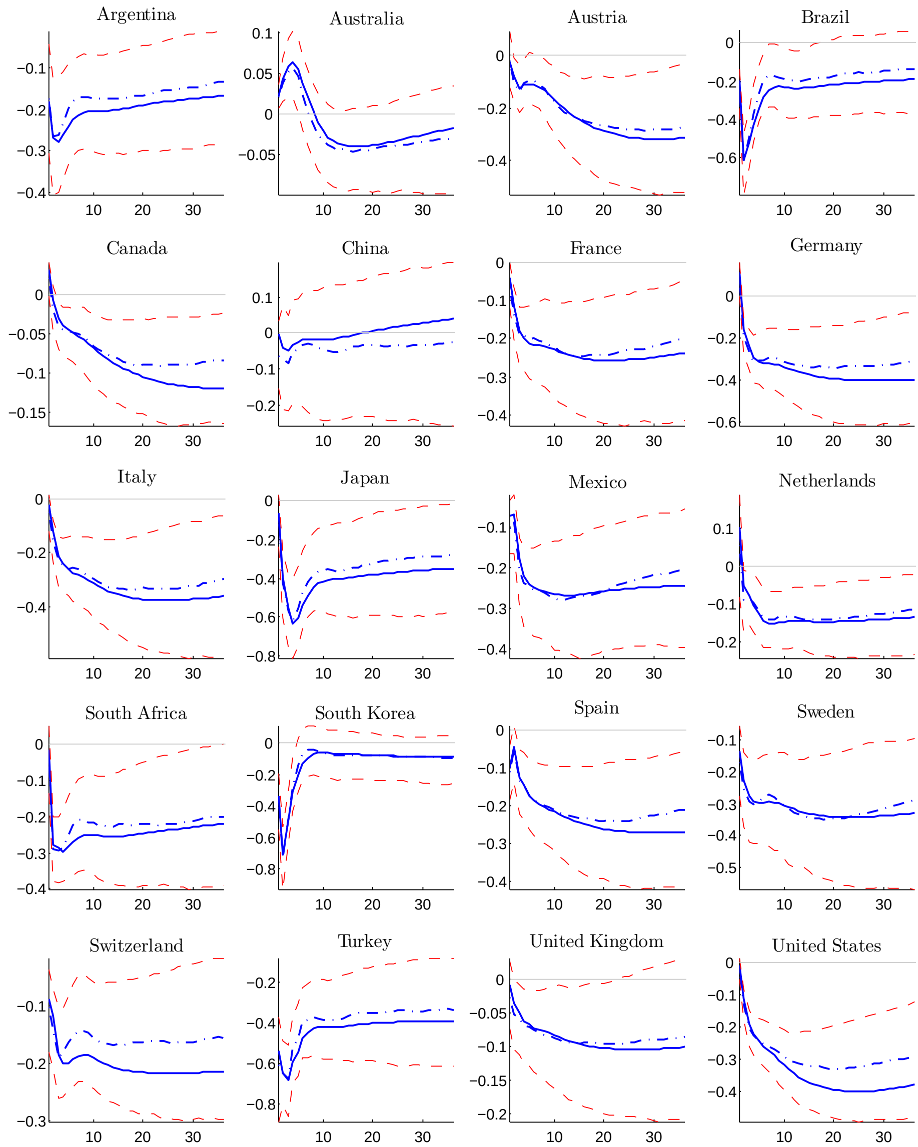
[12] In reality, industrial production fell by about 17 percent between Dec. 2007 and Jun. 2009. Thus, the relatively parsimoniously specified GVAR accounts for about 50 percent of the decline.

Figure 4.a: *Generalized impulse responses for financial stress to a global financial stress shock*



NOTES: The solid blue line represents the mean impulse response, the dashed-dotted blue line the median impulse response, and the dashed red lines represent the 66 percent bias-corrected bootstrap error bands.

Figure 4.b: *Generalized impulse responses for industrial production to a global financial stress shock*



Notes: The solid blue line represents the mean impulse response, the dashed-dotted blue line the median impulse response, and the dashed red lines represent the 66 percent bias-corrected bootstrap error bands.

3.4.2 A US financial stress shock

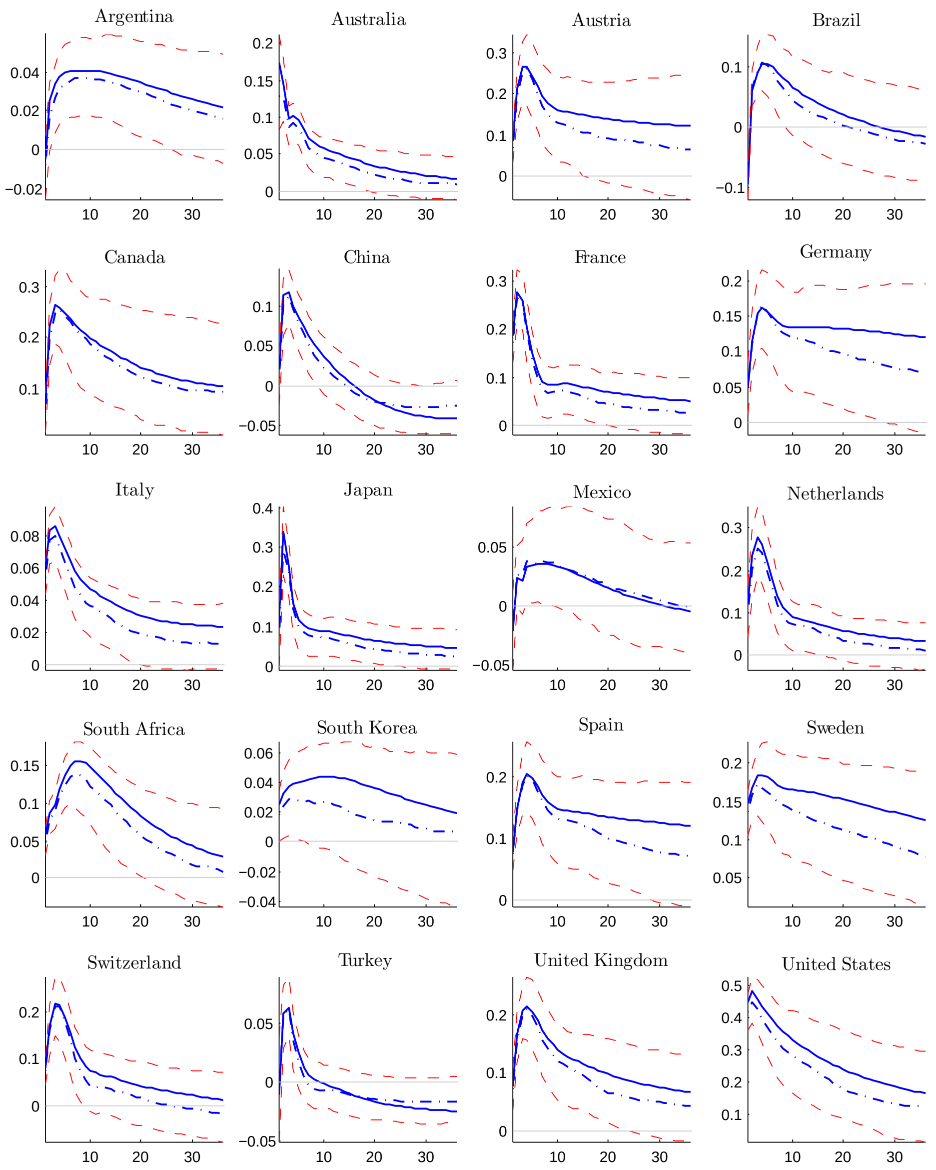
To investigate how financial stress is transmitted internationally when the original shock is limited to a single country, we plot GIRFs of financial stress and industrial production corresponding to a standardized shock to financial stress in the US in Figures 5.a and 5.b. [13]

The transmission of financial stress in the United States to the financial system in other countries is in most cases unambiguous. An increase of the FSI in the United States leads to a persistent increase of financial stress in the other countries – though not significantly so in some cases, such as Mexico or South Korea. The increase of financial stress outside the US is, however, much smaller than the initial shock inside the US. On average, the maximum increase is less than half the size of the standardized shock to financial stress in the US. On average, the GIRFs show a hump-shaped responses indicating that the transmission takes some time; on average the largest impact of financial stress in the other countries is reached after 3 to 4 months. There are some countries, however, that are most heavily affected almost at impact. Examples are Australia, Canada and Japan which presumably have very close financial ties with the US.

The propagation of financial stress in the United States on economic activity in other countries is quite strong. Industrial production declines persistently in almost all countries. Surprisingly the output losses are as high as those in the US in many cases although the effect on financial stress in other countries is more limited. This indicates that a considerable part of the adverse effect on economic activity is not transmitted via financial markets directly but rather indirectly via a fall in foreign demand from the US. Similarly to the transmission of financial stress, industrial production reacts with a considerable time lag in many countries. This indicates that financial stress in the United States does not have an immediate effect on production in other countries but that transmission takes time.

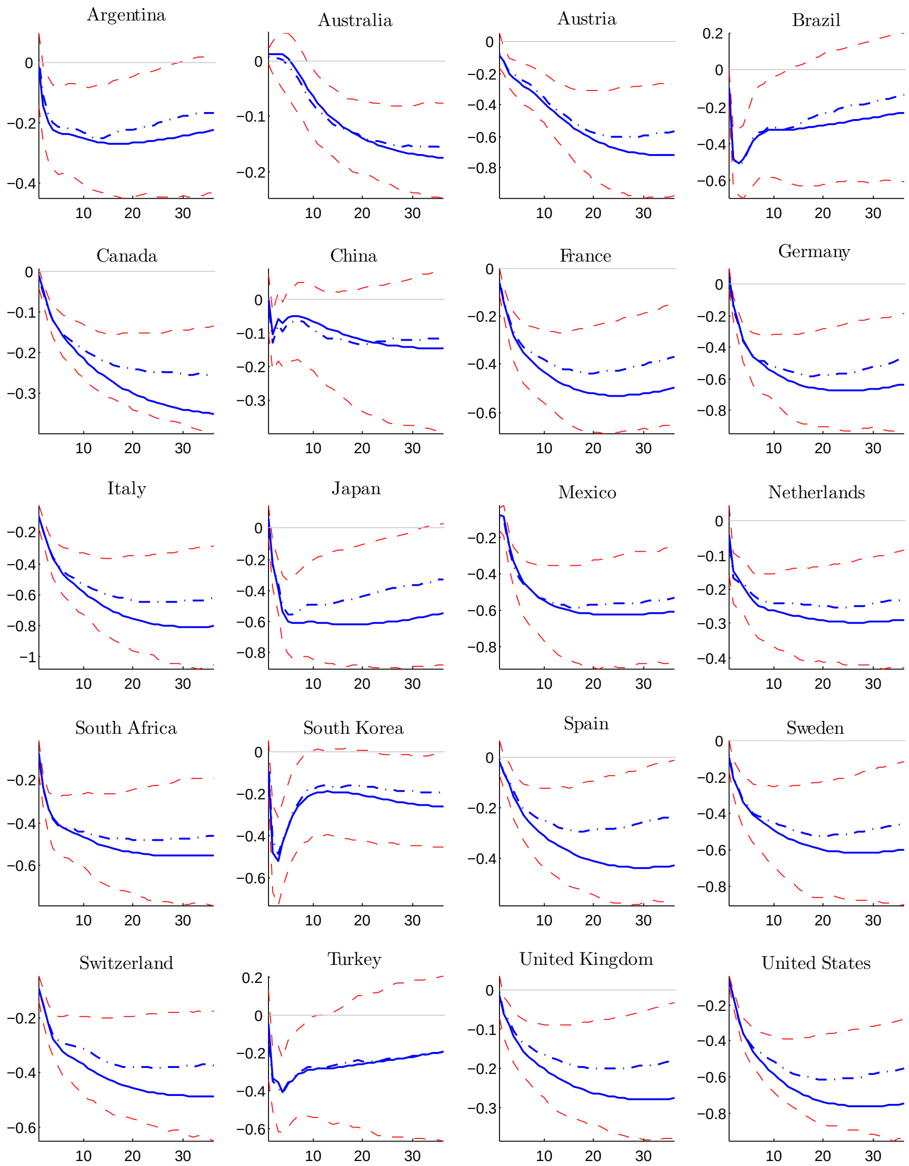
[13] This has been arguably been the plot of the financial crisis of 2007-2009 which had its origins in the turmoils on the financial markets in the US following the burst of the US housing bubble.

Figure 5.a: *Generalized impulse responses for financial stress to a US financial stress shock*



Notes: The solid blue line represents the mean impulse response, the dashed-dotted blue line the median impulse response, and the dashed red lines represent the 66 percent bias-corrected bootstrap error bands.

Figure 5.b: *Generalized impulse responses for industrial production to a negative shock in industrial production in the US*



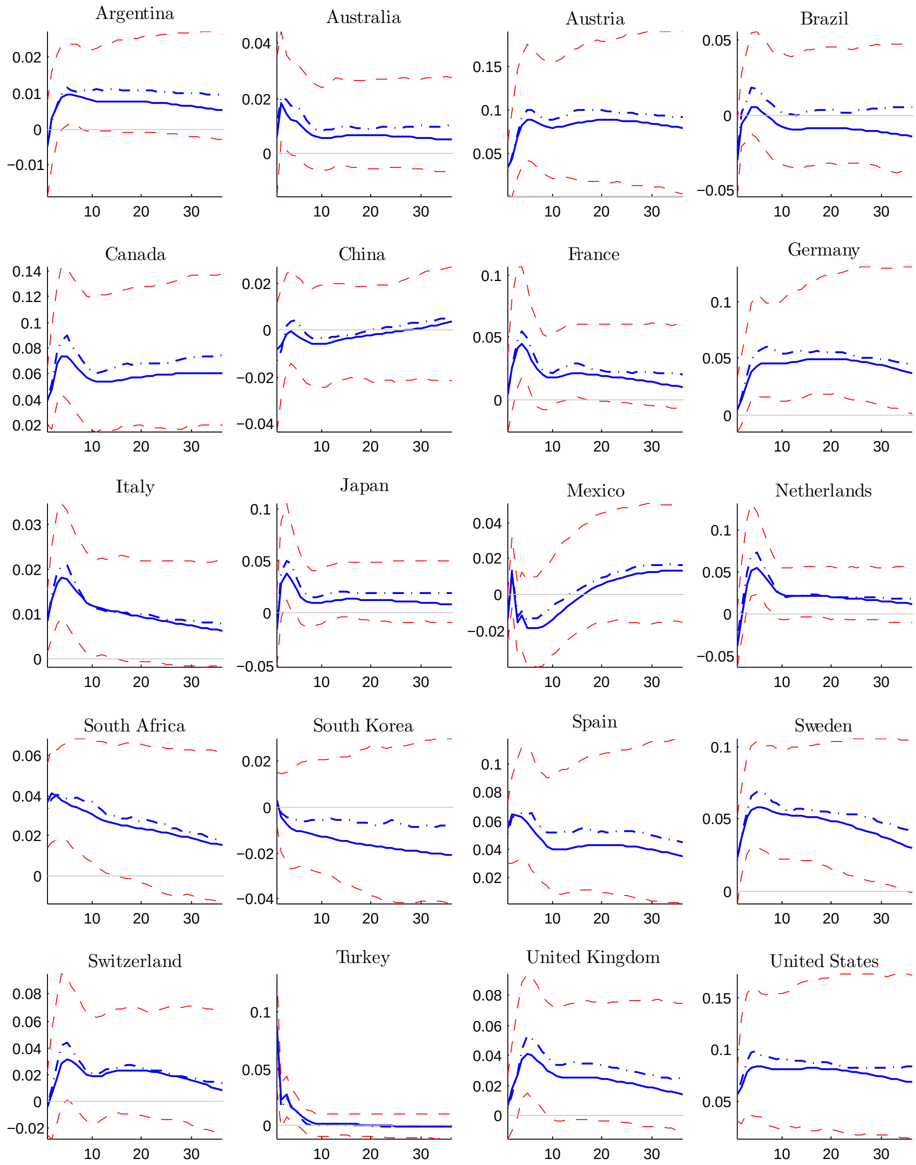
Notes: The solid blue line represents the mean impulse response, the dashed-dotted blue line the median impulse response, and the dashed red lines represent the 66 percent bias-corrected bootstrap error bands.

3.4.3 A shock to US industrial production

Figures 6.a and 6.b show how industrial production and financial stress behave in response to a shock to industrial production in the US. In the United States a fair amount of financial stress is triggered by the slowdown in economic activity which fades only slowly. The rise of financial stress in other countries is much smaller – with the exception of the direct neighbor Canada where the level of financial stress is also strongly affected. Surprisingly, the stress level in neither Mexico nor China – two major trading partners of the United States – are significantly affected following the shock to economic activity in the United States. In most other countries the response of economic activity is lagged and the highest negative effect is often reached not until after six to twenty months.

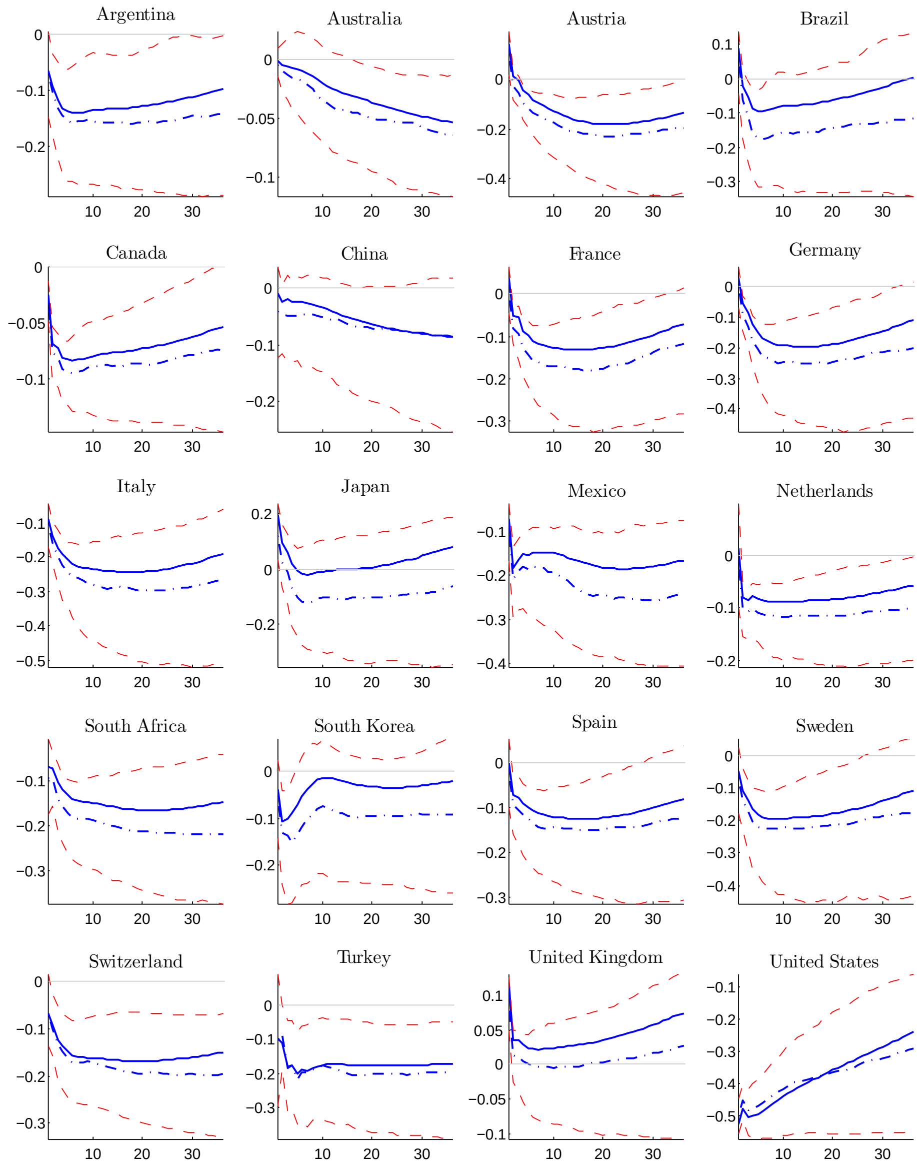
In the United States, industrial production recovers gradually from the initial drop of activity. In other countries, the demand shock triggers a slowdown in industrial production such that the level declines persistently. For some countries, such as the United Kingdom and Japan, the economic contraction is not significant. The strongest effect of an economic contraction in the United States can be expected in Germany and Italy, where the level of industrial productions falls by approximately 0.2 percent after one year.

Figure 6.a: *Generalized impulse responses for financial stress to a negative shock in industrial production in the US*



Notes: The solid blue line represents the mean impulse response, the dashed-dotted blue line the median impulse response, and the dashed red lines represent the 66 percent bias-corrected bootstrap error bands.

Figure 6.b: *Generalized impulse responses for industrial production to a negative shock in industrial production in the US*



Notes: The solid blue line represents the mean impulse response, the dashed-dotted blue line the median impulse response, and the dashed red lines represent the 66 percent bias-corrected bootstrap error bands.

4 Conclusion

This paper analyzes the international transmission of financial stress and its effects on economic activity for 20 countries. Using a dynamic approximate factor model, we construct country specific financial stress indexes (FSI) from 1970 until 2012 on a monthly basis. The FSI are composed by financial indicators such as volatilities on stock markets, bond markets and the foreign exchange market. They succeed in signaling exceptional events that occurred on financial markets in the recent past. An empirical investigation shows that the correlation of financial stress across countries increased notably over the past four decades. Furthermore, the cross-country correlation of financial stress is particularly high during global financial crises. In addition, financial stress is stronger correlated in countries with a high degree of financial openness.

Subsequently, we estimate a GVAR model to analyze the international transmission of financial stress and the propagation of financial stress on economic activity. We show that financial stress significantly reduces economic activity; the negative effects are persistent and the maximum impact lags the shock to financial stress by about one year. Likewise, a shock to financial stress in the United States spreads quickly to financial markets in other countries and has a lagged but persistent effect on economic activity in the other countries. Furthermore, we find that a slowdown in economic activity (demonstrated by a shock to industrial production in the US) leads to a sustained increase in financial stress in most countries of our sample. The effects in this direction are not so large, however, that a financial crisis could be triggered by a prototype recession alone.

Our results indicate that financial stress should be a major concern when analyzing international business cycles. In addition, the result have important implication for economic policy. Because of the strong economic impact of financial shocks, the results implicate that monitoring of financial stress should be of interest for both monetary and fiscal policy makers. Since the financial cycle and the business cycle are significantly synchronized internationally, it is crucial to consider the global dimension of financial stress even from the perspective of a national policy maker.

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